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Interaction between access management and adverse weather conditions

by

Jonathan Paul Rees

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Transportation

Program of Study Committee:
Shauna Hallmark, Major Professor
David Plazak
Stephen Andrle

Iowa State University
Ames, Iowa
2004

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Graduate College
Iowa State University

This is to certify that the master's thesis of

Jonathan Paul Rees

has met the requirements of Iowa State University

Signatures have been redacted for privacy

To all my friends and family, for all of their support and encouragement.

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ACKNOWLEDGMENTS

I would like to give special thanks to my thesis committee, Dr. Shauna Hallmark, Mr. David Plazak, and Mr. Stephen Andrle for dedicating countless hours to my research and education over the past few years. I value the time they spent with me in the classroom and while working at CTRE. I would also like to thank Dr. Souleyrette, the DOGE of the Transportation program.

I would like to thank Dr. I-Shian Suen for his assistance in the initial stages of this research, particularly with GIS assistance. As well, I would like to thank Mr. Zach Hans for GIS assistance. I would like to thank staff at the Des Moines MPO, particularly Becky Auel, Adam Garms, and Adam Noelting for help with the driveway inventory. Thank you to CTRE staff and students for the support and encouragement. Special thanks to "Team Plazak": Jamie Luedtke, Chris Kukla, Jared Noelting and Gregg Karssen.

Most importantly I would like to thank all of my family and friends for their continuing support. I would like to thank my parents, John and Connie, as they taught me the importance of hard work and responsibility. I would like to thank my sister and brother-in-law, Sherry and Todd as they have been great role models. Also, I would like to thank my grandparents, Franklin and Frances Benson, and Milo and Sophia Rees for their love, support, and good food. A special thanks to my best friend/little brother Michael Collet. Also, much thanks to all of the support from friends who reside in the land of Beaverdale, especially Josh Haun and Claude Frazier IV.

DISCLAIMER

Crash and road data used for this study is property of the Iowa Department of Transportation. The data was used solely for the academic purpose of this research. Any results or opinions expressed in this study are those of the author and do not represent the views of the Iowa DOT.

ABSTRACT

Rear-end, left and right-turn collisions are typical collision types which are a result of road segments with poor access management characteristics. There are numerous features that characterize access management such as the density of traffic signals, commercial driveways, and median type along roadways. Previous studies have found that access management techniques, can improve roadway safety by reducing the amount of rear-end, left and right-turn related collisions.

Environmental conditions have an impact on roadway safety. Studies have shown that adverse conditions create additional risk to drivers. Adverse conditions such as rain, snow, sleet, and hail can result in reduced visibility and vehicle traction.

This research explores the relationship between access management characteristics and adverse conditions. Urban arterial roadways in the metropolitan area of Des Moines, Iowa were used for this study. Linear regression was used to determine the relationship between access management characteristics and crashes under different environmental conditions. Access management characteristics include traffic signal density, commercial driveway density, and median type. The environmental conditions explored were clear and adverse weather, surface, and light conditions.

Results from the linear regression indicate that there is a positive relationship between crashes under adverse conditions and access management characteristics. More specifically, linear regression equations show a positive relationship between traffic signal densities and commercial driveway densities and crashes during adverse conditions. Results from the

sample segments indicate that roadways with good access management features can provide improved safety not only under clear conditions, but during adverse conditions as well.

CHAPTER 1. INTRODUCTION

Importance of Access Management

Access management, the practice of controlling the number of access points along a roadway, has become an important strategy to help improve the safety and flow of traffic along roadways. The practice of access management is important especially along arterials in commercialized urban areas. The performance of access management can be evaluated by the flow of traffic, such as level of service and observing crash trends. Past and current studies have shown that access management techniques are beneficial to urban arterials, as it not only improves safety, as well the speed and flow of traffic.

Need for Research

Of the access management research, the emphasis of crash data has typically been on the type, severity, frequency, and rate of collisions and their relationship to roadway and traffic features. Such research has revealed that roadways with access control generally provide improved safety and traffic flow compared to roads with poor access control. These studies do not take into account the role that weather conditions play on safety. Access management studies use crash data from all weather, surface, and lighting conditions, from which the majority of crashes occur under clear weather, dry surface, and daytime lighting (see Chapter 3).

Environmental factors have a large impact on driving conditions and vary by season, location, and year. Harsh weather conditions such as heavy snow, rain, sleet, and hail can create additional risk to traffic by reducing vision and maneuverability of a vehicle, decreasing driving response times and increasing stopping distance. As studies show, reducing the number of conflict points on a roadway through access management provides improved safety, however the studies do not take into account the environmental conditions. Weather, surface, and lighting conditions are commonly observed to show the relationship between adverse conditions and roadway safety; however, the relationship between adverse weather, surface, and lighting conditions and access management have not yet been explored.

Research Purpose

The purpose of this research is to determine whether access controlled arterials improve safety under different weather, surface, and lighting conditions. This study uses descriptive and inferential statistics to determine the relationship between access-related crashes under different weather, surface, and lighting conditions along urban arterial road segments with differing levels of access. Computer programs used for this research include a geographic information system (ArcView GIS) and Statistical Analysis Software (S-PLUS). The GIS was used for the data management and map making, and the statistical software package was used to determine the relationship between access management and adverse weather conditions using linear regression.

Hypothesis

Past research has shown that access controlled arterials provide safer service compared to those with little or no access control. The hypothesis for this study is that access management features play a role in safety under adverse environmental conditions. More specifically, access-controlled arterials provide improved safety under clear weather, surface, and lighting conditions, as well under adverse weather, surface, and lighting conditions for the sample arterials in the Des Moines metropolitan area. For this study the median type, traffic signal density, and commercial driveway density are used to indicate the level of access for the arterials.

Thesis Organization

This thesis is made up of seven chapters, the first three providing background on the topic and the remaining focusing on the methodology, statistics, and conclusion of the research. The chapters are organized as shown:

Chapter 1. Introduction
Chapter 2. Access management literature review
Chapter 3. Adverse weather condition literature review
Chapter 4. Methodology
Chapter 5. Descriptive statistics
Chapter 6. Inferential statistics
Chapter 7. Conclusion

Chapters two and three provide an overview of current research in the areas of access management and crash safety under adverse conditions. Chapter four, the methodology describes how the sample data were selected for the study, and how they will be analyzed to determine whether to accept or reject the research hypothesis. Chapter five, descriptive statistics, provides an overview of the study crash records and access management characteristics for the study segments. Chapter six, inferential statistics, describes the method for determining the statistical relationship between access management and adverse conditions using linear regression. Chapter seven provides conclusions based on findings from the descriptive and inferential statistics, which were used to determine whether the research hypothesis was accepted or rejected. In addition, the concluding chapter provides additional commentary on ideas for future research concerning these topics.

CHAPTER 2. ACCESS MANAGEMENT

Access Management Overview

Access management is defined as the process that provides access to land development while simultaneously preserving the flow of traffic on the surrounding road system in terms of safety, capacity and speed *(1)*. This is accomplished through the management of land use, driveways, medians, traffic signals, and other roadway characteristics, such as roadway geometry.. Generally, roadways in need of improved access management are urban arterials and other primary roads that are expected to provide safe and efficient movement of traffic, as well as access to property.

Roadway Classification and Access

Roadways are classified by the importance of their mobility and corresponding access functions *(2)*. Roadway functional classifications include:

- Freeways
- Arterials
- Collectors
- Local Roads

(Source: Iowa Access Management Handbook, 2000)

The four functional classifications provide different levels of access based on the traffic traversing them. Arterials are roadways which have the highest mobility of through traffic that provide access to land parcels, whereas freeways are fully access-controlled and provide no direct access to individual land parcels. Local roadways have the lowest access control however, they are exposed to less through traffic, as they typically have a high density of residential driveways. Figures 2-1 and 2-2 show the relationship between access control and roadway functional classification. As figure 2-2 shows, as the proportion of through traffic decreases, the level of access increases, meaning there are more driveways that provide access to and parcels.

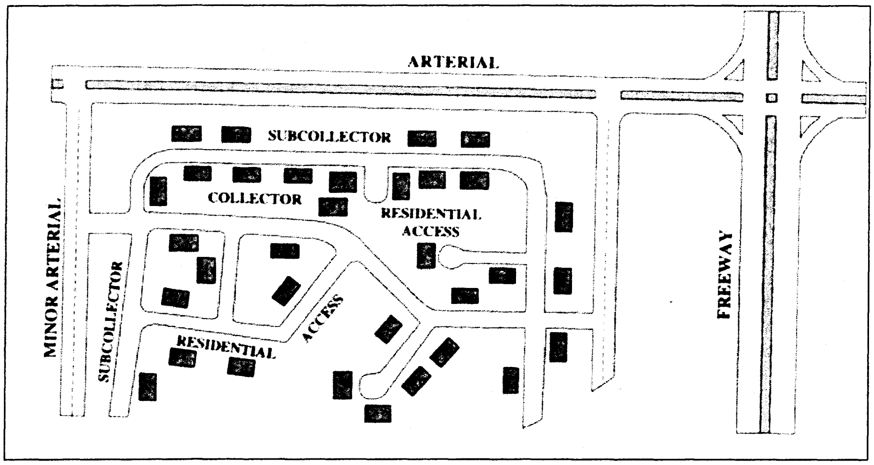

Figure 2-1. Roadway Classification and Access
(Source: Iowa Access Management Handbook, 2000)

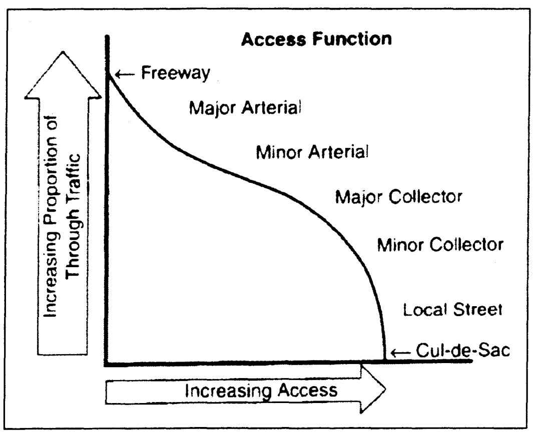

Figure 2-2. Relationship between Roadway Classification and Access
(Source: Access Management Manual, TRB, 2003)

The Iowa Access Management Handbook provides a description of each roadway classification with corresponding function and characteristics. As Table 2-1 shows, the main purpose of freeway, arterial, and collector roads is to serve traffic movement outside and inside the community (intra and inter-community travel), whereas, the main purpose of local roads is to provide access to land parcels, particularly residential use *(3)*. Generally, the higher the roadway classification (with freeway being the highest), the speed limit and intersection spacing tend to be higher, with increased access control.

Table 2-1. Roadway Classification and Characteristics

Classification	– Main Function – Traffic Movement	Land Access		– Characteristics – Speed Limit (mph)	Minimum Intersection Spacing	Direct Land Access
Freeway and Expressway	X		Inter-community travel	45 and greater	1 mile	None
Primary Arterial	X	Secondary function	Inter- and intra-community travel	35 to 55	1/2 mile	Limited: major traffic generators only
Secondary Arterial	X	Secondary function	Intra- and inter-community travel	30 to 45	1/4 mile	Restricted: some movements prohibited; number & spacing of driveways controlled
Collector	X	Secondary function	Collect & distribute traffic between local streets & arterials; should not extend across arterials	25 to 35	300 feet	Safety controls; some regulation of access
Local Street		X	Land access	20 to 25	300 feet	Safety controls only; unlimited access

(Source: Iowa Access Management Handbook, 2000)

Conflict Points and Access Management

Access management aims at improving roadways by reducing the number of conflict points along a roadway. A conflict in traffic occurs when the paths of vehicles intersect, with each intersecting movement being a potential collision *(4)*. There are five types of traffic conflicts: diverging, merging, weaving, crossing, and stop/queuing. Figure 2-3 provides illustrations for each of these collision types.

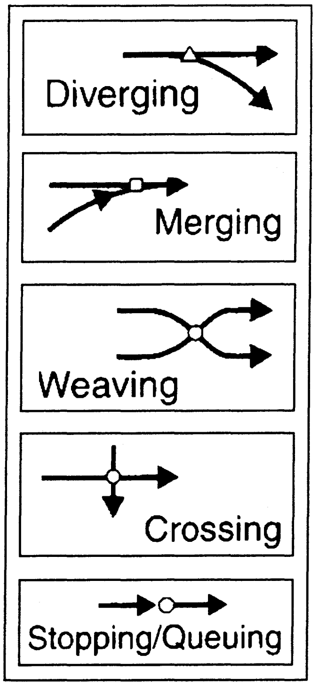

Figure 2-3. Conflict Types
(Source: Access Management Manual, TRB, 2003)

Figure 2-4 shows the possible conflict points at a typical four-way intersection. There are a total of 32 possible conflict points, 16 crossing movements, 8 diverging and 8 merging movements *(1)*. As well, table 2-2 shows the conflict points for intersections with a principal and minor road crossing paths. These conflict points can be reduced through access management techniques, for this situation primarily with a raised median.

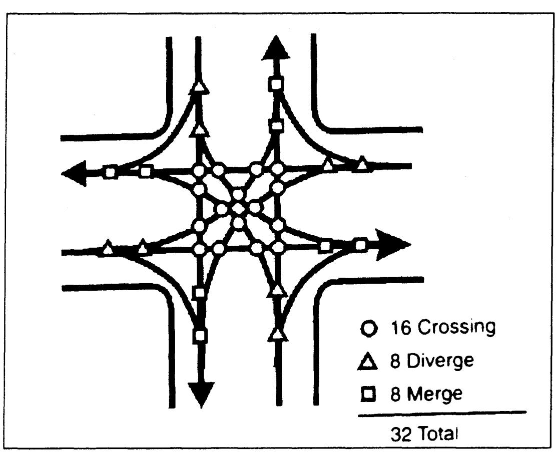

Figure 2-4. Four Way Intersection- 32 Conflict Points
(Source: Access Management Manual, TRB, 2003)

Table 2-2. Total Possible Conflict Points for Different Intersection Configurations

Principal Road	**Minor Road**	**Conflict Points**
Two lanes	Single driveway	9
Two lanes	Two lanes or opposing driveways	32
Four lanes	Single driveway	11
Four lanes	Two lanes or opposing driveways	40
Four lanes	Four lanes	52

(Source: Iowa Access Management Handbook, 2000)

Contributing Factors to Poor Access

There are numerous indicators that define whether access management along a roadway is good or poor. For this research, access management is evaluated by the density of driveways which provide access to commercial business, traffic signal density, median type, and crash history from the study area. The following sections of this chapter provide an overview of these access management characteristics and their impact on safety.

Access Management and Collisions

One of the greatest indicators of poor access management is to look at crash frequencies along a roadway. The most common access-related collisions are rear-end collisions. Rear-end collisions are common due to stop and go traffic which is the result of a high density of traffic signals within close proximity of each other. Left-turn related access crashes are those typically where there is a traversable (non-raised) median, which allows free left-turn movements anywhere along a roadway. Driveways along a roadway usually result in numerous crashes, especially those with a high density of commercial driveways, which generate larger volumes of traffic.

There are numerous access treatments which, according to research, have shown many positive effects. Research has shown that the treatment of a non-traversable median along urban arterials can reduce crashes by 55 percent, decrease delay by 30 percent, and increase capacity by 30 percent *(4)*. In addition, applying left-turn bays can reduce crashes anywhere from 25 to 50 percent on four-lane roads and reduce un-signalized intersection crashes up to 75 percent *(4)*. The addition of right-turn bays can reduce collisions by up to 20 percent *(4)*. Overall, access management techniques not only improve the safety of roadways, they also improve the service and capacity.

Studies of cities in Iowa such as Ames, Ankeny, Clive, Fairfield, Mason City, and Spencer, have found that access management projects in Iowa have improved safety *(3)*. The studies have indicated that access management improvements reduced crash frequencies from 10 to 65 percent, depending on the roadways and cities in the studies (*3*). Of these collisions, personal injury crashes decreased by 25 percent and property damage only crashes decreased by nearly 50 percent *(3)*.

Driveways and Access Management

Of the above mentioned strategies, the most effective is to limit the number of driveways along the roadway. Roadways with a low density of driveways compared to those with a high density of driveways perform much better in terms of safety because there are less conflict points. The density of driveways per mile or block is important to keep at a minimum for improved safety. Municipalities have the right to limit the number of driveways per lot to avoid multiple driveways which are common in commercial areas (gas stations, fast food etc.). As the number of driveways per mile or block increases the crash rate increases considerably along urban arterials *(5)*. Table 2-3 shows the relationship between driveway densities and crash rates for urban arterials.

Table 2-3. Driveway Density and Crash Rates

Driveways per Mile	Approx. Number of Driveways per 500-foot City Block	Representative Accident Rate for a Multilane, Undivided Roadway	Increase in Accidents Associated with Higher Driveway Density
Under 20	Under 2	3.4	-
20 to 40	2 to 4	5.9	74%
40 to 60	4 to 6	7.4	118%
Over 60	Over 6	9.2	171%

(Source: Access Management Manual, TRB, 2003)

Not only is it important to limit the number of driveways along the roadway, the distance between driveways plays a big role in access management. A minimum distance between driveways is important, as it minimizes the number of access points that a driver has to monitor *(5)*. Minimum access spacing should be based on the characteristics of the roadway functional classification, geometric characteristics, land use, and traffic conditions. Table 2-4 shows some general guidelines for driveway frequency and spacing based on urban arterial speeds.

Table 2-4. Driveway Spacing for Urban Arterials

Posted Speed on Arterial Street (mph)	Centerline to Centerline Driveway Spacing (feet)	Approx. Number of Driveways per 500-foot Block Face
20	85	About 6
25	105	5
30	125	4
35	150	3
40	185	3
45	230	2
50	275	Fewer than 2

(Source: Access Management Manual, TRB, 2003)

For this research, commercial driveways will be examined, primarily because the sample roadways are primary roads, with moderate to little or no residential access. As well, residential driveways don't generate large amounts of traffic like commercial uses. Driveways are classified as having low, medium, or high volumes based on the number of daily trips generated *(3)*. A low volume driveway is typically is a residential driveway, or any driveway with a traffic volume less than 500 vehicle trips per day and less than 50 vehicle trips per hour *(3)*. Medium volume driveways are those with traffic daily traffic volumes from 500 to 1,500 vehicles and 150 per peak hour *(3)*. High volume density driveways are those with over 1,500 daily traffic volumes and 150 or more vehicle trips per peak hour *(3)*. Commercial driveway volumes differ depending on the location and classification of roadway, but are generally medium and high volume driveways along urban arterials.

Commercial driveways not only pose threat due to increased traffic, but there are often numerous driveways per commercial lot. For instance gas stations, fast food restaurants, and retail stores generally provide numerous driveways. This is common, as businesses want to maximize the amount of access to their lots, to ensure that customers do not miss the turn and increase business. These driveways can be problematic because they are generally close together and have poor sight distance from objects such as signage, advertising, landscaping and other vehicles.

Traffic Signals and Access Management

When considering access management, the density of traffic signals is also important. Roadways with numerous, closely spaced traffic signals commonly experience frequent stopping, queuing, and delay *(4)*. Research from *The Colorado Access Demonstration Project* found that signal spacing of ½ mile could reduce total hours of vehicle delay by nearly 60 percent compared to spacing of a quarter mile *(4)*. The addition of each traffic signal per mile along a roadway potentially decreases the average speed by two to three miles per hour *(4)*.

Rear-end collisions are common along roadways with a high density of traffic signals, due to stop and go traffic. According the *Access Management Manual* published by the Transportation Research Board (TRB), several studies have shown that as the frequency of traffic signals increases the frequency of crashes also increases *(4)*. Figure 2-5 shows the effect that traffic signals in urban and suburban settings have on roadways with anywhere from 10 to 70 access points. Studies have shown that crash rates increase by 1.0 for the addition of up to two traffic signals per mile *(4)*.

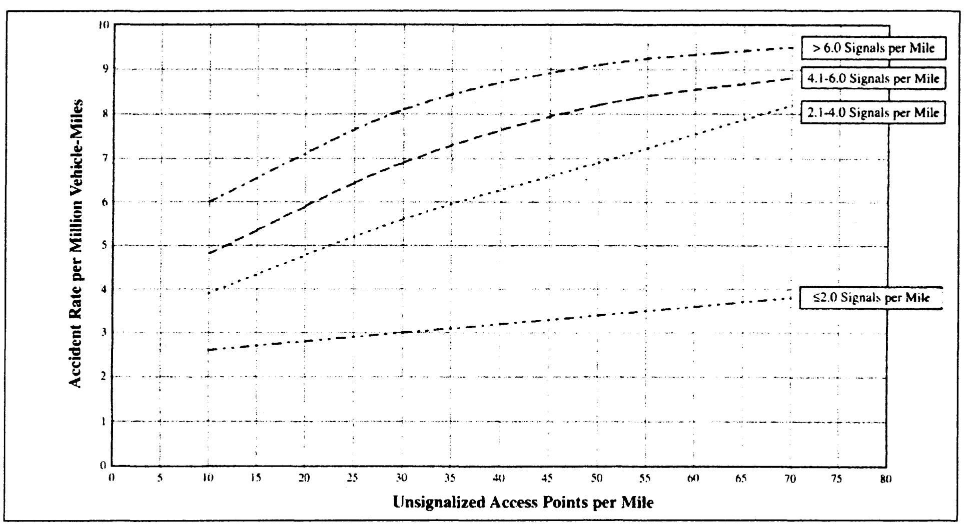

Figure 2-5. Relationship between Traffic Signals and Access Points on Crash Rates
(Source: Access Management Manual, TRB, 2003)

To prevent delay and possible conflict, guidelines for signal spacing along urban arterials are suggested. Roadway speeds and signal cycle lengths are important to consider when determining a safe distance for proper signal spacing. For urban arterials a ¼ mile to ½ mile spacing allows signals to synchronize in order to maintain progression speeds up to 30 mph, depending on the cycle length *(4)*. Table 2-5, shows vehicle progression speeds, for different cycle lengths and spacing. This table illustrates that, as the distance between the signals increase the cycle length decreases and progression speeds are much higher. Therefore, arterials with close signal distances usually have low progression speeds. Table 2-6, shows minimum spacing guidelines adopted by the Missouri Department of Transportation for urban areas according to roadway classification *(6)*.

Table 2-5. Progression Speed at Different Cycle Lengths and Signal Spacing

Cycle Length (s)	Spacing 1/8 mi (660 ft)	1/4 mi (1,320 ft)	1/3 mi (1,760 ft)	1/2 mi (2,640 ft)
	Progression Speed (mph)			
60	15	30	40	60
70	13	26	34	51
80	11	22	30	45
90	10	20	27	40
100	9	18	24	36
110	8	16	22	33
120	7.5	15	20	30

(Source: Access Management Manual, TRB, 2003)

Table 2-6. Minimum Signal Spacing Guidelines for Urban Areas

Roadway Classification	Urban Areas
Interstate/Freeway	None
Principal Arterial	1/2 mile (2,640 ft.)
Minor Arterial	1/2 mile (2,640 ft.)
Collector	1/4 mile (1,320 ft.)

(Source: Missouri Department of Transportation Access Management Guidelines, 2003)

Medians and Access Management

Medians play an important role in safety and access management, as they channel right and left-turning movements from one roadway to another *(4)*. There are two types of medians, traversable and non-traversable, or raised medians. Traversable medians are those where vehicles are allowed to make turning movements at any point along the roadway, whereas non-traversable medians provide a physical barrier separating opposite flows of traffic, with breaks to provide access at certain locations.

Raised medians reduce the number of conflict points along roadways, thus providing better safety. For example, a typical four-way intersection has a total of 32 potential conflict points (as shown in figure 2-4 above). The application of a raised median with left-turn bays reduces the total conflict points to a total of eight *(4)*. This is illustrated in Figure 2-6.

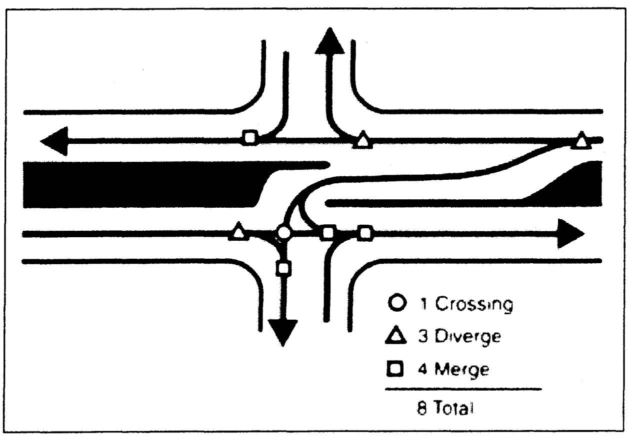

Figure 2-6. Reducing Conflict Points with Raised Medians
(Source: Access Management Manual, TRB, 2003)

Left-turns are problematic along poorly managed roadways due to the exposure of potential conflict to both flows of traffic. Raised medians with left-turn bays provide safer access compared to a traversable median. A raised median with left-turn bay separates the through vehicle from turning vehicles, thus eliminating potential rear-end collisions. Along arterials with traversable medians, an average of 77 percent of the collisions are due to left-turns going into and out of driveways *(4)*. Of these left-turn collisions, approximately 47 percent are left-turn movements into a driveway and 27 percent are turning left out of a driveway onto the roadway *(4)*. See figure 2-7.

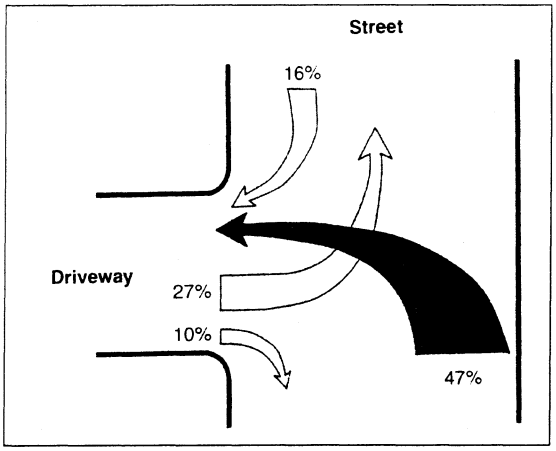

Figure 2-7. Driveway Crash Percentages per Movement
(Source: Access Management Manual, TRB, 2003)

Two-way left-turn lanes (TWLTL) are another type of median, that provides better access compared to undivided roadways; however, they are not as effective as raised medians since they do not restrict turning movements at specific locations. Studies have shown that crash rates improve when using a TWTL compared no median, and improve considerably more when using raised medians *(7)*.

Table 2-7, shows crash rates for urban and suburban areas with different median types and different levels of access. The results show that non-traversable (raised) medians provide much safer access when compared to the undivided and TWLTL *(7)*.

Table 2-7. Representative Accident Rates (per VMT) by Type of Median and Access Points for Urban and Suburban Areas

Total Access Points Per Mile (1)	Median Type		
	Undivided	Two-Way Left-Turn Lane	Non Traversable Median
<20	3.8	3.4	2.9
20.01-40	7.3	5.9	5.1
40.01-60	9.4	7.9	6.8
>60	10.6	9.2	8.2
All	9.0	6.9	5.6

(Source: NCHRP Project 3-52)

CHAPTER 3. ADVERSE WEATHER CONDITIONS

Adverse Weather Conditions Overview

Environmental factors have a large impact on driving conditions and vary by season, location, and year. Harsh weather conditions such as heavy snow, rain, sleet, and hail create additional risk to traffic by reducing vision and maneuverability of a vehicle (losing control), decreasing the drivers response time, and increase stopping distance. Weather conditions in Iowa are unpredictable experiencing heavy rainfall, sleet, snow, and hail.

Weather conditions have an impact on daily commuting. The weather condition plays a role on the type of trips that drivers make. Depending on the weather condition one may or may not travel to the store to pick up a few goods; however, one is more likely to go to work no matter what the weather condition. In this research, there are two important factors that might not be accounted for when looking at crashes and adverse weather conditions. First, depending on how extreme the weather condition is, there may be less vehicles on the roadway than usual. Second, is that the severity of crashes under bad weather conditions tends to be lower because people drive slower, and generally the impact is less severe when an accident occurs.

Weather events affect the behavior of the driver, roadway conditions, and the flow of traffic *(8)*. Depending on the weather condition, there are different impacts that it may have on the roadway and driving conditions *(8)*. During adverse weather conditions, particularly in heavy rainfall, snow, or icy conditions, vehicle headways increase, acceleration decreases, and speeds decrease *(8)*. One particular study in Salt Lake City observed two intersections along arterials under different weather conditions. The study found that rain reduced speeds by 10 percent and sticky snow reduced speeds by 36 percent *(8)*. The same study revealed that start-up delay on wet surfaces was 5 percent higher compared to dry surfaces, and snowy surfaces it was 23 percent higher compared to dry surfaces *(8)*.

Crashes may result due to unfavorable weather conditions, as visibility is impaired and vehicle control is reduced *(9)*. Visibility is defined as "the greatest distance that prominent objects can be seen and identified by unaided, normal eyes *(10)*." Visibility is impaired in many different weather conditions including, snow, sleet/hail, rain, fog, glare and darkness. Such conditions reduce the driver's ability to see objects, such as the roadway and its geometry, traffic control devices, vehicles, and other roadside objects.

Adverse Weather Crash Statistics for the United States

The *Fatality Analysis Reporting System(FARS)* and the *General Estimates System* from the National Highway and Traffic Safety Administration (NHTSA) publishes traffic safety facts each year. The *Traffic Safety Facts 2002* breaks crashes down into numerous categories, including weather conditions *(11)*. As table 3-1 shows, the majority of crashes, (85%) occur under normal weather conditions. Rainy conditions account for nearly 11 percent of the total crashes while snow and sleet only account for approximately 3 percent of the total crashes*(11)*. The percentage of crashes in rain compared to snow conditions could be due to climate differences across the nation as some of the larger populated cities in the states such as California, Florida, and Texas rarely experience snowy weather conditions compared to the Midwest and northern states.

Table 3-1. Weather Condition for Nationwide Crashes, 2002

	Fatal		Injury		Property		Total	
Weather Condition	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Normal	33,585	87.67%	1,661,000	86.11%	3,674,000	84.50%	5,368,585	85.01%
Rain	2,981	7.78%	207,000	10.73%	479,000	11.02%	688,981	10.91%
Snow/Sleet	732	1.91%	45,000	2.33%	159,000	3.66%	204,732	3.24%
Other	594	1.55%	16,000	0.83%	36,000	0.83%	52,594	0.83%
Unknown	417	1.09%	NA	NA	NA	NA	417	0.01%
Total	**38,309**	**100.00%**	**1,929,000**	**100.00%**	**4,348,000**	**100.00%**	**6,315,309**	**100.00%**

(Source: NHTSA, Traffic Safety Facts 2002)

The NHTSA also has record of the light condition under which crashes occur. The majority of collisions occur in the daylight. This is primarily due to the fact that peak hours are generally during daylight hours. Forty-nine percent of the total fatal crashes are during daylight conditions. The majority of injury and property damage crashes, also occur in daylight conditions. The percentage of collisions that occur in the dark (unlit roadways) is considerably low, which likely reflects that the majority of heavily traveled roads at night, such as in urban areas, are properly lit. Unlit roadways are typically in rural settings where there is less traffic or along freeways, which have lower crash rates due to lack of access and less conflict points.

Table 3-2. Lighting Condition for Nationwide Crashes, 2002

	Fatal		Injury		Property		Total	
Light Condition	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Daylight	18,868	49.25%	1,352,000	70.09%	3,018,000	69.40%	4,388,868	69.48%
Dark, but Lighted	6,074	15.86%	301,000	15.60%	645,000	14.83%	952,074	15.07%
Dark	11,481	29.97%	206,000	10.68%	521,000	11.98%	738,481	11.69%
Dawn or Dusk	1,552	4.05%	70,000	3.63%	165,000	3.79%	236,552	3.75%
Unknown	334	0.87%	NA	NA	NA	NA	334	0.01%
Total	**38,309**	**100.00%**	**1,929,000**	**100.00%**	**4,349,000**	**100.00%**	**6,316,309**	**100.00%**

(Source: NHTSA, Traffic Safety Facts 2002)

Adverse Weather Crash Statistics for the State of Iowa

The Iowa Department of Transportation keeps a crash database for all police reported crashes each year. Information on weather, surface, and light condition circumstances are recorded for the collisions. Statistics for Iowa are based on crashes in 2000, which is the most recent crash data available from the Iowa DOT crash database.

In Iowa there is a higher percentage of crashes that occur under adverse weather conditions compared to national percentages. Only 51 percent of the collisions in Iowa occurred under clear weather conditions, a percentage which is much lower than the national percentage of approximately 85 percent. Approximately 7 percent of the total state crashes involved snow, and nearly 5 percent involved rainy conditions. When compared to the national average, the snow related crashes for Iowa was slightly higher. The percentage of rain related collisions was lower for the State of Iowa when compared with the national percentage of crashes. This high percentage of rain related collisions is likely due to Iowa's cold climate. When comparing the percentage of snow related crashes, Iowa also has a higher percentage compared to the national percentage. See table 3-3 for more details.

Table 3-3. Weather Condition for Statewide Crashes, 2000

	Fatal		**Injury**		**Property**		**Total**	
Weather Condition	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Clear	236	52.91%	14,442	52.90%	23,604	50.95%	38,282	51.68%
Cloudy	116	26.01%	6,405	23.46%	10,003	21.59%	16,524	22.31%
Snow	19	4.26%	1,783	6.53%	3,697	7.98%	5,499	7.42%
Unknown	11	2.47%	996	3.65%	3,071	6.63%	4,078	5.51%
Rain	17	3.81%	1,470	5.38%	2,163	4.67%	3,650	4.93%
Strong Wind	17	3.81%	851	3.12%	1,480	3.19%	2,348	3.17%
Mist	12	2.69%	627	2.30%	1,055	2.28%	1,694	2.29%
Fog	15	3.36%	285	1.04%	504	1.09%	804	1.09%
Sleet/Hail	1	0.22%	252	0.92%	426	0.92%	679	0.92%
Other	2	0.45%	192	0.70%	325	0.70%	519	0.70%
Total	**446**	**100.00%**	**27,303**	**100.00%**	**46,328**	**100.00%**	**74,077**	**100.00%**

(Source: Iowa DOT Crash Database, 2000)

Similar to that of the national percentage of light condition crashes in 2000, over 66 percent of the collisions in Iowa occurred in the daylight. Collisions that occurred in the dark on unlit roadways in Iowa are somewhat higher compared to that of the national total percentage, nearly 16 percent. This percentage could be due to Iowa's rural character which includes many unlit roadways. Dark roadways with lighting made up nearly 13 percent of the total crashes in 2000. Combined, collisions that occurred in dusk or dawn lighting make up nearly 5 percent of the total crashes, which was consistent with but slightly higher than that of the national percentage in 2002 of nearly 4 percent.

Table 3-4. Lighting Condition for Statewide Crashes, 2000

	Fatal		Injury		Property		Total	
Light Condition	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Daylight	252	56.63%	25,811	71.64%	24,780	61.64%	41,895	65.09%
Dark, Not Lighted	134	30.11%	4,245	11.78%	7,610	18.93%	10,654	16.55%
Dark, Lighted	35	7.87%	4,405	12.23%	5,198	12.93%	8,074	12.54%
Dusk	11	2.47%	1,039	2.88%	1,307	3.25%	2,007	3.12%
Dawn	9	2.02%	486	1.35%	958	2.38%	1,336	2.08%
Unknown	4	0.90%	45	0.12%	351	0.87%	395	0.61%
Total	**445**	**100.00%**	**36,031**	**100.00%**	**40,204**	**100.00%**	**64,361**	**100.00%**

(Source: Iowa DOT Crash Database, 2000)

The Iowa crash database also has record of the road surface condition at the time of accidents. These are consistent with the weather related collisions, with over 53 percent of the collisions occurring on dry surface conditions. Snowy and wet surface conditions make up 11 percent (each) of the total crashes, and over 9 percent of the crashes occurred on icy road surface conditions. See table 3-5 for more details.

Table 3-5. Surface Condition for Statewide Crashes, 2000

	Fatal		Injury		Property		Total	
Road Surface Condition	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Dry	480	65.48%	29,386	58.06%	41,534	50.73%	71,400	53.60%
Unknown	30	4.09%	4,492	8.88%	11,236	13.72%	15,758	11.83%
Wet	90	12.28%	6,355	12.56%	9,045	11.05%	15,490	11.63%
Snow	41	5.59%	4,684	9.25%	9,988	12.20%	14,713	11.04%
Ice	49	6.68%	4,175	8.25%	8,230	10.05%	12,454	9.35%
Gravel	40	5.46%	1,171	2.31%	1,355	1.65%	2,566	1.93%
Other	3	0.41%	228	0.45%	307	0.37%	538	0.40%
Debris	0	0.00%	69	0.14%	101	0.12%	170	0.13%
Mud	0	0.00%	52	0.10%	78	0.10%	130	0.10%
Total	**733**	**100.00%**	**50,612**	**100.00%**	**81,874**	**100.00%**	**133,219**	**100.00%**

(Source: Iowa DOT Crash Database, 2000)

Research on Crashes and Adverse Weather Conditions

A recent study has found that the last date of precipitation which occurred can have an impact on crash rates *(12)*. For example, several days of precipitation during the past few days would result in fewer rain related collisions today *(12)*. The study found that "a centimeter of precipitation increases the fatal crash rate by about 3 percent if exactly two days have passed since the last precipitation and by about 9 percent if more than 20 days have passed *(12)*. This study found the same pattern for non-fatal crash rates.

It is suggested that over long periods of dry surface conditions, the first precipitation occurrence tends to increase the amount of crashes, because the oils built up over time on the road are washed with the precipitation, thus reducing vehicular traction *(12)*. The crash rates would then tend to reduce if it continued to rain each day, because the rains would wash more oil build up off the roadway *(12)*. Also, after numerous days of precipitation, drivers respond accordingly to the weather condition from experience from previous days of precipitation related events.

Likewise, numerous studies have found that precipitation events that occur after exposure to long dry periods increase because of unfamiliarity of the roadway condition. On the other hand, many studies have shown that the severity of crashes that occur under adverse weather conditions are not as serious compared with those that occur under normal roadway conditions. This is likely because there are less drivers on the roadway when weather conditions are unfavorable for driving. As well, under such weather conditions, the average traffic speed generally decreases, which results in less severe accidents opposed to high speed collisions.

A Minnesota signal study, along Highway 36 in Minneapolis found that under adverse weather conditions average travel speeds and traffic volumes decreased compared to normal weather conditions *(13)*. The traffic volumes were compared at the same time of day for both clear weather conditions and adverse weather conditions. During the adverse weather conditions, traffic volumes decreased anywhere from 15 to 30 percent during peak hours *(13)*. Average speeds decreased from 44 miles per hour under normal driving conditions to as low as 26 miles per hour under adverse conditions *(13)*. A 1977 FHWA study indicates average speed reductions for highways *(13)*. The study found that speeds were reduced by the following percentage *(13)*:

- 13 percent under wet and snowy conditions
- 22 percent under wet and slushy conditions
- 35 percent under sticky snow conditions
- 42 percent under packed snow conditions

These studies examine the relationship between crashes and the roadway surface condition. Access management techniques were not considered when investigating the relationship between the two. Roads with poor access management typically perform at a low level of service (LOS) and experience queuing, bottlenecks, and excessive stop and go traffic. These factors tend to increase the risk of crashes. However, the relationship between access management and adverse weather has not been explored as of yet. As mentioned previously the purpose of this research is to explore the relationship between access management and safety under adverse weather conditions.

CHAPTER 4. METHODOLOGY

This chapter provides an overview of the data collection and statistical analysis methodologies used in this study. This chapter includes in detail the problem statement, hypothesis review, data collection, and statistical methods. Data collection included road segments, commercial driveway locations, and crash records for different weather, surface and lighting conditions. The remaining chapters will provide further information concerning the statistical analysis including descriptive and inferential statistics and conclusions based on the statistical results.

Problem Statement and Hypothesis Review

Roadways with poor access management can produce high risk areas exposing traffic to risky driving conditions. For example an arterial with a high density of commercial businesses, numerous traffic signals, and traversable medians, would likely produce more turning and rear-end collisions than a roadway with frontage roads, consolidated driveways, and non-traversable full raised medians designed to reduced conflict points. As discussed in previous chapters, numerous studies have shown that access management techniques, when properly applied, have resulted in lower frequencies of access-related collisions.

Additionally, there are many environmental factors that present dangerous roadway conditions such as rain, snow, sleet, and hail. Exposure to adverse weather conditions can potentially create additional risk to drivers traversing the roadway, as opposed to driving in clear weather conditions. For example, snow, rain, sleet and hail can result in reduced visibility and pose threat to the road surface condition.

The purpose of this research was to explore the relationship between weather conditions and access management practices. Crash records from 1997-2000 along arterials in the Des Moines metropolitan area were used for this study to determine the relationship between adverse condition and access management safety. The hypothesis for this research is that road segments with good access management characteristics will provide safer driving conditions (as shown by crash rates) under adverse conditions, as well under favorable conditions.

Data Collection

The majority of the data used for this research were obtained from the Iowa DOT. Geospatial data included the state, county, city, roadway (also obtained from DMAMPO), and crash record data. The geospatial data was used in ArcView GIS for data management and map making purposes. As well, 2002 infrared aerial photographs were used for the driveway inventory and assisted as visuals for numerous maps. The infrared aerial photographs were obtained from the Iowa State University Geographic Information Systems Support and Research Facility *(14)*.

Study Area

The study area included all of the cities within the Des Moines Metropolitan Planning Organizations (DMAMPO) planning boundaries. The City of Des Moines accounts for the majority of this area. The cities of Altoona, Ankeny, Bondurant, Clive, Des Moines, Grimes, Johnston, Norwalk, Pleasant Hill, Polk City, Urbandale, Waukee, West Des Moines, and Windsor Heights are all located in the DMAMPO service boundaries. Figure 4-1 shows the location of Des Moines and the cities within DMAMPO boundary.

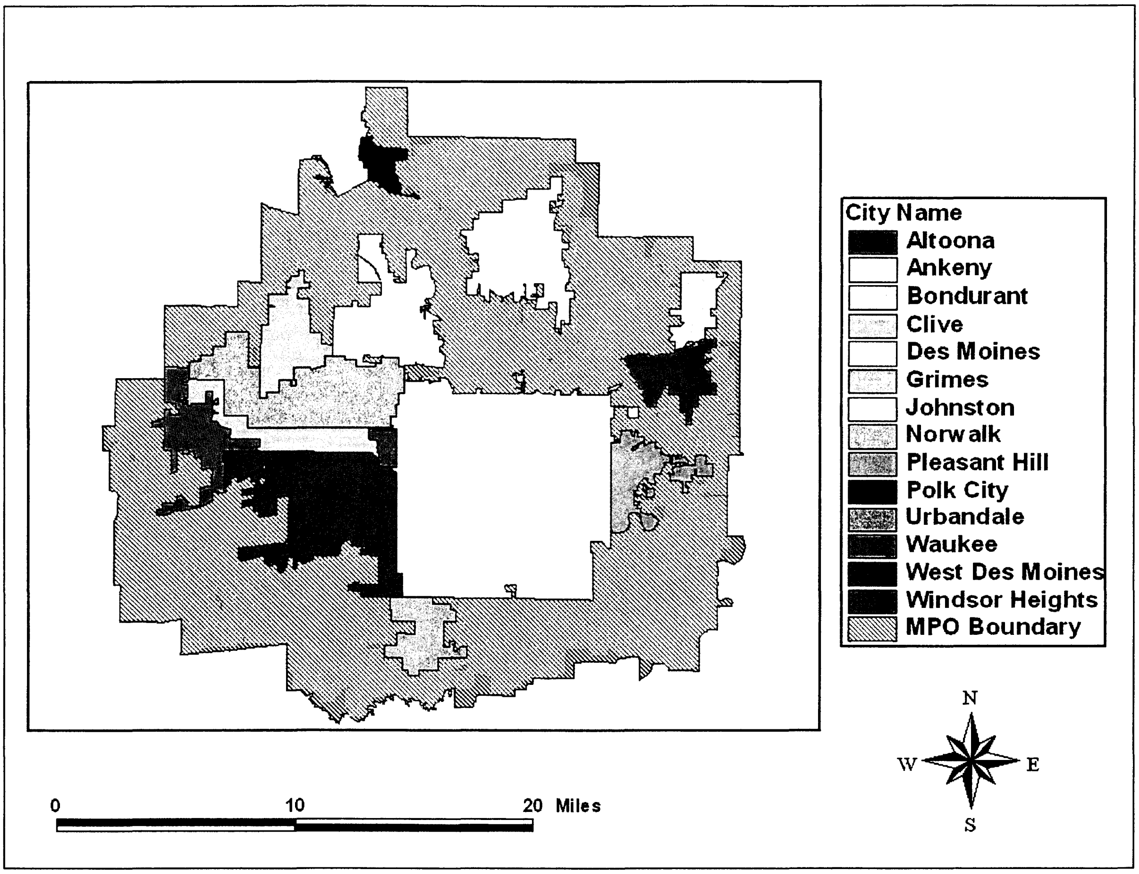

Figure 4-1. Cities in Study Area

All of the city populations in the study area have increased from the year 1980 to 2000, with the exception of Windsor Heights. The City of Johnston has increased considerably by over 237 percent from 1980 to 2000 *(15)*. The cities of Clive, Grimes, Norwalk, Waukee, and West Des Moines have also increased by over 100 percent since 1980 *(15)*. Table 4-1 below shows each cities population for 1980, 1990, and 2000 and the percentage of change from 1980 to 2000.

Table 4-1. City Populations in the Des Moines Metropolitan Area, 1980-2000

City	1980	1990	2000	Percent Change (1980-2000)
Altoona	5,764	7,191	10,274	78.24%
Ankeny	15,429	18,583	26,923	74.50%
Bondurant	1,283	1,584	1,857	44.74%
Clive	6,064	7,462	12,851	111.92%
Des Moines	191,003	193,187	197,533	3.42%
Grimes	1,973	2,653	5,064	156.66%
Johnston	2,617	4,702	8,825	237.22%
Norwalk	2,676	5,725	6,971	160.50%
Pleasant Hill	3,493	3,676	5,095	45.86%
Polk City	1,658	1,908	2,339	41.07%
Urbandale	17,869	23,500	29,066	62.66%
Waukee	2,227	2,512	5,135	130.58%
West Des Moines	21,894	31,695	46,300	111.47%
Windsor Heights	5,474	5,190	4,761	-13.03%
Total	**279,424**	**309,568**	**362,994**	**29.91%**

(Source: SETA, Iowa State University)

Road Selection

After indicating the county and city data files to be used, roadway corridors were selected to represent different levels of access management. Using the roadway geospatial data obtained from the Des Moines MPO, principal and minor arterials located in the DMAMPO service boundaries were selected from the road database. This resulted in a total of 81 corridors. The road files for these 81 corridors were then selected from the Iowa DOT geospatial database. This was done because the Iowa DOT road database has full information concerning the characteristics of the road network.

Segment Selection

The 81 selected corridors were broken into approximately 2 mile segments based primarily on the median type, as indicated in the Iowa DOT database. There were a total of 161 road segments, as listed in table A-1 of the appendix. Of the 161, 9 of the segments

Average Annual Daily Traffic (AADT) information available and were excluded from the study. From the 152 study segments, the average segment length was 2.03 miles.

Median type was used to split the corridors, because it is a useful indicator of the access control at that particular location of the roadway, as described previously in the access management literature review. Roadways with no median are those considered to have poor access control, where those with a full raised median have a high level of access control. Figure 4-2 shows the different median types from which the 161 road segments were selected.

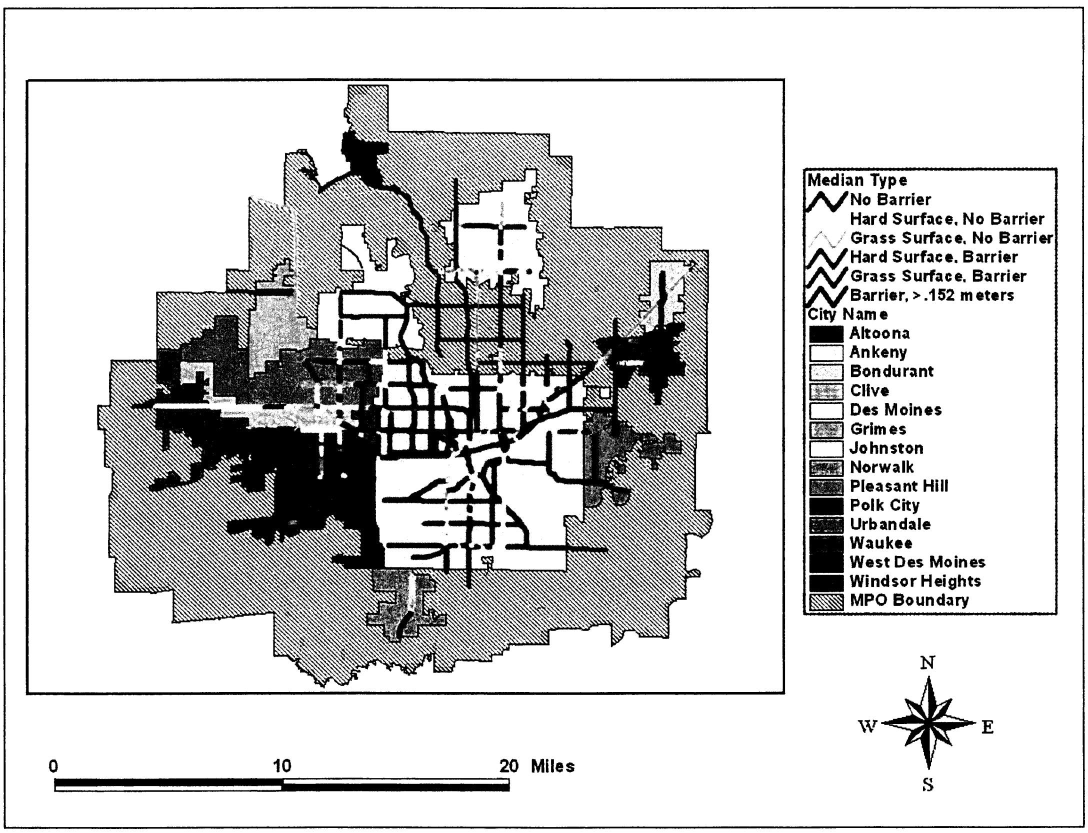

Figure 4-2. Roadways and Median Type

Commercial Driveway Inventory

Commercial driveways are another good indicator of the level of access along a specific road segment. For this study, a driveway inventory for arterials in the Des Moines metropolitan area was collected. Infrared orthophoto's from 2002 and current land use files were used in GIS in order to locate the driveways and distinguish the land use they provide access to, since commercial driveways are those which will be used for further analysis. The orthophotos were provided by the Iowa Department of Natural Resources, and were accessed at the Iowa Geographic Image Map Server *(14)*. The land use files were provided by the Des Moines Area Metropolitan Planning Organization. Geospatial land use files included Dallas, Polk, and Warren Counties.

The infrared orthophotos, with a one-meter resolution, were viewed with supporting road data in GIS. For each study segment, the infrared orthophotos were zoomed in until driveway locations could be identified. A new GIS point shapefile was created for each driveway location. This resulted in 8,819 driveways along the 152 study segments. Along certain segments the driveway locations were not easily identified, therefore, the inventory is not 100 percent accurate, due to possible human error. Examples include segments such as those with close driveway spacing, those in highly urbanized areas (which create shadows on the ground), or areas where the orthophoto's were distorted.

In order to determine which driveways provide access to commercial parcels, the land use data was used in GIS. Current land use for Dallas, Polk, and Warren County were used in the process to locate the commercial driveways. Using GIS the land use data for the three counties were merged together to create one land use file. From the overall land use file, the commercial parcels were selected and saved as a new data file. This parcel selection enabled the driveways inside or within 50 feet of commercial land use to be selected. Of the total 8,819 driveways, approximately 38 percent of them were determined to be commercial driveways, totaling 3,332 commercial driveways. Using the commercial driveway inventory, the density of commercial driveways per mile for each segment was calculated for further analysis. Table A-2 in the appendix provides the commercial driveway densities (per mile) for each study segment.

Traffic Signal Inventory

As described earlier, an abundance of traffic signals can produce rear-end collisions along arterials. Traffic signals in the Des Moines metropolitan area were identified in ArcView. A shapefile and database of traffic signals for the study area was provided by the Des Moines MPO.

The number of traffic signals per segment was figured using ArcView. Once the total traffic signals per segment were figured, the traffic signal density per mile was calculated using ArcView. This was calculated by dividing the number of commercial driveways per segment by the total segment length (in miles). Table A-2 in the appendix identifies each segment and its corresponding traffic signal density.

Crash Selection

Crash records from the Iowa DOT geospatial database were used for this study. Using ArcView GIS, crashes that occurred from 1997 to 2000 within a distance of 150 feet from the selected roadway segments were selected. This resulted in a total of 23,769 crashes. From the total crashes, the access-related crashes were selected. The following collision types were selected to represent access crashes:

- Broadside/Left-turn
- Rear-end
- Rear-end/Right-turn
- Rear-end/Left-turn
- Broadside/Right Angle
- Broadside/Right Entering
- Broadside/Left Entering

These collision types were selected as the access-related crashes because they are typical collisions that result from poor access management characteristics. From the total crashes, a total of 13,638 access-related crashes were selected. The access-related crashes were used for further statistical analysis.

Weather Related Crashes

To determine the relationship between access management and weather conditions, the weather condition for each crash record was identified. The Iowa DOT geospatial data indicates the weather condition for each crash record. The weather condition is reported by a police officer at the scene of the accident. The weather condition at the time of the accident is usually reported, as opposed to the weather condition when the police officer arrives at the scene. Crash reports from police officers are then entered into the geospatial database. This process is subject to human error for many different reasons, for example, a report may be written illegibly and recorded incorrectly in the geospatial database.

There are two fields in the crash database, which indicate the weather condition for each crash record, the primary weather condition and a secondary weather condition. Two fields are used to indicate multiple weather events in the instance of a collision. For example, if the weather was rainy and a bit foggy at the time of the crash, the first field would indicate the rain event and the second would indicate that it was also foggy. For this study the crash records were grouped according to adverse weather condition versus clear weather condition. Weather conditions are categorized by the Iowa DOT as shown in Table 4-2, and grouped for the purpose of this research as shown in the table. Strong wind, cloudy, other, and unknown weather related crashes were not included because they were not relevant to the study.

Table 4-2. Weather Conditions and Grouping

	Adverse Weather Conditions		
Favorable	**Poor Visibility**	**Reduced Friction**	**Not Included**
Clear	Rain	Snow	Strong Wind
	Mist	Sleet/Hail	Cloudy
	Fog		Other/Unknown

Crash rates for weather condition related collisions were calculated, as described later in this chapter. The crash rates were used for statistical analysis, primarily because they are normalized by VMT along the segment which the crash occurred, allowing for easy comparison throughout the study. The crash rates and statistical analysis are described in more detail in the remaining chapters. Weather conditions were explored in this research to see what, if any, relationship exists between adverse weather conditions and clear weather conditions along road segments with different levels of access in the Des Moines metropolitan area.

There are usually more days with clear weather conditions opposed to adverse weather conditions, therefore crash rates were much lower for the adverse conditions. Depending on how severe the adverse weather condition is, there is usually less traffic on roads under unfavorable conditions. The average number of days with precipitation weather related events in Des Moines was found from 1945 to 1990, as measured at the Des Moines

Airport. Averages were found using the *Meteorological Climate Summary, Version 3.0 (16).* Based on averages taken at the Des Moines Airport from 1945 to 1990, in a year there are 64 days with snow, 131 days with rain (including trace amounts), and 2 days with hail *(16).* Weather occurrences by hourly frequency over the same time period were also figured. On average, 10.8 percent of the time (over the course of a year) in Iowa there is precipitation *(16)*. Other average weather occurrences include:

- Thunderstorm: 1.2%
- Rain/drizzle: 6.5%
- Freezing rain/drizzle: 0.5%
- Snow/sleet: 4.2%
- Fog: 9.9%
- Blowing snow: 0.5%
- Hail: 0.05%

(Source: International Station Meteorological Climate Summary, Version 3.0)

Surface Condition and Crashes

The Iowa DOT geospatial data indicates the surface condition for each crash record as well. The surface condition at the time of accident is recorded by the police officer at the scene of the accident, and then added to the Iowa DOT geospatial database, in the same process as weather conditions are reported, hence there is possibility of human error in the data as described above. For this study, only ice, snow, wet, and dry surface condition related crashes were observed. Surface conditions are categorized in the geospatial database as shown:

- Ice
- Snow
- Wet
- Mud
- Dry
- Loose Gravel

- Debris
- Other/Unknown

The ice, snow, and wet surface conditions were grouped for the study to indicate the adverse related surface conditions.

Lighting Condition and Crashes

The lighting condition observed at the time of crash was recorded by the police officer at the scene. Lighting conditions are recorded in the database as day, dusk, dawn, dark with lit roadway, dark with roadway not lighted, and unknown lighting conditions. For this research the dusk, dawn, dark with lit roadways and dark with unlit roadways were grouped to represent the adverse, or unfavorable lighting conditions versus the daytime lighting conditions.

Light conditions are explored in this research to see what, if any, relationship exists between daytime lighting and nighttime conditions along road segments with different levels of access in the Des Moines metropolitan area. In order for fair comparison, crash rates for the lighting conditions were observed only under dry surface conditions. The AADT for these crash rates were adjusted, as the AADT counts are usually taken during the daylight hours, when there is typically more traffic.

To account for lower amount of traffic during dark or nighttime conditions, the average amount of dark hours per day was figured for Des Moines during 1997-2000. The Astronomical Applications Department (AAD) from the U.S. Naval Observatory was accessed online at http://aa.usno.navy.mil/data/docs/RS_OneYear.html which has a link that provides information on sunset and sunrise times for different locations in U.S. *(17)*.

Using information from the AAD website, the average dark conditions, including dusk and dawn, were figured for each month from 1997 to 2000. The average of nighttime hours for the four-year time period from each month were then averaged in order to determine the overall average of nighttime hours there were in Des Moines from 1997 to 2000. It is noted that hours were rounded off to the nearest hour. For example if the average was 6:30, then 6:00 was used for research purposes or if it was 6:31 then 7:00 was used. See table 4-3 for the average nighttime hours per day for each month.

Table 4-3. Average Dark Hours per 24 hour period by Month for Des Moines, 1997-2000

Month	**Military Time**	**Hourly Time**	**Total Dark Hours**	**Percent of Dark Hours (per day)**
January	17:00-8:00	5:00pm-8:00am	15	62.50%
February	17:00-7:00	5:00pm-7:00am	14	58.33%
March	18:00-6:00	6:00pm-6:00am	12	50.00%
April	19:00-6:00	7:00pm-6:00am	11	45.83%
May	19:00-5:00	7:00pm-5:00am	10	41.67%
June	20:00-5:00	8:00pm-5:00am	9	37.50%
July	20:00-5:00	8:00pm-5:00am	9	37.50%
August	19:00-5:00	7:00pm-5:00am	10	41.67%
September	18:00-6:00	6:00pm-6:00am	12	50.00%
October	18:00-6:00	6:00pm-6:00am	12	50.00%
November	17:00-7:00	5:00pm-7:00am	14	58.33%
December	17:00-8:00	5:00pm-8:00am	15	62.50%
		Total	**143**	**49.65%**

(Source: Astronomical Applications Department, U.S. Naval Observatory)

With the observed data, on average nighttime began at 6:00pm and ended at 6:00am in Des Moines. With the nighttime hours observed for Des Moines over the four year period, the AADT must reflect nighttime hours only. To reflect nighttime hours, past traffic counts must be observed to see what percentage of the total traffic occur during the hours from 6:00 pm to 6:00 am. This information was obtained from the Iowa DOT's report on *Automatic Traffic Recorders, 1993-2003 (18).*

Table 4-4 below shows the percentage of total daily traffic for municipal primary roads in Iowa for 2003 from 6:00pm to 6:00am, based on percentages in the DOT's Automatic Traffic Recorders: 1993-2003. The sum of the nighttime percentages equals 227.08 percent, which averages to 32.44 percent of traffic being during nighttime hours on a daily basis. Therefore, the average percent of daytime traffic is 67.56 percent. These averages were used for figuring the daytime and nighttime AADT's, which were then figured to find night and day VMT's in order to figure crash rates. The AADT was simply multiplied by 0.3244 to figure nighttime VMT and by 0.6756 to figure daytime VMT.

Table 4-4. Hourly Distribution of Daily Traffic from 6pm to 6am for 2003 Municipal Primary Roads

Hour	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total
6:00pm	7.47%	7.92%	7.94%	7.92%	7.96%	7.61%	6.55%	**53.37%**
7:00pm	6.29%	5.59%	5.68%	5.88%	5.88%	6.00%	6.02%	**41.34%**
8:00pm	5.03%	4.16%	4.22%	4.32%	4.41%	4.66%	4.83%	**31.63%**
9:00pm	3.95%	3.41%	3.52%	3.66%	3.71%	3.80%	4.03%	**26.08%**
10:00pm	3.10%	2.67%	2.82%	2.87%	3.02%	3.36%	3.58%	**21.42%**
11:00pm	2.10%	1.73%	1.80%	1.85%	1.95%	2.52%	2.79%	**14.74%**
12:00am	1.28%	1.10%	1.14%	1.18%	1.25%	1.78%	2.01%	**9.74%**
1:00am	1.59%	0.52%	0.66%	0.70%	0.73%	0.69%	1.33%	**6.22%**
2:00am	1.07%	0.33%	0.40%	0.44%	0.47%	0.45%	0.82%	**3.98%**
3:00am	0.71%	0.27%	0.33%	0.35%	0.36%	0.35%	0.55%	**2.92%**
4:00am	0.44%	0.29%	0.33%	0.35%	0.35%	0.33%	0.39%	**2.48%**
5:00am	0.41%	0.57%	0.59%	0.59%	0.59%	0.54%	0.45%	**3.74%**
6:00am	0.69%	1.62%	1.65%	1.61%	1.59%	1.40%	0.86%	**9.42%**
Total	**34.13%**	**30.18%**	**31.08%**	**31.72%**	**32.27%**	**33.49%**	**34.21%**	**227.08%**

(Source: Automatic Traffic Recorders, 1993-2003, Iowa DOT)

Crash Rates

Using ArcView GIS, the access-related crash frequencies per segment were found for each weather, surface, and lighting condition. These crash frequencies were then used to find the access-related crash rate for each segment and differing weather, surface, and lighting conditions. The crash rates indicate how many collisions occur over the road segment for every million vehicle miles traveled for the four-year time period.

For crash rates to be calculated, a weighted AADT first had to be figured to calculate the VMT per road segment. Since each study segment was made up of individual segments, the weighted AADT was calculated as shown:

$$\text{Weighted AADT} = \frac{\text{Segment length} * \text{AADT}}{\text{Total Segment length}}$$

Once the weighted AADT was figured the total VMT can be calculated for each segment. The VMT indicates how many vehicles traversed the segment over a four-year period based on the weighted AADT and segment length. VMT is calculated as shown:

$$\text{VMT} = \text{Length of segment (miles)} * \text{Time Period} * \text{Weighted AADT}$$

*With the time period being 4 * 365, four years with 365 days per year.*

With the following calculations, the crash frequency is multiplied by one million and divided by the total VMT for each segment. This calculation indicates approximately how many crashes one would expect per million vehicle miles for each segment based on the crash records from 1997 to 2000. The formula below displays how crash rates were calculated.

$$\text{Crash Rate} = \frac{\text{Crash Frequency} * 1{,}000{,}000}{\text{Total VMT per segment}}$$

Crash rates were figured using crash frequencies for the different weather, surface, and lighting conditions. The crash rates were then used for statistical analysis. Crash rates were used, rather than crash frequencies, because they are normalized by total VMT, which allows for equal comparison in the statistical analysis based on the AADT and length of each segment, as well the represent exposure to crashes. Table A-3 in the appendix shows crash rates for the study segments.

Descriptive Statistics

Descriptive statistics were used in order to get a better idea of the sample data. The descriptive statistics were observed to identify overall trends of the data, as well, to see if there are any outliers which may produce inaccurate results in the regression model. Chapter five will cover the descriptive statistics in detail, including crash rates for the different weather, surface, and lighting condition related crashes.

Inferential Statistics

Access-related crash rates were figured for weather conditions, surface conditions, and lighting conditions were figured for each segment for statistical analysis. As described above crash rates were used for comparison because they indicate how many crashes one would expect for every million vehicle miles traveled, based on crash frequencies and traffic counts for each segment. For this study crash rates serve as the dependant or response variable. Weather, surface and lighting conditions served as the independent or explanatory variables. S-PLUS statistical software version 6.2 was used to determine the relationship between the dependent and independent variables, which were all quantitative variables.

CHAPTER 5. DESCRIPTIVE STATISTICS

This chapter provides in detail the descriptive statistics for the study. Descriptive statistics provide information on the sample road segments, the crashes along these segments, and the roadway characteristics that indicate the level of access management. This chapter first explores the sample segments and access management indicators including median type, commercial driveway density, and traffic signal density. Following the roadway and access characteristics, the crash records will be covered in detail for different weather, surface, and lighting conditions.

Road Segments and Median Type

There are a total of 152 road segments in the study. As stated in the previous chapter, the study segments include arterial roadways in the Des Moines metropolitan area. From the arterial roads, the study segments were selected based primarily on the median type, and broken at major intersections, approximately 2 miles in length.

As Figure 4-2 shows, the majority of the segments have no barriers, or traversable medians. The road segments total over 311 miles in length. Of the 311 miles, approximately 307 miles, or over 98 percent of the road segments have no barrier. As described earlier segments with no barrier, or traversable medians, are those where left-turns are allowed thus creating potential conflict points. Table 5-1 shows the total mileage by median type for the road segments. Most of the no barrier segments are located in older areas in the City of Des Moines.

Of the segments with no barrier, the majority of them, with 74 percent of the total mileage have a curb less than 0.152 meters. Likewise, nearly 15 percent of the total mileage is hard surface median with no barrier, and 9 percent have a grass surface with no barrier. Of the total mileage with barriers, slightly over 1 percent is grass surface with a barrier. See table 5-1 for the breakdown of median type by mileage for the study segments.

Table 5-1. Roadways and Mileage of Median Type

Median Type	Total Miles	Percent of Total Miles
No Barrier (<.152 meter curb)	232.34	74.50%
Hard Surface, No Barrier	45.40	14.56%
Grass Surface, No Barrier	29.53	9.47%
Hard Surface, Barrier	0.72	0.23%
Grass Surface, Barrier	3.36	1.08%
Barrier (>.152 meters)	0.51	0.16%
Total	**311.85**	**100.00%**

Commercial Driveway Density

As described in the previous chapter, from the total driveway inventory the commercial driveways were identified for the study segments. There were a total of 8,819 driveways along the study segments. Of these, nearly 38 percent or 3,332 are commercial driveways. The driveway counts were then used to calculate the driveway density per mile for each segment. Roadways with a high density of driveways usually produce more access-related crashes, such as left and right-turn collisions, compared to roadways with a low density of driveways.

The total number of driveways and commercial driveways was figured for each segment. The commercial driveway density was calculated per segment by dividing the number of commercial driveways for each segment by the segments length in miles. As table A-2 in the appendix shows, the commercial driveway density ranges from zero to 58 commercial driveways per mile. The average commercial driveway density from the 152 segments was 10.76 per mile, which is slightly higher than the median at 8.62 driveways per mile.

Of the commercial driveway densities, 113 of the segments (74 percent of the total) have commercial driveway densities that vary anywhere from zero to 14.99 driveways per mile. Of the 152 total segments 56 of them (nearly 37 percent) of them range from zero to 4.99 driveways per mile, 32 segments have a commercial driveway density from 5.00 to 9.99, and 25 segments with a density from 10.00 to 14.99. There are 15 segments with a commercial driveway density from 15.00 to 19.99 and 17 segments with 25 or more commercial driveways per mile. There are only 7 segments with 20.00 to 24.99 commercial driveways per mile. Table 5-2 summarizes the commercial driveway densities for the segments.

Table 5-2. Commercial Driveway Density Summary

Commercial Driveway Density (per mile)	Segment Count	Percent of Total
0 to 4.99	56	36.84%
5.00 to 9.99	32	21.05%
10.00 to 14.99	25	16.45%
15.00 to 19.99	15	9.87%
20.00 to 24.99	7	4.61%
25+	17	11.18%
Total	**152**	**100.00%**

From the segments with a commercial driveway density of 25.00 or higher, the majority of them are within the City of Des Moines. Douglas Avenue, Ingersoll Avenue, Southwest 9th Street, and Southeast 14th Street have at least a 3 mile stretch with a commercial driveway density exceeding 25 driveways per mile. Segments outside of the City of Des Moines with the highest commercial driveway density include:

- 22^{nd} Street in West Des Moines
- Merle Hay Road in Johnston
- South Ankeny Boulevard in Ankeny
- Adventureland Drive in Altoona
- Douglas Avenue in Urbandale.

Figure B-1 in the appendix shows segment locations with a commercial driveway density of 25 or more per mile, with 1 being the highest commercial driveway density and 17 being the lowest.

Traffic Signal Density

As mentioned earlier, traffic signals are a major contributor to rear-end collisions. For this study, the density of signals per mile for each road segment was observed to see if it has an effect on the crash rates under different weather, surface, and lighting conditions. The average traffic signal density for the 152 segments is 1.86 signals per mile with a median of 1.54. There are several segments with a signal density of zero and the highest with 8.93 traffic signals per mile.

The majority of the segments have a traffic signal density from zero to 3.99 signals per mile. There are 88, or nearly 58 percent of the segments with a traffic signals density from zero to 1.99. Over 30 percent or 46 segments have a traffic signal density from 2.00 to 3.99 signals per mile. Of the remaining 18 segments, 12 of them have a signal density of 4.00 to 5.99, 5 of them with a signal density of 6.00 to 7.99, and 1 has a signal density of 8.00 to 9.99. See table 5-3 for more details.

Table 5-3. Traffic Signal Density Summary

Traffic Signal Density (per mile)	Segment Count	Percent of Total
0 to 1.99	88	57.89%
2.00 to 3.99	46	30.26%
4.00 to 5.99	12	7.89%
6.00 to 7.99	5	3.29%
8.00 to 9.99	1	0.66%
Total	**152**	**100.00%**

As figure B-2 in the appendix shows, the majority of the segments with a signal density exceeding 4.00 per mile are located within the City of Des Moines. The majority of Grand Avenue has a signal density above 4 signals per mile. As well, 31st Street, Martin Luther King Jr. Parkway, Southwest 9th Street and West 19th Street have segments over one mile in length with a high traffic signal density. There are 3 segments in West Des Moines with a signal density over 4; they are University Avenue (which separates Clive and West Des Moines), 22nd Street, and 35th Street.

Crash Data

The majority of the access-related crashes along the study segments are rear-end collisions. Of the total access-related crashes, 7,037 are rear-end collisions which make up over 51 percent of the total access crashes and over 29 percent of the total crashes. There were 3,899 right-turn collisions, which is nearly 29 percent of the total access crashes and over 16 percent of the total crashes. There were 2,702 total left-turn collisions, making up nearly 20 percent of the total access crashes and over 11 percent of the total crashes. Access-related crashes account for over 57 percent of the total crashes that occurred along the study segments from 1997 to 2000. See table 5-4 for details.

Table 5-4. Access Crash Breakdown

Collision Type	Access Crashes	Percent of Total Access Crashes	Percent of Total Crashes
Left-Turn	2,702	19.81%	11.37%
Rear-End	7,037	51.60%	29.61%
Right-Turn	3,899	28.59%	16.40%
Total	**13,638**	**100.00%**	**57.38%**

From the 152 study segments, over 79 percent have access-related crash frequencies ranging anywhere from zero to 99 crashes. Over half of the study segments, or 77, have crash frequencies from zero to 49 crashes. There are 28 segments, or over 18 percent of the total with a access crash frequency from 100 to 199 crashes. There are only 20 segments with a crash frequency over 200. Only 3 of the segments have a crash frequency exceeding 400 access-related crashes. The average segment length for each frequency category is noted in table 5-5. As the table shows, the average segment length with crash frequencies exceeding 150 are anywhere from 2.55 to as high as 3.34 miles, whereas, the segments ranging from zero to 149 crash frequencies have a lower average segment length ranging from 1.60 to 2.19 miles.

Table 5-5. Access Crash Frequency

Access Crashes	Segment Count	Percent of Total	Average Segment Length (miles)
0 to 49	77	50.66%	1.60
50 to 99	27	17.76%	2.19
100 to 149	17	11.18%	2.02
150 to 199	11	7.24%	2.76
200 to 249	6	3.95%	2.66
250 to 299	4	2.63%	3.09
300 to 349	2	1.32%	2.55
350 to 399	5	3.29%	3.57
400+	3	1.97%	3.34
Total	**152**	**100.00%**	-

From the 10 segments with a crash frequency of 300 or higher, all of these segments are within the City of Des Moines, with the exception of Douglas Avenue which partially extends into Urbandale. The highest crash frequency was a total of 593 access crashes along Southeast 14th Street, which is much higher than the 2nd highest with 437 crashes along East Euclid Avenue. See figure 5-3 in the appendix for the segments with access crash frequencies of 300 or higher. They are listed with number 1 having the highest crash frequency.

Crash Rates

Using the crash frequency for access-related crashes, crash rates per million vehicle miles traveled (VMT) was figured for each segment. From the 152 segments, the majority of the segments have a crash rate ranging anywhere from zero to 5.99 crashes per million VMT. There are 57 segments, or 37 percent of the segments, with a crash rate from zero to 1.99. As indicated in table 5-6, there is likely a relationship between the average commercial driveway and signal density and crash rates among the study segments. Notice that the segments with crash rates from zero to 1.99 have a significantly lower average commercial driveway and signal density compare to those with crash rates exceeding 2.00 crashes per million VMT.

Table 5-6. Crash Rates for Access Crashes

Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 1.99	57	37.50%	5.37	0.70
2.00 to 3.99	48	31.58%	11.28	1.95
4.00 to 5.99	30	19.74%	18.20	2.71
6.00 to 7.99	7	4.61%	12.49	3.25
8.00 to 9.99	7	4.61%	11.55	4.19
10.00 to 11.99	2	1.32%	28.17	5.12
12.00+	1	0.66%	16.67	5.56
Total	**152**	**100.00%**	-	-

As indicated in the previous table, there are only 17 segments with crash rates of 6.00 or higher. Figure B-4 in the appendix shows the segments with 6.00 crashes per million VMT or higher. As shown on the map, the majority of the segments are located in the City of Des Moines. There are 4 segments in West Des Moines, and 1 in Johnston, Ankeny, and Altoona. The majority of the segments are in the City of Des Moines, most likely because they are older arterials that are built up and provide access to heavy amounts of traffic to commercial land uses. However, West Des Moines has grown as a result of sprawl from the City of Des Moines, with most of the roads newer compared to those in Des Moines, thus providing newer more safe and efficient access to commercial land parcels.

Weather Condition Crashes

The majority of the collisions occurred under clear weather conditions, make up over 42 percent of the collisions. Strong wind and cloudy weather conditions accounted for over 16 percent (each) of the total crashes; however, these conditions will not be used for further analysis, as they have no impact on the road surface condition and little impact which might result in an accident. Snow accounted for nearly 12 percent of the total crashes and rain for over 6 percent. It is important to keep in mind that clear condition events occur more frequently each year opposed to adverse weather events in Iowa.

Table 5-7. Weather Condition Summary for Total Crashes

Weather Condition	Crash Frequency	Percent of Total
Snow	2,800	11.78%
Sleet/Hail	139	0.58%
Rain	1,516	6.38%
Mist	693	2.92%
Fog	325	1.37%
Strong Wind	3,886	16.35%
Cloudy	3,948	16.61%
Clear	10,197	42.90%
Other/Unknown	265	1.11%
Total Crashes	**23,769**	**100.00%**

The weather condition for the access-related crashes were very similar to that of the total crashes. Nearly 42 percent of the collisions were under clear weather conditions. Combined, strong wind and cloudy weather events make up approximately 34 percent of the total access-related collisions. Snow makes up almost 12 percent of the total access crashes and rain almost 7 percent. See table 5-8 for more details.

Table 5-8. Weather Condition Summary for Access Crashes

Weather Condition	Crash Frequency	Percent of Total Access Crashes
Snow	1,612	11.82%
Sleet/Hail	63	0.46%
Rain	904	6.63%
Mist	381	2.79%
Fog	204	1.50%
Strong Wind	2,336	17.13%
Cloudy	2,385	17.49%
Clear	5,674	41.60%
Other/Unknown	79	0.58%
Total Crashes	**13,638**	**100.00%**

Exactly half of the segments, with a total of 76 have crash rates from clear weather conditions anywhere from zero to 0.99 crashes per million VMT. Over 29 percent of the segments have clear weather crash rates of 1.00 to 1.99 crashes per million VMT and there are 19 segments with a crash rate from 2.00 to 2.99. Only 12 segments have clear weather crash rates exceeding 3.00 crashes per million VMT. For the study segments, a relationship is noticed between the clear weather condition crash rates and the commercial and traffic signal densities. As the table below shows, the 76 segments with low crash rates have an average commercial driveway density and average signal density much lower compared to the rest.

Table 5-9. Crash Rates for Clear Weather Conditions

Clear Weather Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 0.99	76	50.00%	6.18	1.09
1.00 to 1.99	45	29.61%	14.49	2.08
2.00 to 2.99	19	12.50%	17.40	2.88
3.00 to 3.99	3	1.97%	16.57	6.18
4.00 to 4.99	8	5.26%	14.57	3.40
5.00 to 5.99	1	0.66%	16.67	5.56
6.00+	0	0.00%	-	-
Total	**152**	**100.00%**	-	-

There are fewer crashes that occurred under adverse weather conditions compared to clear weather conditions, primarily because there is more traffic during clear weather conditions and there are more clear weather condition days in the year then there are adverse. Shown in table 5-10, the adverse weather crash rate category includes those crashes which occurred under rain, mist, fog, snow, sleet, and hail related weather conditions.

From the study segments, 62 of them or slightly over 40 percent have adverse weather crash rates from zero to 0.49 crashes per million VMT. There are 50 segments with an adverse weather crash rate ranging from 0.50 to 0.99 crashes per million VMT and 21 segments with a crash rate from 1.00 to 1.49. From the remaining 19 segments, 11 have crash rates from 1.50 to 1.99, 6 with crash rates ranging from 2.00 to 2.49, and 2 segments have crash rates exceeding 2.50. As noticed with the clear weather condition crash rates, there also seems to be a relationship between adverse weather crashes and the commercial driveway density and traffic signal density. As table 5-10 shows, the crash rates from zero 0.49 have a commercial driveway density and signal density significantly lower compared to the higher crash rates.

Table 5-10. Crash Rates for Adverse Weather Conditions

*Adverse Weather Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 0.49	62	40.79%	5.12	0.73
0.50 to 0.99	50	32.89%	14.18	2.06
1.00 to 1.49	21	13.82%	16.60	2.87
1.50 to 1.99	11	7.24%	12.34	3.53
2.00 to 2.49	6	3.95%	12.26	4.62
2.50 to 2.99	1	0.66%	12.74	4.55
3.00+	1	0.66%	37.69	2.51
Total	**152**	**100.00%**	**-**	**-**

**Includes access crashes that occurred under rain, mist, fog, snow, sleet, or hail conditions*

Figure B-5 in the appendix shows locations segments with higher crash rates under adverse conditions. As discovered previously with the access crash rates, the majority of these segments are located in the City of Des Moines along older 4-lane arterials. Included are two segments in West Des Moines and one in Ankeny. This trend can be explained primarily because the segments located in Des Moines are older with less access management techniques.

Surface Condition Crashes

The majority of the crashes (69%) majority of them occurred under dry surface conditions. Wet surface conditions accounted for nearly 19 percent of the total crashes. Icy road conditions make up over 7 percent and snow conditions make up over 3 percent of the total crashes. See table 5-11 for more details.

Table 5-11. Surface Condition Summary for Total Crashes

Surface Condition	Crash Frequency	Percent of Total Crashes
Ice	1,737	7.31%
Snow	755	3.18%
Wet	4,437	18.67%
Mud	11	0.05%
Dry	16,369	68.87%
Loose Gravel	20	0.08%
Debris	10	0.04%
Other/Unknown	430	1.81%
Total	**23,769**	**100.00%**

Next, the frequency for access crashes and surface conditions was observed. As seen with the total crashes, the majority of the collisions occurred under dry surface conditions, with over 71 percent. Slightly higher than the total crashes, wet surface conditions were higher for access crashes with almost 20 percent of them. Over 19 percent of the crashes or 2,705 occurred under wet surface conditions. Combined, ice and snow surface conditions accounted for over 8 percent of the total access-related crashes.

Table 5-12. Surface Condition Summary for Access Crashes

Surface Condition	Crash Frequency	Percent of Total Access Crashes
Ice	767	5.62%
Snow	353	2.59%
Wet	2,705	19.83%
Mud	4	0.03%
Dry	9,696	71.10%
Loose Gravel	2	0.01%
Debris	5	0.04%
Other/Unknown	106	0.78%
Total	**13,638**	**100.00%**

From the 152 segments, 83 or over 54 percent of them have dry surface condition crash rates from zero to 1.99 crashes per million VMT. There are 28 segments with a crash rate ranging from 2.00 to 2.99 and 19 segments with crash rates varying from 3.00 to 3.99. Of the remaining 22 segments, 7 of them have crash rates from 4.00 to 4.99, 6 from 5.00 to 5.99, 7 from 6.00 to 6.99, 1 from 7.00 to 7.99, and 1 with over 9.00 crashes per million VMT. As noticed with the weather condition crash rates, the dry surface condition crash rates from zero to 0.99 have a significantly lower average commercial driveway density and traffic signal density, thus showing a possible relationship between access crashes and commercial driveway and traffic signal density.

Table 5-13. Crash Rates for Dry Surface Conditions

Dry Surface Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 0.99	43	28.29%	4.66	0.65
1.00 to 1.99	40	26.32%	9.12	1.64
2.00 to 2.99	28	18.42%	14.32	1.94
3.00 to 3.99	19	12.50%	16.31	2.95
4.00 to 4.99	7	4.61%	19.19	2.61
5.00 to 5.99	6	3.95%	13.71	2.93
6.00 to 6.99	7	4.61%	15.33	4.19
7.00 to 7.99	1	0.66%	18.65	7.73
8.00 to 8.99	0	0.00%	-	-
9.00+	1	0.66%	16.67	5.56
Total	**152**	**100.00%**	-	-

Crash rates were figured for the access-related crashes that occurred under unfavorable conditions, including icy, snowy, or wet conditions. From the 152 segments, 53 or nearly 35 percent of them have crash rates from zero to 0.49, 44 have crash rates from 0.50 to 0.99 and 33 of them have crash rates from 1.00 to 1.49 crashes per million VMT. From the remaining 22 segments, 8 have crash rates from 1.50 to 1.99, 8 from 2.00 to 2.49, 3 from 2.50 to 2.99, and 3 exceeding 3.00. As noted above, the majority of the adverse surface condition crash rate segments have an average commercial driveway density and traffic signal density much lower compared to the segments with higher crash rates.

Table 5-14. Crash Rates for Adverse Surface Conditions

*Adverse Surface Condition Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 0.49	53	34.87%	5.57	0.71
0.50 to 0.99	44	28.95%	12.92	1.76
1.00 to 1.49	33	21.71%	14.59	2.68
1.50 to 1.99	8	5.26%	11.18	2.29
2.00 to 2.49	8	5.26%	11.77	4.48
2.50 to 2.99	3	1.97%	14.95	5.14
3.00+	3	1.97%	20.55	3.19
Total	**152**	**100.00%**	-	-

**Includes access crashes that occurred under icy, snowy, or wet surface conditions*

The majority of the segments with high crash rates under adverse surface conditions are located in the City of Des Moines. As found previously with the adverse weather condition related crashes, 8 of the segments were identified as having rather high crash rates under adverse weather conditions. See figure B-6 in the appendix for locations of these segments.

Light Condition Crashes

The majority of the crashes occurred during daylight conditions. This trend is primarily due to the fact that there is more traffic on the road during daylight hours, especially at peak hours. Over 75 percent of the crashes from the selected roadways occurred during the daylight, as people usually travel to and from work, the store, or take leisure trips during daylight hours. Nearly 19 percent of the total crashes occurred during night, with roadway lighting. Over 2 percent of the crashes occurred at night, with no lighting, this is because the majority of the roadways in the study area are lit.

Table 5-15. Lighting Condition Summary for Total Crashes

Lighting Condition	Crash Frequency	Percent of Total Crashes
Day	17,901	75.31%
Dusk	685	2.88%
Dawn	202	0.85%
Dark- lighted roadway	4,413	18.57%
Dark- roadway not lighted	525	2.21%
Unknown	43	0.18%
Total	**23,769**	**100.00%**

Similar to the total crashes, the majority of the total access crashes were during the day. Nearly 79 percent of the access-related collisions occurred under daylight conditions. Likewise, over 16 percent occurred in the dark along roadways where street lighting was present. The remaining crashes occurred under dusk, dawn, dark but lighted roadways. There were 7 crashes where the lighting condition at the time of crash was not recorded and is unknown. See table 5-16 for more details.

Table 5-16. Lighting Condition Summary for Total Access Crashes

Lighting Condition	Crash Frequency	Percent of Total Access Crashes
Day	10,719	78.60%
Dusk	396	2.90%
Dawn	98	0.72%
Dark- lighted Roadway	2,250	16.50%
Dark- roadway not lighted	168	1.23%
Unknown	7	0.05%
Total	**13,638**	**100.00%**

From the 152 segments, 48 percent of them or 73 segments have a crash rate ranging from zero to 2.99 crashes per million VMT during daylight conditions. From these 73 segments, 25 of them have crash rates from zero to 0.99, 24 have crash rates from 1.00 to 1.99, and 24 have crash rates from 2.00 to 2.99. There were 53 segments with a crash rate ranging from 3.00 to 5.99 crashes per million VMT. From these 53 segments, 18 of them have crash rates from 3.00 to 3.99, 19 of them have crash rates from 4.00 to 4.99, and 16 with crash rates from 5.00 to 5.99. The remaining 26 segments have crash rates exceeding 6.00 crashes per million VMT during daylight conditions. The segments with crash rates from zero to 1.99 have an average commercial driveway density and traffic signal density considerably lower than the higher crash rates. This indicates that crash rates tend to be higher along segments with a high density of commercial driveways and traffic signals.

Table 5-17. Crash Rates for Daylight Conditions

Daylight Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Density (per mile)
0.00 to 0.99	25	16.45%	3.71	0.57
1.00 to 1.99	24	15.79%	5.66	0.66
2.00 to 2.99	24	15.79%	10.75	1.91
3.00 to 3.99	18	11.84%	11.27	1.75
4.00 to 4.99	19	12.50%	15.23	2.25
5.00 to 5.99	16	10.53%	17.86	2.33
6.00 to 6.99	8	5.26%	11.82	2.99
7.00 to 7.99	5	3.29%	13.58	3.96
8.00 to 8.99	2	1.32%	26.57	3.07
9.00 to 9.99	5	3.29%	10.21	3.48
10.00 to 10.99	1	0.66%	8.47	5.29
11.00 to 11.99	3	1.97%	19.99	3.06
12.00+	2	1.32%	17.66	6.64
Total	**152**	**100.00%**	-	-

As the table shows, the number of segments decrease as the crash rates increase, except there is a jump from 6 segments with a crash rate of 4.50 to 4.99 to 11 segments with a crash rate over 5.00 crashes per million VMT. In addition, the average commercial driveway density and traffic signal density are much lower for the segments with a crash rate of 0.99 or lower compared to the segments with higher crash rates. Figure B-7 in the appendix shows locations segments with high crash rates under dark conditions. These include crashes which occurred under nighttime and dusk or dawn lighting conditions.

Table 5-18. Crash Rates for Nighttime Conditions

Nighttime Crash Rate (Access Crashes)	Segment Count	Percent of Total	Average Commercial Driveway Density (per mile)	Average Traffic Signal Count (per mile)
0.00 to 0.49	38	25.00%	5.41	0.62
0.50 to 0.99	21	13.82%	6.38	1.11
1.00 to 1.49	13	8.55%	11.81	1.91
1.50 to 1.99	18	11.84%	9.52	2.12
2.00 to 2.49	18	11.84%	13.72	1.95
2.50 to 2.99	12	7.89%	14.53	1.98
3.00 to 3.49	6	3.95%	23.62	2.87
3.50 to 3.99	4	2.63%	14.25	2.69
4.00 to 4.49	5	3.29%	10.82	2.58
4.50 to 4.99	6	3.95%	18.95	3.48
5.00+	11	7.24%	16.61	4.72
Total	**152**	**100.00%**	-	-

Candidate Segments for Further Research

From the study segments, ones with high crash rates under adverse conditions were identified. The majority of the segments with high crash rates under adverse conditions are located in the City of Des Moines, and have high signal and commercial driveway densities. For example segments along University Avenue, Southwest 9th Street, and Grand Avenue had high crash rates under adverse conditions.

There were three segments identified with a very low density of commercial driveways and traffic signals, however the crash rates under adverse conditions was higher than most of the study segments. These segments are 28th Street and 31st Street from University Avenue to Grand Avenue and 35th Street from University Avenue to Ashworth Road.

A windshield survey was conducted for these three segments in order to determine why they might have such high crash rates under adverse conditions. The windshield survey indicated that all of these segments had similar characteristics; they all are narrow 2-lane roadways with a high density of residential driveways (which were not observed for this study) that cross major intersections and have extremely hilly terrain with steep sloped hills. As well, there is no median along each of these roadways, thus queuing is a problem when left-turns are being made. These segments likely have such high crash rates under adverse conditions due to the combination of the steep sloped hills, which result in poor site distance, and the stop and go traffic from left-turn queues and signals at the major intersections. Figures 5-1 and 5-2 illustrate the steepness of these roadways, which would pose additional risk under rainy, icy, or snowy conditions.

Figure 5-1. 31st Street, north of Ingersoll Avenue (facing south)

Figure 5-2. 28th Street, north of Ingersoll Avenue (facing north)

These segments are those which would likely need access management techniques applied to them in order to provide safer driving conditions to users, particularly under adverse conditions. Likewise, these segments should be considered for further research.

This chapter provides the descriptive statistics for access crash rates and commercial driveway and traffic signal density under different conditions, however, the relationship and the strength of the relationship between the two (access management and adverse conditions) needs to be addressed. The next chapter will explore the relationship between access management and adverse environmental conditions, using linear regression to determine the strength between crash rates under differing conditions with segments at various levels of access management.

CHAPTER 6. INFERENTIAL STATISTICS

Inferential Statistics Overview

The purpose of this chapter is to determine the relationship between environmental factors and access management features and the strength of the relationship between the two. Inferential statistics allow for predictions to be made concerning a population, based on the characteristics of the sample information *(18)*. Linear regression is the method used to evaluate the strength of that relationship. The purpose of linear regression is to see if there is an association between the variables, to study the strength of the association through correlation, and to study the form of the relationship to estimate the prediction equation *(18)*.

More specifically a multivariate regression was used since there were multiple explanatory variables for the study. Explanatory or independent variables in this study include median type, traffic signal density, and commercial driveway density. All of these variables are quantitative allowing for easy comparison and use in the regression model. The following introduces the variables in the study and the results from the regression analysis. Conclusions based on inferential statistics from the regression model are explored in the following chapter.

Independent Variables

Median Type

Since the study segments had different median types, the median type with no barrier was expressed as a percentage of the total miles with no barrier along the segment. For example, if a segment had 1.10 miles with no barrier and 0.56 miles with raised median, then

0.6627, or 66.27% was used in the regression model. This was done primarily because the majority of median type for the study segments was no barrier, therefore, the segments with the lowest percentage with no median represented good access management. The median type was excluded in the final regression models, as it was found to have no relationship with the crash rates, likely because there was not enough variation in median types.

Commercial Driveway Density

Another quantitative variable used for this study was the commercial driveway density per mile. For example, if there is a 2.10 mile segment with 18 commercial driveways, then the commercial driveway density is 8.57 commercial driveways per mile. As explained in previous chapters, the number of commercial driveways along a segment can have an impact on the safety of the roadway, by producing additional conflict points and stop and go traffic. The higher the commercial driveway density, the increased exposure to conflict points exists. Segments with good access management, have a low density of commercial driveways, thus having a higher distance between driveways allowing drivers more response time to make safe turning movements. As explored in previous chapters, remedies for segments with a high density of commercial driveways are frontage/backage roads and driveway consolidation.

Traffic Signal Density

The third quantitative variable used for this study was the traffic signal density per mile. Traffic signal density was included in this study because it is common that arterials with a high density of traffic signals usually have a high percentage of rear-end collisions. Rear-end collisions, were identified as access-related crashes for this study. Arterials with a high density of traffic signals usually experience stop-and-go traffic, which can result in numerous rear-end collisions and rear-end turning collisions at driveways mid-block due to queued traffic. Traffic signals were included in the regression model to determine if there is a relationship between adverse environmental conditions and clear weather conditions at different levels of access management.

Dependent Variables

Crash rates per million VMT were the dependent variables for this study. Crash rates were used for this study, since they are normalized per million VMT, which allows for equal comparison among all segments. Crash rates were used for different environmental conditions, weather, surface, and lighting conditions. A multivariate regression model was created for each environmental condition using the three independent variables. There were a total of nine regression models for the following crash rates under each condition type :

1. Clear weather conditions
2. Rain, mist, and fog weather conditions
3. Snow, sleet, and hail weather conditions
4. Icy surface conditions
5. Snowy surface conditions
6. Wet surface conditions
7. Dry Surface Conditions
8. Daylight
9. Dark

Weather Condition Crash Rates

Crash rates for clear weather conditions and adverse weather conditions were figured separately as dependent variables for the first regression models. As discussed in the methodology, there are more days with clear weather conditions in a year than there are adverse weather conditions. Also, during severe weather condition events, there is usually less traffic on the road. These assumptions must be considered when comparing adverse weather event crash data and clear weather crashes.

The independent variables were commercial driveway and traffic signal densities, excluding median type as explained previously. This was done in order to determine the relationship, if any, between the crash rates under the differing conditions and the access factors. In the regression model crash rates for adverse conditions included crashes which occurred under snow, sleet/hail, rain, mist, and fog conditions. The adverse conditions were grouped together with two different groups. Rain, mist, and fog weather events were grouped together since they all potentially contribute to reduced visibility. As well, snow, sleet, and hail events were grouped together, as they are weather conditions that not only have the potential to reduce visibility, they also contribute to adverse surface conditions.

Surface Condition Crash Rates

Next, crash rates for the surface condition related crashes were used in the regression model with traffic signal and commercial driveway density as the independent variables. For the surface condition, the dry crash rates and adverse crash rates were figured separately for the regression models. The adverse crash rates consisted of crashes which occurred under icy, snowy, and wet surface conditions. These were all explored in separate regression models.

Light Condition Crash Rates

Crash rates for both daytime and nighttime conditions (which included dusk and dawn) were figured for all of the segments. The crash rates were used as the dependent variable with median type, traffic signal and commercial driveway density as the independent variables. As mentioned previously, the AADT was multiplied by 0.6756 for daytime crashes and 0.3244 for nighttime crashes to account for the fact that there are different volumes of traffic at night than there are during the day (as discussed in the methodology). The AADT for nighttime and daytime lighting condition crashes were then used to figure the VMT per segment which allowed for the crash rates to be figured. The nighttime and daytime crash rates were used as the dependent variables with the median type, traffic and commercial driveway density as the independent variables. The nighttime or dark crashes where grouped for this study, which include dusk and dawn crash events, to represent the adverse conditions versus the crashes during daylight conditions.

Linear Regression

S-PLUS version 6.2, a statistical software package was used for this research to determine the relationship between the dependent variables and independent variables. Stepwise regression was used for this study, thus the independent variables with no effect were dropped from the model. For this study, the only variable to be dropped from the model was the no barrier median type, as it was found to have a very weak relationship with the dependent variable in each model. This is due to the fact that the majority of the segments have very high percentages of median type with no barrier, therefore there was no relationship found due to the lack of representation for all median types.

The linear regression function with multiple variables, which was used for this study is:

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3$$

-With X's as the independent variables, β's are the parameters or regression coefficient, and βo is the intercept.

The hypothesis for this research is that access management characteristics have an impact on safety under different environmental conditions. More specifically, access management characteristics improve safety under clear weather conditions and adverse weather conditions. The research hypothesis for this study is expressed as:

$$\text{Ha: At least one } \beta i \neq 0$$

In simple terms, the research hypothesis indicates that at least one of the independent variables (access management characteristics) is related to the dependant variable (crash rates) for each environmental condition. Meaning that there is a relationship between either median type, traffic signal density, and commercial driveway density and crash rates for adverse conditions.

The crash rates for each condition type were plotted with the commercial driveway density and traffic signal density to see if a linear relationship existed. The median type was not plotted, as it was found previously that there was no interaction between the two. Plotting the data points is helpful in determining whether linear regression is the appropriate type of model to use *(18)*. Figures C-1 to C-18 in the appendix show the scatter plots for each condition type with commercial driveway density and traffic signal density. As the scatter plots reveal, a linear relationship exists between the dependant variable and independent variables for every condition, although the relationship is not very strong. In each case, for every condition, as the crash rate increases, the traffic signal density and commercial driveway density increases also indicating a positive relationship.

Next, using S-Plus the correlation coefficient was determined for each weather condition with traffic signal density and commercial driveway density as the independent variables. The correlation coefficient is denoted simply as R, and can be transformed to the R-squared value which also known as the coefficient of determination. The R-squared value is used to measure to which degree any variable can be used to predict another *(19)*.

Correlation coefficient or R values range anywhere from -1 to +1. "Values of -1 and +1 signify an exact positive and negative relationship between the variables, where a value of zero indicates a no relationship between the variables *(20)*." This means that the relationship between the variables is strongest at -1 and +1, and weakens as it approaches zero. Depending on the relationship between the dependant and independent variables, the correlation coefficient can have a positive or negative slope *(20)*. When transformed to R-squared, values range anywhere from zero to 1. As the R-squared value approaches 1, the stronger the relationship exists. An R-squared value of zero indicates that no linear relationship exists, where a value of 1 indicates a strong linear relationship. An R-squared value of 0.3355 suggests that 33.55% of the variation in the dependant variable is explained by its association with independent variables, with the remaining 66.45% is unexplained through linear regression *(19)*.

An F-statistic was determined for each model. The F-statistic supports the R-squared value, allowing one to determine whether to reject or accept the research hypothesis. An F-statistic close to one indicates that null hypothesis is true. As the F-statistic increases, this provides evidence that the research hypothesis is true. The higher the F-statistic, or further away from the value of one, the more evidence to accept the research hypothesis and reject the null. The following indicates the output from each model, per environmental condition, for both adverse and favorable conditions.

Weather Condition Regression Results

Table 6-1 shows the results from the regression output with clear weather conditions as the dependent variable. As the table shows, both the commercial driveway density and traffic signal density are significant at the 0.05 level. As the table shows, the traffic signal density, with a t-value of 6.8223 has the highest significance. From the weather condition models, the R-squared value was the highest for clear weather conditions with a value of 0.3239. The F-statistic for the clear weather condition is 35.7, which is the highest for all of the weather condition types.

Table 6-1. Clear Weather Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.4695	0.1289	3.6424	0.0004
Commercial Driveway Density	0.0266	0.0079	3.3809	0.0009
Traffic Signal Density	0.2960	0.0434	6.8223	0.0000

R-Squared: 0.3239
F-statistic: 35.7

Next, values from the regression output table were used to figure the linear prediction equation between the clear weather condition crashes and the access management variables. The prediction equation illustrates that the expected crash rate, based on the sample segments under clear weather conditions, would only be 0.47 crashes per million VMT, if there are no commercial driveways and no traffic signals. When adding commercial driveways and traffic signals to this model, the crash rate is expected to increase. The prediction equation for this model is: $E(Y)=0.4695+0.0266*cdd+0.2960*tsd$

Where:
E(Y)=expected crash rate per million VMT under clear weather conditions
cdd= commercial driveway density
tsd= traffic signal density

The adverse weather conditions were modeled separately as well. For the low visibility conditions of rain, mist, and fog the independent variables were both found significant at the 0.05 level, with the traffic signal density being the most significant. The R-squared value was slightly lower than compared to the clear weather conditions (0.2939), as well, the same for the F-statistic of 31.01.

Table 6-2. Rain, Mist, Fog Weather Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.0928	0.0423	2.1922	0.0299
Commercial Driveway Density	0.0078	0.0026	3.0356	0.0028
Traffic Signal Density	0.0916	0.0142	6.4325	0.0000

R-Squared: 0.2939
F-statistic: 31.01

The prediction equation for rain, mist, and fog weather conditions indicates that the crash rates are expected to increase as the number of commercial driveways and traffic signals increase. The prediction equation for rain, mist, and fog weather conditions is shown as:

$$E(Y)=0.0928+0.0078*cdd+0.0916*tsd$$

Where:
E(Y)=expected crash rate per million VMT under rain, mist, and foggy weather conditions
cdd= commercial driveway density
tsd= traffic signal density

The snow, sleet, and hail related weather conditions had the lowest correlation as shown in table 6-3. As the table shows, the traffic signal density is the only independent variable which was significant at the 0.05 level. The R-squared value for the snow, sleet, and hail conditions is 0.2645, with an F-statistic of 26.79. This is still significant; however, it is not as highly correlated as was found for the clear weather or rain, mist, fog weather events.

As mentioned in previous chapters, this could be explained because there are fewer days with these types of conditions, as well, there is usually less traffic on the road under such conditions.

Table 6-3. Snow, Sleet, Hail Weather Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.1886	0.0408	4.6262	0.0000
Commercial Driveway Density	0.0042	0.0025	1.6882	0.0935
Traffic Signal Density	0.0904	0.0137	6.5845	0.0000

R-Squared: 0.2645
F-statistic: 26.79

The prediction equation for snow, sleet, and hail related weather conditions indicates that the expected crash rates are expected to increase as the number of commercial driveways and traffic signals increase, as was found for the other weather conditions. The prediction equation for snow, sleet, and hail related weather conditions is shown as:

$$E(Y)=0.1886+0.0042*cdd+0.0904*tsd$$

Where:
E(Y)=expected crash rate per million VMT under snow, sleet, and hail weather conditions
cdd= commercial driveway density
tsd= traffic signal density

Surface Condition Regression Results

Linear regression models were found in S-Plus for the different surface conditions as well. As was discovered for the weather conditions, the median type seemed to have no relationship, so the commercial driveway density and traffic signal density were the independent variables. The commercial driveway density and traffic signal density were both found significant at the 0.05 level. With a value of 0.3842 for the R-squared value and

46.48 for the F-statistic, the dry surface condition was the most strongly related surface condition.

Table 6-4. Dry Surface Condition Regression Output

	Value	Std. Error	t value	Pr(>[t])
Intercept	0.8352	0.1968	4.2448	0.0000
Commercial Driveway Density	0.0431	0.0120	3.5918	0.0004
Traffic Signal Density	0.5267	0.0662	7.9517	0.0000

R-Squared: 0.3842
F-statistic: 46.48

The prediction equation for dry surface conditions indicates that the expected crash rates are expected to increase as the number of commercial driveways and traffic signals increase, as was found previously for the various weather conditions. The prediction equation for dry surface conditions is shown as:

$$E(Y)=0.8352+0.0431*cdd+0.5267*tsd$$

Where:
E(Y)=expected crash rate per million VMT under dry surface conditions
cdd= commercial driveway density
tsd= traffic signal density

Next, the relationship between wet surface condition crashes and the two independent variables was found. Both of the variables were found significant at the 0.05 level as shown in table 6-5. The R-squared value and F-statistic for wet surface condition crashes was slightly lower than that of the dry surface conditions. The R-squared value is 0.3288 with an F-statistic of 36.49.

Table 6-5. Wet Surface Condition Regression Output

	Value	Std. Error	t value	Pr(>[t])
Intercept	0.2024	0.0650	3.1140	0.0022
Commercial Driveway Density	0.0113	0.0040	2.8587	0.0049
Traffic Signal Density	0.1584	0.0219	7.2357	0.0000

R-Squared: 0.3288
F-statistic: 36.49

The prediction equation for the wet surface condition crashes and variables is shown below. The linear prediction equation indicates that crashes are expected rise under wet surface conditions, as the commercial driveway density and traffic signal density increases.

$$E(Y)=0.2024+0.0113*cdd+0.1584*tsd$$

Where:
E(Y)=expected crash rate per million VMT under wet surface conditions
cdd= commercial driveway density
tsd= traffic signal density

Table 6-6 shows the regression output for icy surface condition crashes. As the table shows, the traffic signal density was the only variable which is significant at the 0.05 level. The commercial driveway density was found not significant at the 0.05 level with a value of 0.3058. The R-squared value for icy surface conditions was low, with a value of 0.05767, indicating that a weak linear regression applies to this model. Likewise, the F-statistic for icy surface conditions is lower compared to the other conditions, with a value of 4.559.

Table 6-6. Ice Surface Condition Regression Output

	Value	Std. Error	t value	Pr(>[t])
Intercept	0.1282	0.0234	5.4836	0.0000
Commercial Driveway Density	0.0015	0.0014	1.0277	0.3058
Traffic Signal Density	0.0200	0.0079	2.5478	0.0119

R-Squared: 0.05767
F-statistic: 4.559

The linear prediction equation indicates that crashes are expected rise under icy surface conditions, as the commercial driveway density and traffic signal density increases. However, as indicated by the R-squared value and F-statistic, there is a very weak linear association for this model. The prediction equation for the icy surface condition crashes and the independent variables is shown:

$$E(Y)=0.1282+0.0015*cdd+0.0200*tsd$$

Where:
E(Y)=expected crash rate per million VMT under icy surface conditions
cdd= commercial driveway density
tsd= traffic signal density

Table 6-7 shows the regression results for snow related surface conditions accidents. The table shows that the traffic signal density was the only variable significant at the 0.05 level. The commercial driveway density was not significant with a value of 0.9765. The R-squared value was 0.2155, with an F-statistic of 20.59.

Table 6-7. Snow Surface Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.0271	0.0139	1.9542	0.0525
Commercial Driveway Density	0.0000	0.0008	-0.0295	0.9765
Traffic Signal Density	0.0293	0.0047	6.2704	0.0000

R-Squared: 0.2166
F-statistic: 20.59

The linear prediction equation for snow surface related crash rates indicates that crashes are expected rise under snowy surface conditions, as the commercial driveway density and traffic signal density increases. However, as indicated by the R-squared value and F-statistic, there is a weak linear association for this model.

E(Y)=0.0271+0.0000*cdd+0.0293*tsd

Where:
E(Y)=expected crash rate per million VMT under snow surface conditions
cdd= commercial driveway density
tsd= traffic signal density

Light Condition Regression Results

Table 6-8 shows the results from the regression output for crashes during daylight conditions. As the table shows, both the commercial driveway density and traffic signal density are significant at the 0.05 level. The traffic signal density, with a t-value of 7.88 had the highest significance. From the two lighting condition models, the R-squared value was the highest for daylight conditions with a value of 0.3689. The F-statistic for the daylight conditions is 43.56 which indicates that a strong linear relationship is present.

Table 6-8. Daylight Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	1.5546	0.3126	4.9733	0.0000
Commercial Driveway Density	0.0605	0.0191	3.1728	0.0018
Traffic Signal Density	0.8289	0.1052	7.8768	0.0000

R-Squared: 0.3689
F-statistic: 43.56

The linear prediction equation indicates that crashes are expected rise during daylight crashes, as the commercial driveway density and traffic signal density increases. As the prediction equation shows, crash rates during daylight conditions are expected to increase as the commercial driveway density and traffic signal density increases.

The prediction equation for the daylight crashes and the independent variables is shown below.

E(Y)=1.5546+0.0605*cdd+0.8289*tsd

Where:
E(Y)=expected crash rate per million VMT under daylight conditions
cdd= commercial driveway density
tsd= traffic signal density

As table 6-9 shows the commercial driveway density and traffic signal density were both found significant at the 0.05 level under dark light conditions. With a t-value of 7.57 the traffic signal density was found more significant than the commercial driveway density, as shown in the table. Similar to the trend found for daylight conditions, the R-squared value for nighttime or dark conditions is slightly higher with a value of 0.3696. As well the F-test is similar to that of daytime conditions but slightly higher with a value of 43.69.

Table 6-9. Dark Condition Regression Output

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.4760	0.2150	2.2133	0.0284
Commercial Driveway Density	0.0486	0.0131	3.7017	0.0003
Traffic Signal Density	0.5481	0.0724	7.5720	0.0000

R-Squared: 0.3696
F-statistic: 43.69

The prediction equation for nighttime crashes and the independent variables is shown below. The linear prediction equation indicates that nighttime crashes are expected to increase as the commercial driveway density and traffic signal density increase.

E(Y)=0.4760+0.0486*cdd+0.5481*tsd

Where:
E(Y)=expected crash rate per million VMT under dark/ nighttime conditions
cdd= commercial driveway density
tsd= traffic signal density

From all of the regression models above the one with the strongest F-statistic under adverse conditions is the dark or nighttime condition. As the summary output table for this model shows, the commercial driveway density and traffic signal density were significant at the 0.05 level, however, the traffic signal density was found to be more significant. For this reason, the model was re-run with only the traffic signal density. As expected the traffic signal density under dark conditions was found significant at the 0.05 level. The R-squared value of 0.3117 indicates a moderate to strong linear relationship, with a high F-statistic of 67.92.

Table 6-10. Dark Condition Regression Output II

	Value	**Std. Error**	**t value**	**Pr(>[t])**
Intercept	0.8903	0.1912	4.6550	0.0000
Traffic Signal Density	0.6065	0.0736	8.2412	0.0000

R-Squared: 0.3117
F-statistic: 67.92

The linear prediction equation for this model is shown below. It indicates that the crash rate under dark conditions is expected to increase as the traffic signal density increases.

$$E(Y)=0.8903+0.6065*tsd$$

Where:
E(Y)=expected crash rate per million VMT under dark conditions
tsd= traffic signal density

Linear Regression Summary

The linear regression results indicate that both the commercial driveway density and traffic signal density are significant in the majority of the models. As the regression outputs show, the traffic signal density had the highest correlation in all of the models. The median type, no barrier, was thrown out of each model as it was found to have no relationship, likely because the majority of the study segments had a high percentage of no median.

With the two independent variables, commercial driveway density and traffic signal density in the model, the R-squared values in almost every model indicated a moderate linear relationship. All of the R-squared values ranged consistently from 0.2645 to 0.3842, excluding the R-squared value for icy surface condition crashes. The lowest R-squared value was observed under icy surface conditions with a value of 0.05767, and the highest R-squared value observed was under dry surface conditions with a value of 0.3842. These R-squared values all indicate that there is a moderate linear relationship with traffic signal density and commercial driveway density in the model.

Crash rates for the adverse conditions were much lower compared to the clear conditions. This is due to the fact that there is less traffic during adverse conditions, and there are less adverse weather conditions than there are clear conditions in Iowa. This trend is shown by the prediction equations from the different regression models. Likewise, the regression results show that there is less correlation under the adverse conditions compared to clear weather conditions. This is likely because there were more crashes under clear conditions based on the sample segment crash data.

CHAPTER 7. CONCLUSIONS

The purpose of this study was to explore the relationship between access management and safety under various environmental conditions, including clear and adverse weather, surface and light conditions. From sample segments and crash data in the Des Moines metropolitan area, a relationship between access management characteristics under adverse conditions was discovered throughout the course of this study. This chapter provides results based on the previous chapters in this study.

Access management characteristics have been explored in previous studies and found to improve safety along roadways. Access management characteristics include median type, amount of driveways, and traffic signals. However, current access management studies neglect to observe the relationship between access management and weather conditions. Iowa has extreme weather conditions ranging from heavy rainfall in the spring and ice and snow during the winter. For this reason Des Moines, Iowa was a good study location to explore the relationship between access management and adverse conditions along urban arterials.

Research Hypothesis and Results

The research hypothesis for this study is that arterial road segments with good access management characteristics, such as raised median and low commercial driveway and traffic signal densities, provide improved safety under clear weather conditions and adverse weather conditions compared to those with bad access management characteristics. For this research, safety is indicated by crash rates per million VMT, hence the research hypothesis is stating that crash rates will likely be lower for arterials with good access management characteristics. It is expected that crash rates will likely increase as the level of access management becomes worse under clear and adverse weather conditions. This hypothesis was established based on current access management studies which indicate that access management improves overall roadway safety.

As indicated in the previous chapter, the traffic signal density and commercial driveway density tend to have a significant impact on crash rates under nearly all of the environmental conditions tested. The only variable in the study which was found to have no significant impact on the crash rates was the median type; however, that was due to lack of representation for all median types. The results from the previous chapter indicate that the two variables, traffic signal density and commercial driveway density do have an impact on crash rates under nearly all of the weather conditions. As the inferential statistics show, the most significant variable is the traffic signal density.

There was failure to reject the research hypothesis for this study, thus rejecting the null hypothesis, as it was found that crash rates tend to be higher for the segments with high commercial driveway and traffic signal densities. This relationship was visible through trends found in the inferential statistics chapter and the descriptive statistics chapter as well. The scatter plots in the Appendix C clearly indicate a positive linear relationship, although a weak relationship, between each variable under each environmental condition. The prediction equations in the previous chapter also support the research hypothesis, as they indicate that crash rates are higher along the segments with a high density of traffic signals and commercial driveways. This was found for all of the environmental conditions.

Using the prediction equations for each condition, crash rates were figured with different levels of the traffic signal and commercial driveway density. Tables D-1 to D-9 in the appendix show the relationship between the two variables and predicted crash rates under each condition. To figure the crash rates, traffic signal densities of 0, 2, 4, 6, and 8 per mile were figured, with commercial driveway densities of 0, 5, 10, 15, and 20 per mile. This resulted in a total combination of 25 different predicted crash rates per environmental condition.

An urban arterial with good access management would have anywhere from 0 to 2 traffic signals per mile and 0 to 5 commercial driveways per mile. A moderate traffic signal density would range from 2 to 4 traffic signals per mile and 5 to 10 commercial driveways per mile. Urban arterials with a traffic signal density exceeding 4 signals per mile and 10 commercial driveways per mile would be considered as having poor access management. The tables clearly indicate that under every different condition, the expected crash rates increase as the levels of access management increase.

Need for Future Research

There are many possibilities for follow up to this research. The main emphasis of this study was to determine what if any relationship exists between access management and adverse conditions. Through statistical analysis, it was determined that access management characteristics, such as commercial driveways and traffic signal densities play a role in safety under adverse conditions. The relationship between each condition and access management is different, as was shown in the previous chapter. It is suggested that different statistical models be evaluated for future research on this topic, as Poisson regression is commonly used for many crash studies.

This study looked at weather, surface, and light conditions separately. Future research could include combinations of these different conditions. Combinations could include adverse weather conditions during daylight and dark conditions, and different surface conditions for both daylight and dark conditions. Adverse weather combinations should be observed in conjunction with darkness because such conditions pose additional threat, as they reduce visibility and in many cases result in windshield glare in precipitation related weather events. Also, for this research, adverse weather condition related crashes were grouped based on low visibility (rain, mist, and fog) and reduced traction (snow, sleet, hail). Another idea for further research could look at each of these conditions individually rather than grouping them, to see what if any relationship exists. This may produce different results than were found in this study.

As mentioned at the end of chapter 5, the segments of 31st, 28th, and 35th Street were identified as having low traffic signal densities and commercial driveway densities, however, they were ranked highly based on adverse weather condition crash rates. The windshield survey revealed that all of these segments have a hilly terrain with steep roads, which under adverse conditions such as rain, ice, and snow might pose increased risk to safety. Also they had a high density of residential driveways. Further research could look at physical features such as this to help identify other problem segments and possible solutions to these problems. As well, it might be interesting to look at both the total driveway density and the commercial driveway density.

As the inferential statistics revealed in the previous chapter, the traffic signal density had the biggest impact on the different weather conditions. A study with adverse conditions and traffic signal characteristics would help to further identify the relationship between the two. For example, exploring the relationship between traffic signal spacing and timing under the different conditions might reveal results which could be used to improve urban arterial safety under different conditions.

Medians are a good indicator off access management, and play a big role in safety. The median type was thrown out of this study since there was not enough representation for all of the different median types. Further research might include study areas with roadways with various median types.

This study was limited to arterials in the Des Moines metropolitan area. Results would likely vary among urban areas nationwide. The issue of access management and adverse weather conditions may be more threatening in certain regions while in others it may be insignificant. Likewise, urban areas of different populations might reveal different results. Further research might explore the relationship between access management and adverse weather conditions for cities of different locations and population. Such research could be used to indicate particular road segments which could be improved through access management; as well it could identify which segments are top priority for salt and plowing under adverse conditions.

APPENDIX A

This appendix contains additional figures and tables for chapter four.

Table A-1. Study Segments and Locations

Road Name	Segment ID	Location	City
Grant Street/ 1st Avenue	1	North 2nd Street to Northeast 38th Avenue	Bondurant, Altoona
West 1st Street	2	Irvingdale Drive to Northwest Greenwood Street	Ankeny
West 1st Street	3	Northwest Greenwood Street to North Ankeny Boulevard	Ankeny
West 1st Street/ East 1st Street	4	North Ankeny Boulevard to Southeast Grant Street	Ankeny
East 1st Street	5	Southeast Grant Street to Delaware Avenue	Ankeny
Southwest State Street/ 2nd Avenue	6	Southwest Oralabor Road to 66th Avenue	Ankeny
2nd Avenue	7	66th Avenue to North 54th Avenue	
2nd Avenue	8	North 54th Avenue to Broadway Avenue	
2nd Avenue	9	Broadway Avenue to University Avenue	Des Moines
Southeast 6th Street	10	Scott Avenue to Indianola Avenue	Des Moines
Southeast 5th Street	11	Indianola Avenue to East Army Post Road	Des Moines
Northwest 6th Drive	12	Northwest 16th Street to Aurora Avenue	
6th Avenue	13	Aurora Avenue to I-235	Des Moines
Southwest 8th Street	14	Northeast 56th Street to 1st Avenue	Altoona
8th Street Southeast/ Northeast 46th Avenue	15	1st Avenue to Northeast 80th Street	Altoona
West 9th Street	16	Keo Way to Morgan Street	Des Moines
Southwest 9th Street	17	Morgan Street to Fulton Drive	Des Moines
Southwest 9th Street/ HighwayR63	18	Fulton Drive to Highway 5	Des Moines
North Ankeny Boulevard	19	Northwest 20th Street to Southwest 2nd Street	Ankeny
South Ankeny Boulevard	20	Southwest 2nd Street to Southeast Shurfine Drive	Ankeny
South Ankeny Boulevard/ North 14th Street	21	Southeast Shufine Drive to South Oralabor Road	Ankeny
Northeast 14th Street	22	South Oralabor Road to Northeast 52nd Avenue	Ankeny
East 14th Street	23	Northeast 52nd Avenue to East Ovid Avenue	Des Moines
East 14th Street	24	East Hull Avenue to Johnson Court	Des Moines
Southeast 14th Street	25	Johnson Court to Army Post Road	Des Moines
Johnson Court/ East 15th Street	26	University Avenue to Southeast 14th Street	Des Moines
West 15th Street	27	Crocker Street to Ingersoll Avenue	Des Moines
West 19th Street	28	MLK Jr Parkway to Center Street	Des Moines
Northwest 26th Street	30	Southwest Oralabor Road to Northwest Morningstar Drive	
28th Street	31	University Avenue to Grand Avenue	Des Moines
East 29th Street	32	Northeast 49th Avenue to East Euclid Avenue	Des Moines
30th Street	33	Euclid Avenue to Forest Avenue	Des Moines
East 30th Street	34	East University Avenue to CBQ Street	Des Moines
31st Street	35	University Avenue to Grand Avenue	Des Moines
35th Street	36	Ashworth Road to E.P. True Parkway	West Des Moines
Northeast 38th Street	37	Northeast 54th Avenue to Easton Boulevard	Des Moines
41st Street	38	Beaver Avenue to Forest Avenue	Des Moines
42nd Street	39	Forest Avenue to Grand Avenue	Des Moines
50th Street	40	University Avenue to Grand Avenue	West Des Moines
Northwest 54th Avenue	41	Northwest 26th Street to 2nd Avenue	
Northeast 54th Avenue	42	2nd Avenue to Northeast 22nd Street	
55th Street	43	Franklin Avenue to University Avenue	Des Moines

Table A-1. Study Segments and Locations (Continued)

Road Name	Segment ID	Location	City
55th Street/ 56th Street	44	University Avenue to Grand Avenue	Des Moines
Northeast 56th Street	45	Northeast 62nd Avenue to University Avenue	Altoona, Pleasant Hill
60th Street	46	University Avenue to Westown Parkway	West Des Moines
60th Street	47	Westown Parkway to E.P. True Parkway	West Des Moines
Northwest 62nd Avenue	48	Northwest 86th Street to Northwest Beaver Drive	Johnston
63rd Street	49	Hickman Road to Ashworth Road	Windsor Heights, West Des Moines, Des Moines
63rd Street	50	Ashworth Road to Army Post Road	West Des Moines/ Des Moines
70th Street	51	Meredith Drive to Douglas Avenue	Urbandale
Northwest 70th Avenue	52	Northwest 86th Street to Northwest Beaver Drive	Johnston
Northwest Beaver Drive	53	Northwest 70th Avenue to Northwest Beaver Drive	Johnston
Northwest 66th Avenue	54	Northwest Beaver Drive to Northwest 6th Drive	Johnston
Northwest 6th Drive/ Northwest 65th Lane/ Northeast 66th Avenue	55	Northwest 66th Avenue to Northeast 22nd Street	
72nd Street	56	Douglas Avenue to 73rd Street	Urbandale
73rd Street	57	72nd Street to Center Street	Windsor Heights
8th Street	58	Center Street to Railroad Avenue	West Des Moines
74th Street/ Y Avenue	59	University Avenue to Ashworth Road	West Des Moines
Northwest Urbandale Avenue	60	Meredith Drive to 100th Street	Urbandale
100th Street	61	Northwest Urbandale Drive to University Avenue	Urbandale, Clive
35th Street	62	University Avenue to Ashworth Road	West Des Moines
Northwest 112th Avenue/ West Bridge Road	63	Northwest Beaver Drive to South 3rd Street	Polk City
Northwest 9th Street/ Adventureland Drive	64	Northeast 56th Street to Prairie Meadows Drive	Altoona
Adventureland Drive	65	Prairie Meadows Drive to Northwest 14th Avenue	Altoona
Adventureland Drive	66	Northwest 14th Avenue to 1st Avenue	Altoona
East Army Post Road	67	Southwest 42nd Street to Fleur Drive	Des Moines
East Army Post Road	68	Fleur Drive to Southeast 14th Street	Des Moines
Army Post Road	69	Southeast 14th Street to 36th Street	Des Moines
Southeast 64th Avenue	70	Southeast 36th Street to Southeast 52nd Street	
Army Post Road	71	Southwest 74th Street to Southwest 28th Court	West Des Moines, Des Moines
Ashworth Road	72	74th Street to 63rd Street	West Des Moines
Northwest Beaver Drive/ Beaver Avenue	73	River Bend to Northwest Frost Way	Johnston
Beaver Avenue	74	Northwest Frost Way to 41st Street	Des Moines
Bell Avenue	75	Fleur Drive to Thomas Beck Road	Des Moines
Thomas Beck Road	76	Bell Avenue to Clifton Avenue	Des Moines
Clifton Avenue/ Indianola Ave	77	Thomas Beck Road to Southeast 1st Street	Des Moines
Southeast 1st Street	78	Indianola Avenue to Southwest 1st Street	Des Moines
Scott Avenue	79	Southwest 1st Street to Southeast 15th Street	Des Moines
Broadway Avenue	80	2nd Avenue to Northeast 14th Street	Des Moines
Northeast 46th Avenue	81	Northeast 14th Street to Hubbell Avenue	
Cottage Grove Avenue	82	28th Street to West 19th Street	Des Moines
Crocker Street	83	West 19th Street to West 15th Street	Des Moines
Northeast 22nd Street/ Delaware Avenue	84	Southeast 54th Street to East Euclid Avenue	Des Moines
Delaware Avenue/ East 21st Street	85	East Euclid Avenue to Hubbell Avenue	Des Moines

Table A-1. Study Segments and Locations (Continued)

Road Name	Segment ID	Location	City
Euclid Avenue	86	MLK Jr Parkway to 2nd Avenue	Des Moines
East Euclid Avenue	87	2nd Avenue to Hubbell Avenue	Des Moines
East 22nd Street	88	Easton Boulevard to Hubbell Avenue	Des Moines
Easton Boulevard	89	East 22nd Street to East 42nd Street	Des Moines
Easton Boulevard/ Northeast 23rd Avenue	90	East 42nd Street to Northeast 56th Street	Des Moines, Pleasant Hill
E.P. True Parkway	91	60th Street to Grand Avenue	West Des Moines
Fleur Drive	92	Grand Avenue to East Army Post Road	Des Moines
Fleur Drive/ 85th Avenue	93	East Army Post Road to Highway 5	Des Moines
Grand Avenue	94	360th Street to 50th Place	West Des Moines
Grand Avenue	95	50th Street to 63rd Street	West Des Moines
Grand Avenue	96	63rd Street to West 9th Street	Des Moines
East Grand Avenue	97	West 9th Street to East 18th Street	Des Moines
Guthrie Avenue	98	East 14th Street to Dixon Street	Des Moines
Guthrie Avenue	99	Dixon Street to Delaware Avenue	Des Moines
Guthrie Avenue	100	Delaware Avenue to East 29th Street	Des Moines
Hickman Road	101	T Avenue to Woodsland Parkway	Waukee, Urbandale/ Clive
Hickman Road	102	Woodsland Parkway to I-35	Urbandale/ Clive
Hickman Road	103	I-35 to 68th Street	Urbandale/ Clive
Hickman Road	104	68th Street to Beaver Avenue	Des Moines
Hickman Road/ Arlington Avenue	105	Beaver Avenue to Franklin Avenue	Des Moines
Hubbell Avenue	106	East Grand Avenue to Northeast 46th Avenue	Des Moines
Hubbell Avenue	107	Northeast 46th Avenue to Northeast 2nd Street	Altoona, Bondurant
Highway 141	108	Northwest 102nd Avenue to Northwest 52nd Avenue	Grimes
Sunset Street	109	Iowa 28 to Gordon Avenue	Norwalk
Sunset Street	110	Gordon Avenue to Coolidge Street	Norwalk
Broadway Street	111	Big Creek to Northwest 26th Street	Polk City
Iowa 44/ 1st Street	112	X Avenue to Iowa 141	Grimes
Ingersoll Avenue	113	56th Street to West 18th Street	Des Moines
Ingersoll Avenue	114	West 18th Street to West 14th Street	Des Moines
Northwest 16th Street	115	Northwest 110th Avenue to Northwest 102nd Avenue	
Northwest Irvindale Drive	116	Northwest 102nd Avenue to West 1st Street	Ankeny
Southwest Irvindale Drive	117	West 1st Street to Southwest Magazine Road	Ankeny
Irvindale Drive	118	Southwest Magazine Road to Southwest Oralabor Road	Ankeny
Keo Way	119	West 19th Street to I-35	Des Moines
Keo Way	120	I-35 to 9th Street	Des Moines
Lower Beaver Road	121	Beaver Avenue to Douglas Avenue	Des Moines
Maury Street	122	Southeast 6th Street to East 30th Street	Des Moines
McKinley Avenue	123	Southwest 34th Street to Indianola Drive	Des Moines
Meredith Drive	124	Northwest Urbandale Drive to 100th Street	Urbandale
Meredith Drive	125	100th Street to 70th Street	Urbandale
Meredith Drive	126	70th Street to Merle Hay Road	Urbandale
Meredith Drive	127	Merle Hay Road to Beaver Avenue	Des Moines
Merle Hay Road	128	Northwest 62nd Avenue to I-35	Johnston
Merle Hay Road	129	I-35 to Douglas Avenue	Urbandale, Des Moines
Merle Hay Road	130	Douglas Avenue to Hickman Road	Des Moines
MLK Jr Parkway	131	Euclid Avenue/ Douglas Avenue to Urbandale Avenue	Des Moines
MLK Jr Parkway	132	Urbandale Avenue to Hickman Road	Des Moines
MLK Jr Parkway	133	Hickman Road to University Avenue	Des Moines
MLK Jr Parkway	134	University Avenue to Ingersoll Avenue	Des Moines
Southwest Oralabor Road	135	Northwest 26th Street to South Ankeny Boulevard/ North 14th Street	Ankeny
Southwest Oralabor Road	136	South Ankeny Boulevard/ North 14th Street to I-35	Ankeny

Table A-1. Study Segments and Locations (Continued)

Road Name	Segment ID	Location	City
Park Avenue	137	63rd Street to Southwest 61st Street	Des Moines
Park Avenue	138	Southwest 61st Street to Fleur Drive	Des Moines
Park Avenue	139	Fleur Drive to Southeast 14th Street	Des Moines
Pleasant Hill Boulevard	140	Maple Drive to Vandalia Road	Pleasant Hill
Railroad Avenue	141	Grand Avenue to 63rd Street	West Des Moines
University Avenue	142	74th Street to 59th Court	Clive/ West Des Moines
University Avenue	143	59th Court to I-35	Clive/ West Des Moines
University Avenue	144	I-35 to 22nd Street	Clive/ West Des Moines
University Avenue	145	86th Street to 55th/ 56th Street	Clive, Windsor Heights, Des Moines
University Avenue	146	55th/ 56th Street to 5th Avenue	Des Moines
University Avenue	147	5th Avenue to Illinois Street	Des Moines
University Avenue	148	Illinois Street to East 14th Street	Des Moines
University Avenue/ East University Avenue	149	East 14th Street to Hubbell Avenue	Des Moines
East University Avenue	150	Hubbell Avenue to Copper Creek Road	Des Moines, Pleasant Hill
Valley Drive	151	Park Avenue to Fleur Drive	Des Moines
Vandalia Road	152	East 30th Street to Southeast 60th Street	Des Moines, Pleasant Hill
Northwest 86th Street	153	Northwest 70th Avenue to Northwest 62nd Avenue	Johnston
Northwest 86th Street	154	Northwest 62nd Avenue to Northwest 54th Avenue	Johnston
Northwest 86th Street	155	Northwest 54th Avenue to Meredith Drive	Johnston, Urbandale
86th Street	156	Meredith Drive to University Avenue	Urbandale, Clive
22nd Street	157	University Avenue to Woodland Avenue	West Des Moines
22nd Street	158	Pleasant Street to Woodland Avenue	West Des Moines
Indianola Drive	159	Southeast 1st Street to Army Post Road	Des Moines
Douglas Avenue	160	109th Street to 79th Street	Urbandale
Douglas Avenue	161	79th Street to MLK Jr Parkway	Urbandale, Des Moines

Table A-2. Study Segments and Commercial Driveway and Traffic Signal Density

Segment ID	Segment Length (miles)	Commercial Driveway Density (per mile)	Traffic Signal Density (per mile)
1	5.01	6.19	0.20
2	0.36	2.78	0.00
3	1.57	7.02	2.55
4	0.18	16.67	5.56
5	0.90	20.11	1.12
10	1.49	9.38	2.01
11	2.34	2.14	1.71
12	4.33	5.32	0.00
13	2.84	20.77	3.17
14	3.94	4.57	0.76
15	1.01	17.87	1.99
16	1.14	6.12	6.99
17	0.45	0.00	0.00
18	4.72	32.84	1.69
19	1.18	17.83	1.70
20	1.34	27.69	2.25
21	0.68	4.39	2.93
22	3.25	18.49	0.92
23	1.95	24.60	2.05
24	2.64	16.32	4.17
25	4.13	26.90	2.42
26	0.95	8.47	5.29
27	0.48	10.33	0.00
28	1.18	2.54	5.08
30	3.75	0.80	0.27
31	1.10	12.73	3.64
32	1.48	10.14	1.35
33	1.77	5.66	1.13
34	1.73	15.63	1.74
35	1.10	12.74	4.55
36	0.99	2.01	2.01
37	3.06	2.94	0.65
38	0.45	8.93	0.00
39	1.31	14.48	3.81
40	4.15	4.34	1.45
41	1.80	3.90	0.56
42	2.01	10.93	0.99
43	0.75	0.00	1.34
44	1.23	0.00	2.44
45	5.02	5.18	0.40
46	1.41	3.56	0.00
47	2.95	1.36	0.34
48	2.10	8.09	2.38
49	4.01	1.50	1.00
50	0.99	19.21	1.01
51	2.28	5.26	0.00
52	0.83	4.80	0.00
54	2.63	1.52	0.00
55	2.70	13.35	0.00
56	0.81	2.46	1.23
57	1.87	14.45	2.68
58	1.50	13.31	3.33
59	1.22	6.54	1.63
61	2.20	9.53	2.72
62	1.02	8.82	7.84
63	2.28	0.44	0.00

Table A-2. Study Segments and Commercial Driveway and Traffic Signal Density (Continued)

Segment ID	Segment Length (miles)	Commercial Driveway Density (per mile)	Traffic Signal Density (per mile)
64	0.51	27.50	1.96
65	0.51	9.82	0.00
66	0.90	3.33	0.00
67	1.78	1.13	0.56
68	2.46	42.77	2.44
69	2.63	5.69	0.38
70	1.76	1.14	0.00
71	3.47	1.44	0.00
72	5.47	4.57	2.19
73	1.95	20.50	0.00
74	2.97	12.12	2.02
75	0.26	7.69	3.85
76	1.15	3.48	0.00
78	0.62	32.52	3.25
79	0.93	11.80	0.00
80	1.01	58.19	0.00
81	4.36	12.38	0.23
82	0.71	5.60	4.20
83	0.22	13.39	8.93
84	4.20	13.09	0.48
85	1.90	31.56	1.58
87	3.71	17.81	2.70
88	0.28	25.00	0.00
89	2.54	19.26	1.18
90	1.51	4.62	0.00
91	3.33	3.60	0.90
92	3.97	11.10	2.27
93	1.16	6.92	0.87
94	2.46	0.41	0.00
95	5.00	16.99	1.60
96	3.90	18.21	4.36
97	2.20	18.65	7.73
98	0.80	11.24	2.50
99	0.17	0.00	5.95
100	0.99	4.02	2.01
101	5.71	2.63	0.00
102	0.97	3.09	1.03
103	3.72	4.83	2.95
104	1.88	19.66	2.66
105	2.66	9.01	1.50
106	4.93	24.55	1.62
107	5.59	0.18	0.18
108	7.91	0.13	0.13
109	1.55	0.64	0.00
110	1.37	12.38	2.18
111	8.45	0.59	0.00
112	3.10	6.45	0.64
113	2.71	36.87	2.21
114	0.31	12.94	6.47
115	1.01	0.00	0.00
116	1.00	0.00	1.00
117	0.97	1.03	2.06
118	0.97	0.00	0.00
119	0.43	9.22	2.30
120	0.62	16.10	3.22

Table A-2. Study Segments and Commercial Driveway and Traffic Signal Density (Continued)

Segment ID	Segment Length (miles)	Commercial Driveway Density (per mile)	Traffic Signal Density (per mile)
121	1.69	5.33	1.18
122	2.46	10.57	0.41
123	4.33	9.93	0.92
124	0.50	1.98	0.00
125	2.25	1.78	0.44
126	0.76	3.95	1.32
127	1.04	9.64	0.96
128	1.37	25.60	2.19
129	1.60	11.90	2.50
130	1.06	29.36	2.84
131	0.24	25.42	4.24
132	0.67	28.32	1.49
133	1.03	9.75	4.87
134	1.04	1.93	3.86
135	2.70	0.00	1.11
136	1.24	4.04	0.00
137	0.24	0.00	4.13
138	2.78	5.40	0.72
139	2.47	6.49	1.62
140	2.08	2.88	0.00
141	1.48	8.78	0.68
142	0.94	9.53	2.12
143	0.86	4.67	2.33
144	1.94	14.46	4.13
145	2.28	24.11	3.07
146	3.57	22.67	3.36
147	0.40	37.69	2.51
148	0.81	14.74	3.69
149	1.11	12.59	3.60
150	2.67	15.75	2.25
151	2.05	2.93	0.49
152	3.72	4.83	0.00
153	1.06	0.94	0.00
154	0.90	7.81	0.00
155	1.11	6.31	1.80
156	2.57	12.09	3.51
158	0.65	0.00	6.14
157	0.39	28.13	2.56
159	4.19	10.98	1.43
160	2.12	4.25	1.42
161	3.86	25.67	3.11

Table A-3. Crash Rates per Million VMT for Access Crashes

	Weather Condition				Surface Condition			Lighting Condition			
Segment ID	Clear	Rain, Mist, Fog	Snow, Sleet/ Hail	Ice	Snow	Wet	Dry	Day	Dusk/ Dawn	Dark-Lit	Dark-Not lit
1	0.55	0.07	0.24	0.10	0.03	0.14	0.99	1.19	0.00	0.07	0.00
2	0.54	0.00	0.00	0.27	0.00	0.00	0.80	1.07	0.00	0.00	0.00
3	2.03	0.24	0.42	0.42	0.28	0.56	2.58	2.97	0.14	0.70	0.03
4	5.37	0.85	1.13	0.28	0.57	1.98	9.61	9.61	0.57	2.26	0.00
5	1.35	0.32	0.41	0.45	0.09	0.59	2.21	2.61	0.23	0.45	0.05
10	1.27	0.30	0.55	0.30	0.18	0.73	2.25	2.49	0.24	0.73	0.00
11	2.14	0.29	0.21	0.16	0.12	0.74	3.29	3.50	0.04	0.82	0.00
12	0.11	0.11	0.06	0.00	0.00	0.17	0.11	0.28	0.00	0.00	0.00
13	1.93	0.56	0.63	0.07	0.23	0.82	3.17	3.39	0.11	0.81	0.05
14	1.89	0.47	0.50	0.24	0.08	0.79	2.89	3.11	0.23	0.68	0.00
15	0.74	0.21	0.32	0.21	0.00	0.11	1.80	1.80	0.11	0.21	0.00
16	2.20	0.70	0.55	0.40	0.20	1.15	3.66	3.86	0.20	1.35	0.00
17	0.87	0.07	0.27	0.13	0.20	0.33	1.00	1.13	0.13	0.40	0.00
18	1.07	0.27	0.32	0.13	0.02	0.49	1.75	2.00	0.06	0.33	0.00
19	0.81	0.30	0.41	0.15	0.10	0.46	1.57	1.93	0.05	0.25	0.10
20	1.75	0.69	0.50	0.22	0.03	0.94	2.91	3.47	0.09	0.44	0.09
21	0.13	0.00	0.13	0.00	0.00	0.19	0.13	0.32	0.00	0.00	0.00
22	0.55	0.08	0.04	0.02	0.02	0.11	0.93	0.97	0.04	0.04	0.04
23	0.79	0.11	0.39	0.11	0.03	0.39	1.52	1.77	0.05	0.18	0.10
24	1.22	0.46	0.53	0.18	0.05	0.81	2.90	3.34	0.08	0.57	0.01
25	1.30	0.40	0.33	0.17	0.05	0.69	2.22	2.49	0.13	0.48	0.07
26	4.17	0.98	1.10	0.29	0.33	1.88	6.58	7.39	0.41	1.39	0.04
27	2.53	0.00	0.54	0.54	0.00	0.18	3.43	3.43	0.36	0.36	0.00
28	4.01	0.89	0.83	0.38	0.13	1.59	6.81	6.62	0.38	1.91	0.06
30	0.34	0.14	0.14	0.07	0.00	0.27	0.89	1.16	0.00	0.07	0.00
31	1.86	1.08	1.24	0.31	0.15	2.01	3.41	4.49	0.46	0.93	0.00
32	1.15	0.42	0.21	0.10	0.00	0.63	1.57	2.10	0.00	0.21	0.00
33	1.87	0.59	0.88	0.29	0.12	1.11	3.22	3.57	0.18	1.17	0.00
34	1.80	0.38	0.13	0.13	0.00	0.63	2.26	2.18	0.13	0.79	0.04
35	3.99	1.25	1.55	0.52	0.66	1.84	6.64	7.90	0.22	1.55	0.07
36	1.10	0.49	0.37	0.24	0.24	0.49	2.69	3.06	0.24	0.37	0.00
37	1.56	0.73	0.62	0.00	0.00	1.14	2.28	2.90	0.10	0.52	0.00
38	0.57	0.19	0.38	0.00	0.00	0.57	0.94	1.32	0.00	0.19	0.00
39	2.56	0.60	0.60	0.19	0.08	1.02	4.86	4.97	0.30	0.87	0.00
40	1.04	0.17	0.35	0.24	0.11	0.41	1.62	1.86	0.09	0.43	0.02
41	0.00	0.70	0.70	0.00	0.00	0.70	2.11	2.81	0.00	0.00	0.00
42	1.22	0.24	0.37	0.12	0.00	0.73	2.69	2.94	0.12	0.37	0.12
43	0.93	0.37	0.37	0.19	0.00	0.93	1.67	2.42	0.00	0.37	0.00
44	0.75	0.08	0.38	0.00	0.15	0.45	1.74	1.96	0.08	0.30	0.00
45	0.71	0.22	0.49	0.31	0.00	0.27	1.55	1.33	0.09	0.53	0.18
47	2.61	0.26	0.26	0.52	0.00	0.00	5.49	4.70	0.00	1.31	0.00
48	0.91	0.08	0.08	0.08	0.12	0.25	1.12	1.45	0.00	0.12	0.00
49	1.16	0.42	0.59	0.13	0.11	0.80	2.15	2.53	0.15	0.49	0.02
50	0.53	0.16	0.17	0.15	0.02	0.23	0.84	1.01	0.05	0.15	0.02
51	2.17	0.14	0.14	0.00	0.14	0.87	2.89	3.76	0.00	0.00	0.14
52	0.11	0.06	0.06	0.11	0.00	0.06	0.06	0.17	0.00	0.00	0.06
53	0.69	0.00	0.00	0.00	0.14	0.00	0.69	0.82	0.00	0.00	0.00
54	0.29	0.10	0.19	0.14	0.00	0.24	0.52	0.67	0.00	0.14	0.10
55	0.43	0.00	0.21	0.11	0.00	0.11	0.53	0.75	0.00	0.00	0.00
56	0.21	0.10	0.10	0.00	0.00	0.21	0.73	0.84	0.00	0.10	0.00
57	1.34	0.39	0.30	0.23	0.14	0.66	2.18	2.52	0.05	0.59	0.07
58	0.97	0.05	0.46	0.20	0.00	0.36	1.99	2.15	0.10	0.31	0.00
59	1.54	0.51	1.20	0.17	0.00	0.85	4.96	5.13	0.17	0.51	0.17
61	0.60	0.17	0.26	0.15	0.11	0.24	1.10	1.37	0.02	0.21	0.00
62	3.50	0.93	0.93	0.39	0.21	1.47	6.61	6.61	0.21	1.72	0.14

Table A-3. Crash Rates per Million VMT for Access Crashes (Continued)

Segment ID	Weather Condition			Surface Condition				Lighting Condition			
	Clear	Rain, Mist, Fog	Snow, Sleet/ Hail	Ice	Snow	Wet	Dry	Day	Dusk/ Dawn	Dark- Lit	Dark- Not lit
63	0.00	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.08	0.00	0.00
64	4.18	0.89	0.75	0.75	0.15	1.49	6.26	6.41	0.15	1.94	0.15
65	0.31	0.00	0.47	0.47	0.00	0.16	0.78	0.78	0.00	0.62	0.00
66	0.94	0.00	0.71	0.71	0.24	0.00	1.88	2.12	0.24	0.47	0.00
67	0.00	0.00	0.04	0.04	0.00	0.00	0.13	0.13	0.00	0.04	0.00
68	1.78	0.50	0.62	0.30	0.11	0.91	2.82	3.17	0.15	0.78	0.06
69	0.15	0.12	0.02	0.00	0.00	0.10	0.27	0.34	0.00	0.00	0.02
70	0.11	0.06	0.11	0.06	0.00	0.06	0.44	0.44	0.06	0.00	0.06
71	0.61	0.27	0.09	0.06	0.02	0.32	1.04	1.29	0.04	0.08	0.09
72	1.03	0.28	0.45	0.40	0.07	0.47	1.83	2.04	0.18	0.56	0.01
73	0.22	0.00	0.04	0.04	0.00	0.00	0.36	0.40	0.00	0.00	0.00
74	1.39	0.43	0.47	0.19	0.13	0.68	2.60	2.97	0.04	0.55	0.04
75	0.70	0.23	1.40	0.00	0.23	1.40	3.98	4.68	0.23	0.94	0.00
76	0.15	0.00	0.38	0.08	0.00	0.08	0.61	0.53	0.00	0.23	0.00
78	0.63	0.09	0.45	0.09	0.00	0.27	1.52	1.43	0.09	0.36	0.00
79	1.19	0.00	0.34	0.00	0.00	0.51	1.87	2.21	0.00	0.17	0.00
80	2.03	0.60	0.48	0.24	0.00	0.60	4.54	3.82	0.24	0.84	0.48
81	0.62	0.02	0.19	0.14	0.05	0.12	0.88	1.05	0.02	0.10	0.02
82	0.99	0.37	0.25	0.00	0.12	0.99	1.24	1.86	0.12	0.37	0.00
83	2.73	0.34	0.68	0.68	0.00	0.00	5.81	4.78	0.34	1.37	0.00
84	0.30	0.12	0.09	0.06	0.03	0.15	0.60	0.66	0.06	0.12	0.00
85	2.63	0.36	0.72	0.30	0.24	0.84	4.00	4.84	0.18	0.48	0.00
87	1.70	0.54	0.42	0.21	0.12	0.95	2.83	3.14	0.17	0.79	0.04
88	1.85	1.85	0.00	0.00	0.00	1.85	5.56	5.56	0.00	1.85	0.00
89	1.38	0.35	0.19	0.10	0.06	0.58	2.32	2.19	0.10	0.87	0.00
90	0.47	0.23	0.23	0.23	0.00	0.23	1.17	1.64	0.00	0.00	0.00
91	0.80	0.15	0.22	0.19	0.00	0.22	1.27	1.29	0.12	0.27	0.00
92	0.70	0.26	0.16	0.10	0.04	0.47	1.11	1.22	0.09	0.42	0.01
93	0.46	0.00	1.83	0.92	0.00	0.00	2.29	3.66	0.00	0.00	0.00
94	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12	0.00	0.00	0.00
95	0.94	0.25	0.40	0.15	0.07	0.46	1.71	1.80	0.16	0.38	0.04
96	2.07	0.30	0.39	0.19	0.12	0.65	3.30	2.83	0.16	1.29	0.05
97	4.67	1.24	1.06	0.30	0.50	2.07	7.57	8.17	0.28	2.02	0.10
98	4.22	2.02	0.18	0.55	0.55	2.75	5.50	6.24	0.92	2.20	0.00
99	0.00	0.58	0.58	0.00	0.00	1.15	1.15	1.73	0.00	0.58	0.00
100	1.91	0.88	0.95	0.51	0.07	1.69	3.52	4.54	0.15	1.25	0.00
101	0.13	0.06	0.02	0.00	0.01	0.10	0.22	0.25	0.03	0.03	0.02
102	0.30	0.09	0.09	0.09	0.00	0.21	0.64	0.77	0.09	0.04	0.04
103	0.60	0.12	0.24	0.08	0.04	0.25	1.18	1.33	0.02	0.20	0.01
104	2.28	0.62	0.52	0.32	0.11	1.03	3.37	3.73	0.36	0.73	0.04
105	0.93	0.27	0.45	0.34	0.07	0.52	1.90	2.15	0.16	0.43	0.09
106	1.58	0.45	0.41	0.15	0.11	0.81	2.70	3.06	0.19	0.54	0.02
107	0.45	0.16	0.22	0.05	0.00	0.22	0.86	0.83	0.01	0.16	0.12
108	0.09	0.02	0.03	0.02	0.00	0.03	0.18	0.21	0.00	0.00	0.02
109	0.04	0.00	0.00	0.00	0.04	0.04	0.17	0.21	0.00	0.04	0.00
110	0.39	0.00	0.08	0.15	0.00	0.08	0.62	0.69	0.08	0.08	0.00
111	0.18	0.04	0.06	0.04	0.00	0.04	0.28	0.36	0.00	0.00	0.00
112	0.81	0.13	0.22	0.06	0.09	0.28	1.50	1.78	0.06	0.09	0.00
113	2.07	0.49	0.40	0.33	0.09	1.05	3.41	3.97	0.16	0.87	0.00
114	2.35	1.57	0.78	0.00	0.00	1.17	3.92	4.31	0.39	0.39	0.00
115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	0.24	0.00	0.24	0.00	0.00	0.24	0.97	1.21	0.00	0.00	0.00
117	0.18	0.00	0.00	0.00	0.00	0.00	0.27	0.18	0.09	0.00	0.00
118	0.19	0.00	0.00	0.00	0.09	0.00	0.19	0.28	0.00	0.00	0.00
119	2.80	0.29	0.44	0.15	0.00	1.03	2.95	3.54	0.00	0.44	0.15
120	1.89	0.50	0.57	0.06	0.32	0.95	3.66	4.22	0.13	0.50	0.13
121	1.01	0.13	0.07	0.27	0.07	0.27	1.27	1.41	0.13	0.40	0.00
122	1.40	0.45	0.45	0.08	0.04	0.72	2.38	2.61	0.08	0.61	0.00
123	1.86	0.37	0.37	0.24	0.05	0.76	2.78	2.97	0.13	0.81	0.00

Table A-3. Crash Rates per Million VMT for Access Crashes (Continued)

	Weather Condition			Surface Condition				Lighting Condition			
Segment ID	Clear	Rain, Mist, Fog	Snow, Sleet/ Hail	Ice	Snow	Wet	Dry	Day	Dusk/ Dawn	Dark-Lit	Dark-Not lit
124	0.81	0.00	0.00	0.00	0.00	0.00	1.62	1.22	0.00	0.41	0.00
125	0.50	0.09	0.22	0.12	0.06	0.28	1.00	1.18	0.06	0.19	0.03
126	0.76	0.46	0.23	0.15	0.23	0.53	1.82	2.43	0.08	0.23	0.00
127	0.63	0.21	0.21	0.00	0.00	0.31	1.36	1.36	0.00	0.10	0.21
128	2.81	0.68	0.52	0.19	0.19	1.16	3.84	4.52	0.16	0.71	0.00
129	2.41	0.60	0.74	0.26	0.11	1.26	4.27	4.35	0.19	1.26	0.15
130	1.75	0.44	0.39	0.17	0.03	0.67	3.30	3.35	0.06	0.78	0.00
131	1.13	0.48	0.16	0.00	0.00	0.65	1.94	2.42	0.00	0.16	0.00
132	2.00	0.37	0.47	0.16	0.05	0.68	3.16	2.89	0.05	1.05	0.05
133	1.89	0.65	0.78	0.07	0.07	1.24	4.04	3.97	0.13	1.37	0.07
134	2.55	0.85	0.80	0.32	0.27	1.64	4.08	5.20	0.27	0.85	0.00
135	0.13	0.05	0.16	0.05	0.00	0.08	0.42	0.47	0.00	0.08	0.00
136	1.13	0.25	0.21	0.25	0.08	0.46	1.96	2.51	0.04	0.17	0.04
137	0.64	0.43	0.43	0.43	0.21	0.64	0.85	1.92	0.00	0.21	0.00
138	0.71	0.30	0.13	0.11	0.00	0.54	1.10	1.39	0.15	0.19	0.02
139	1.62	0.41	0.94	0.23	0.08	1.32	3.08	3.65	0.23	0.90	0.04
140	0.29	0.10	0.10	0.19	0.00	0.00	0.48	0.38	0.19	0.10	0.00
141	0.36	0.16	0.10	0.07	0.00	0.23	0.79	0.99	0.00	0.10	0.00
142	4.77	1.50	0.75	0.50	0.25	1.76	6.52	7.78	0.00	1.00	0.50
143	1.48	0.20	0.07	0.13	0.07	0.40	1.94	2.11	0.13	0.23	0.07
144	1.35	0.28	0.46	0.20	0.09	0.64	2.41	2.77	0.14	0.37	0.05
145	1.88	0.42	0.49	0.20	0.05	0.84	3.21	3.38	0.22	0.69	0.00
146	1.92	0.55	0.79	0.31	0.13	1.06	3.41	3.91	0.23	0.79	0.01
147	4.52	1.51	1.83	0.43	0.22	3.34	6.78	7.75	0.32	3.01	0.00
148	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
149	0.93	0.22	0.34	0.07	0.00	0.60	1.64	1.86	0.07	0.37	0.00
150	0.78	0.24	0.26	0.12	0.05	0.42	1.42	1.50	0.02	0.49	0.00
151	0.28	0.00	0.28	0.00	0.00	0.37	0.28	0.55	0.00	0.09	0.09
152	0.16	0.05	0.10	0.05	0.00	0.05	0.21	0.16	0.00	0.16	0.00
153	4.60	0.38	0.77	0.77	0.00	0.77	5.75	6.51	0.38	0.38	0.00
154	0.77	0.09	0.17	0.09	0.09	0.17	1.37	1.46	0.00	0.17	0.09
155	1.32	0.15	0.46	0.20	0.05	0.41	2.89	2.84	0.10	0.46	0.15
156	1.56	0.48	0.51	0.23	0.09	0.83	2.49	3.05	0.08	0.50	0.04
157	3.21	0.64	0.87	0.17	0.29	1.69	5.01	5.71	0.29	1.11	0.06
158	0.00	0.16	0.16	0.00	0.00	0.16	0.16	0.16	0.00	0.16	0.00
159	1.22	0.23	0.19	0.11	0.02	0.50	1.83	1.91	0.11	0.42	0.03
160	0.72	0.24	0.40	0.24	0.04	0.34	1.71	1.90	0.09	0.30	0.06
161	1.54	0.40	0.39	0.14	0.12	0.67	2.75	2.93	0.13	0.59	0.06

APPENDIX B

This appendix contains additional figures and tables for chapter five.

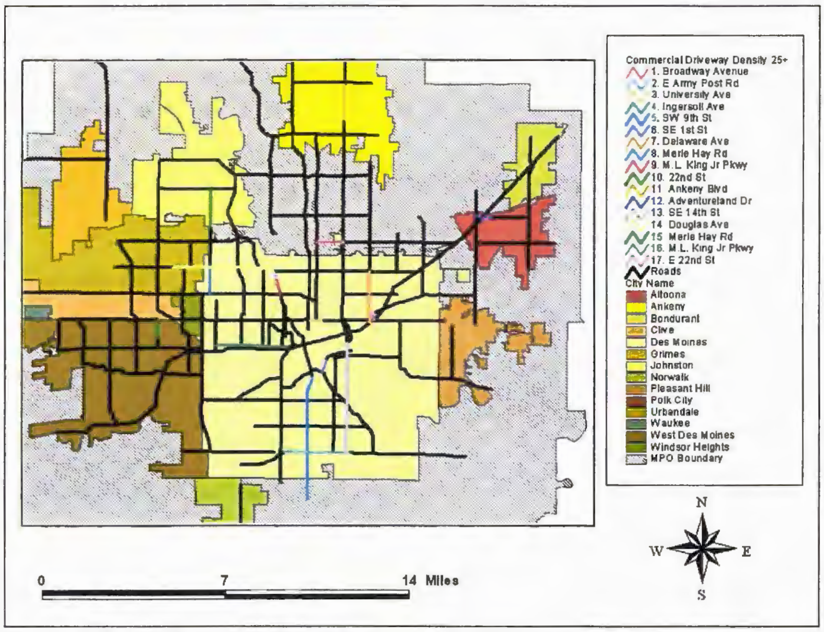

Figure B-1. Segments with Commercial Driveway Densities of 25+ per mile

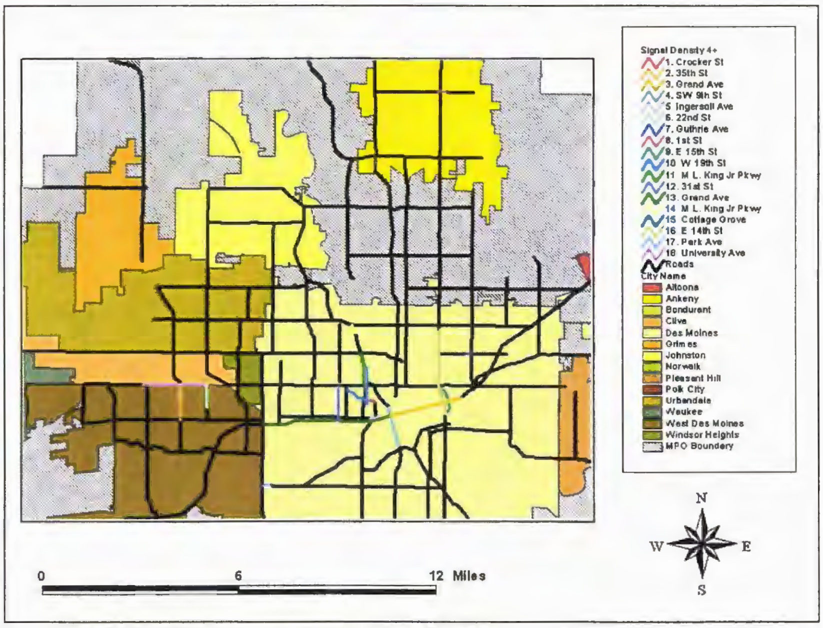

Figure B-2. Segments with Traffic Signal Density 4+ per mile

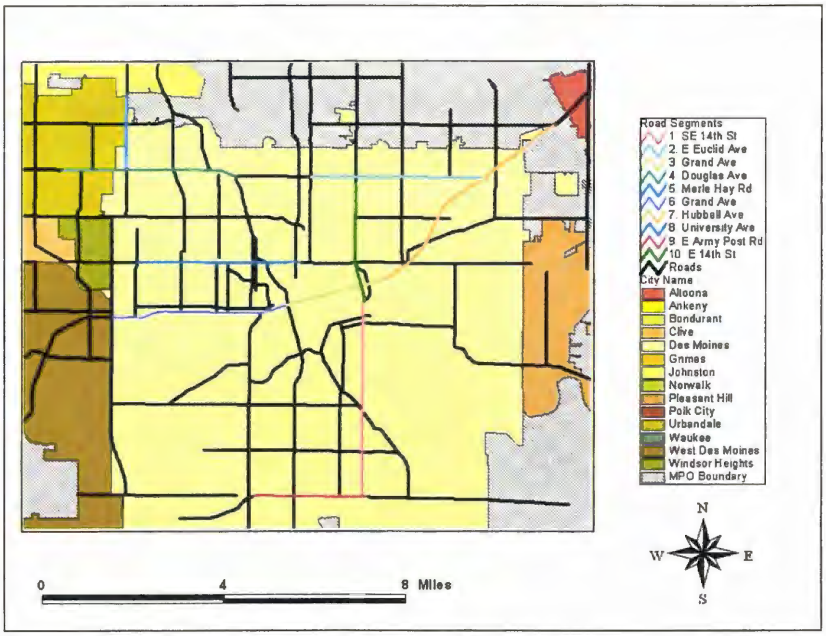

Figure B-3. Segments with Access Crash Frequencies of 300+

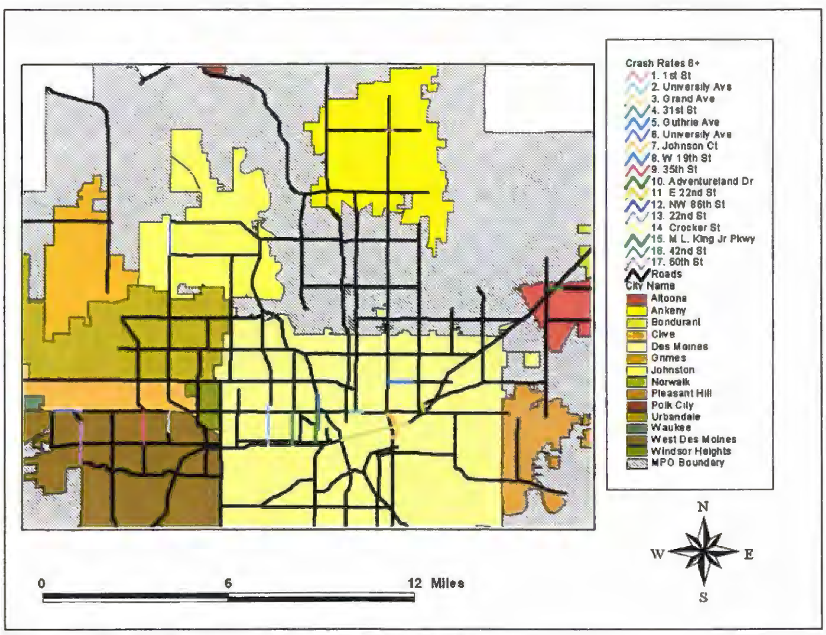

Figure B-4. Segments with Crash Rates 6+

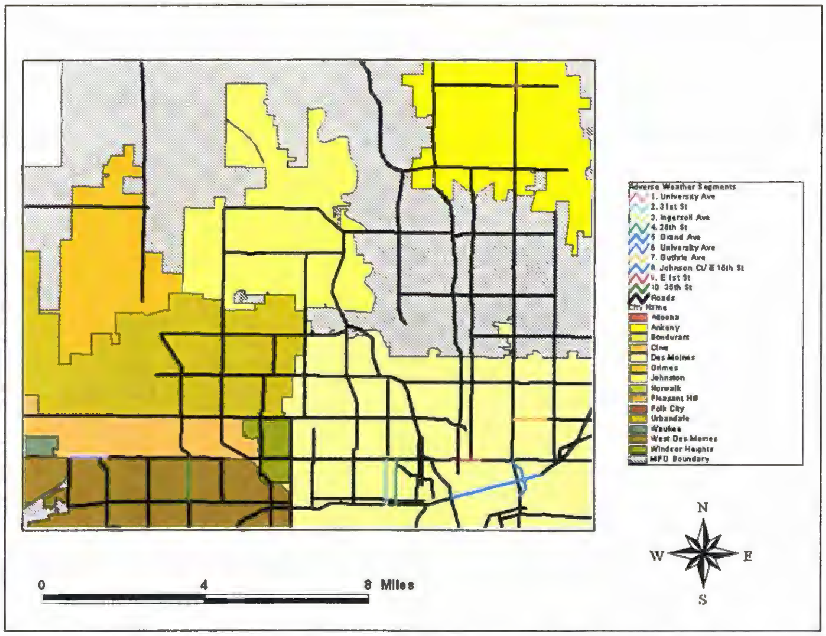

Figure B-5. Segments for Further Research, Adverse Weather Conditions

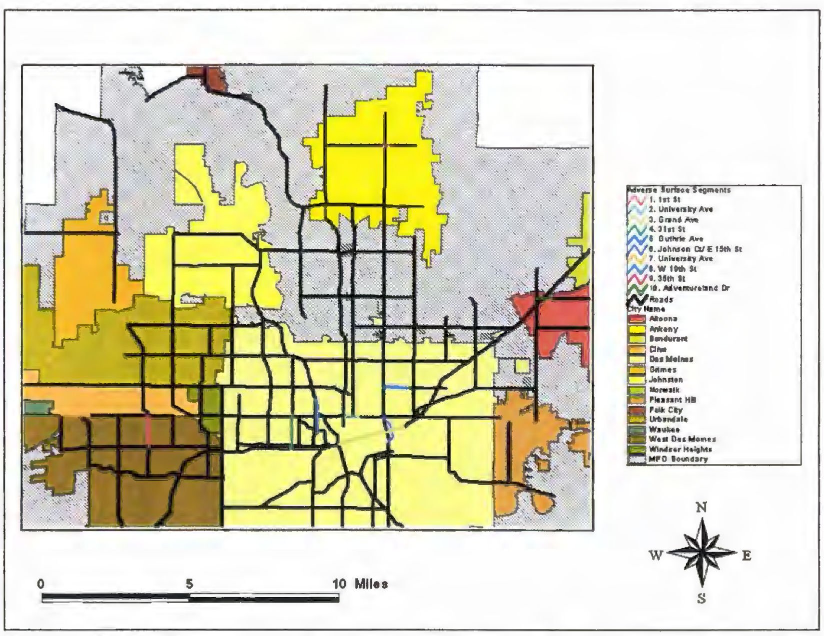

Figure B-6. Segments for Further Research, Adverse Surface Conditions

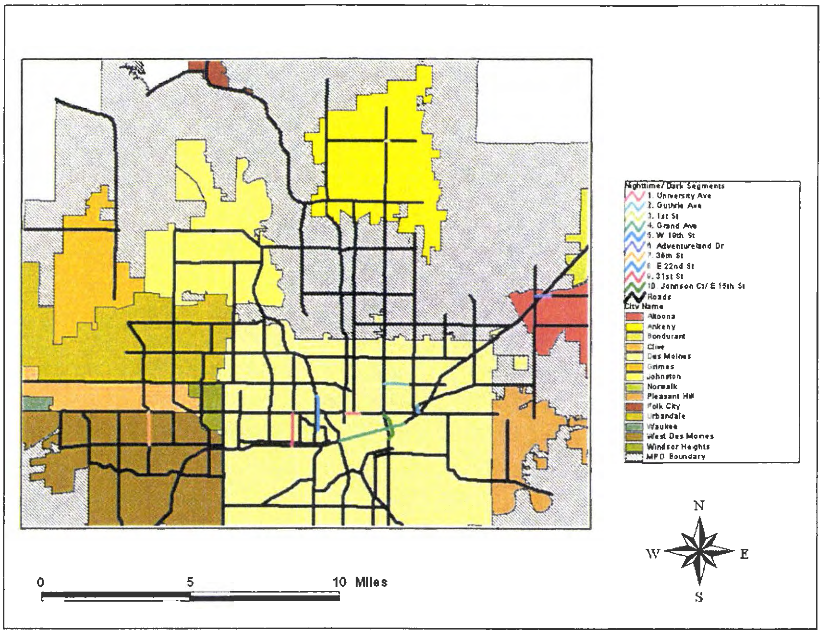

Figure B-7. Segments for Further Research, Nighttime Conditions

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APPENDIX C

This appendix contains additional figures and tables for chapter six.

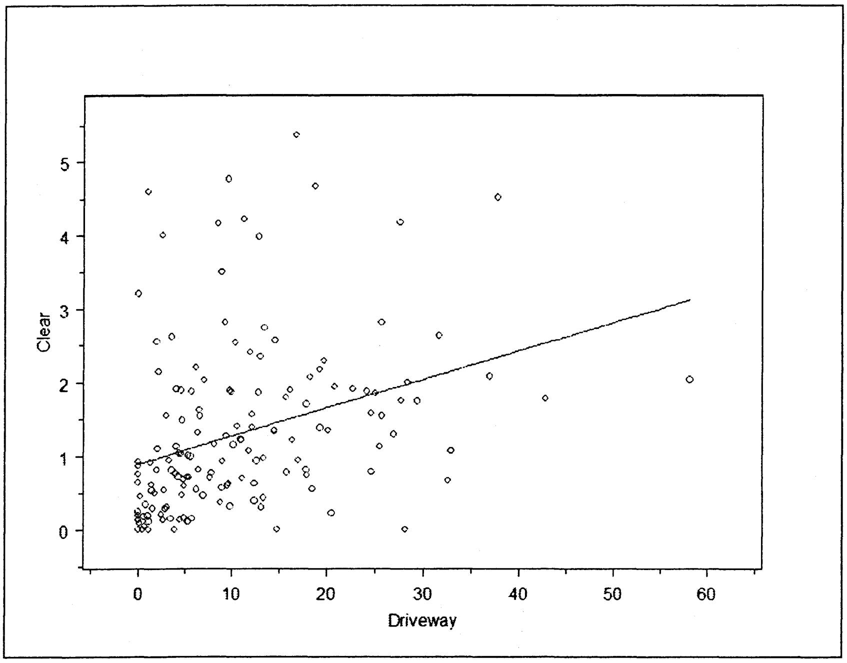

Figure C-1. Clear Weather Crash Rates and Commercial Driveway Density

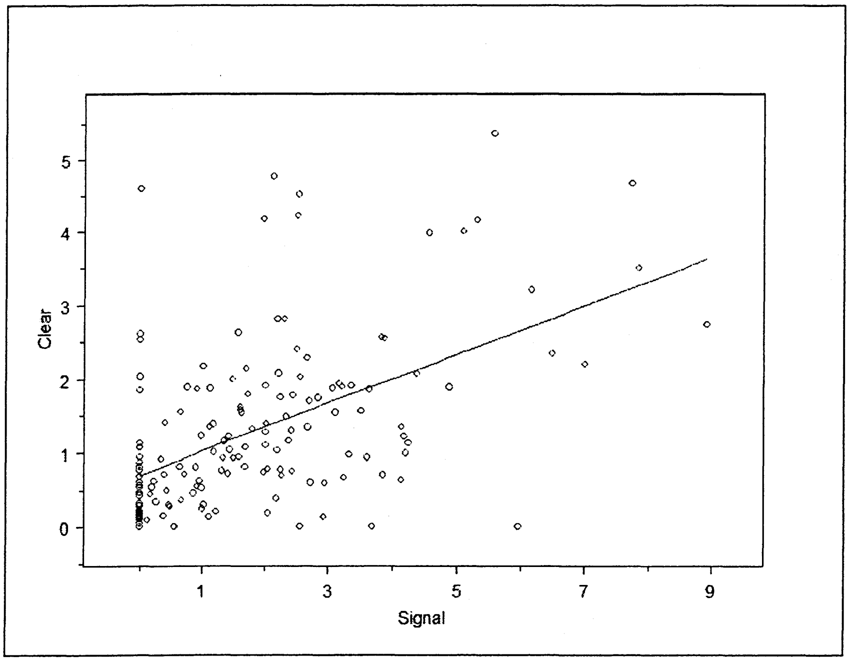

Figure C-2. Clear Weather Crash Rates and Traffic Signal Density

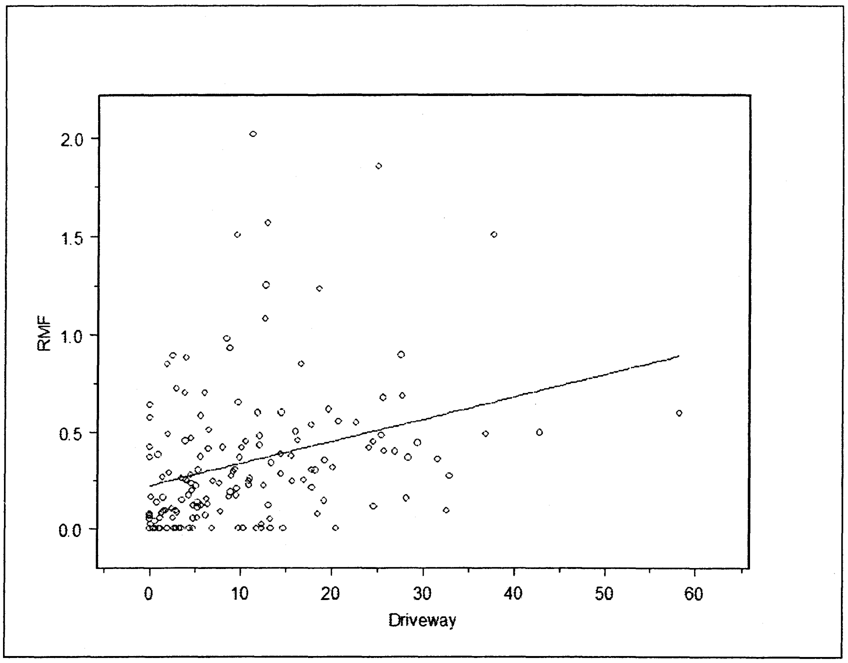

Figure C-3. Rain, Mist, Fog Crash Rates and Commercial Driveway Density

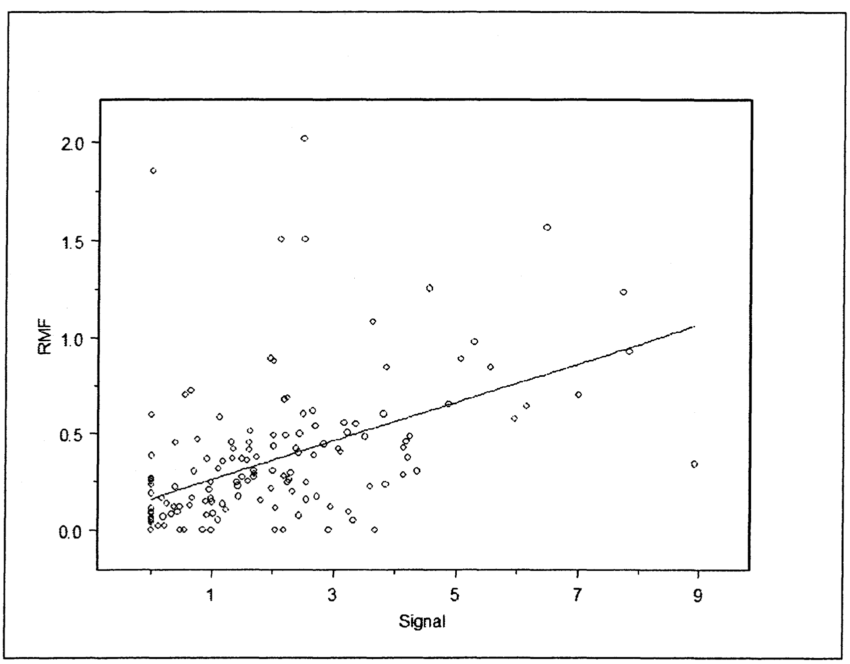

Figure C-4. Rain, Mist, Fog Crash Rates and Traffic Signal Density

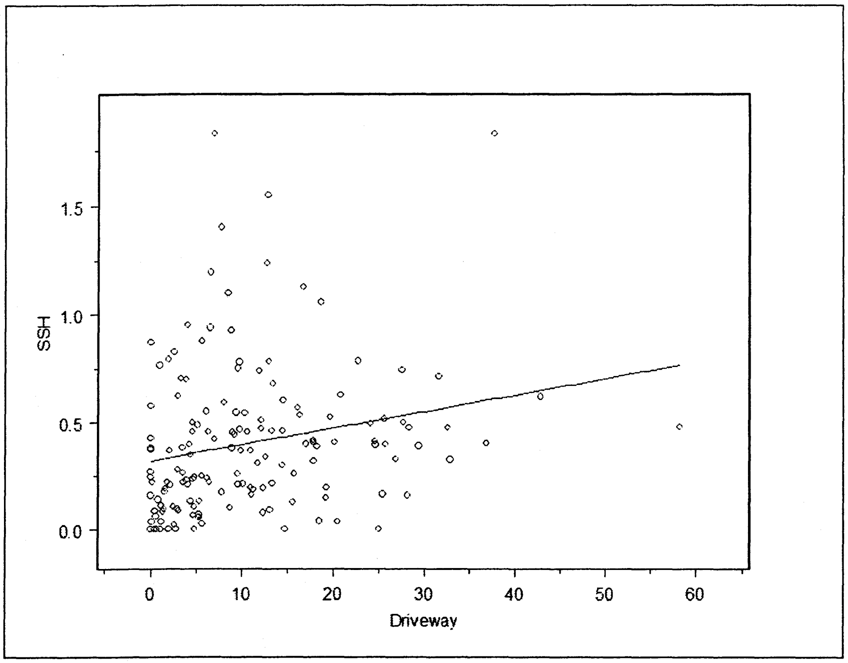

Figure C-5. Snow, Sleet, Hail Crash Rates and Commercial Driveway Density

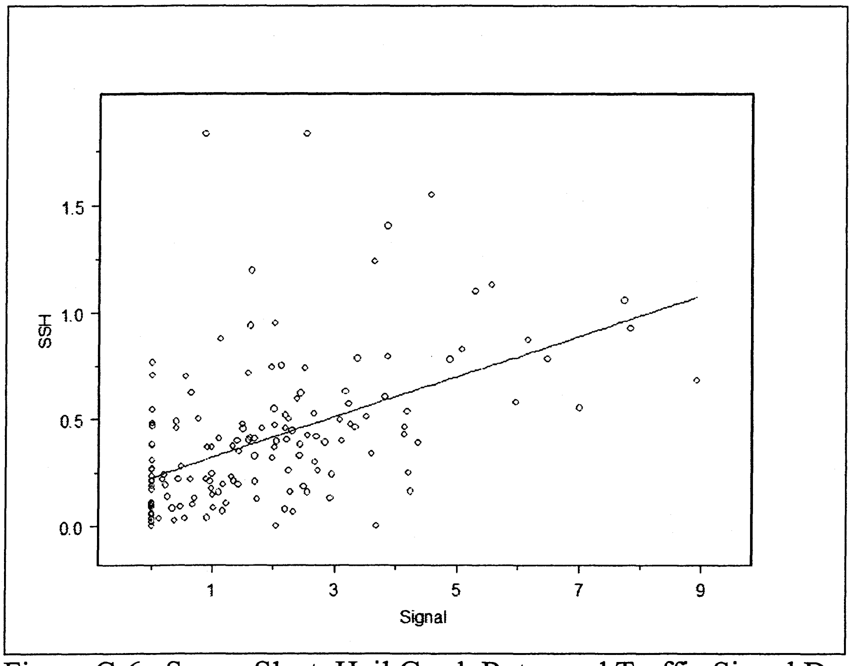

Figure C-6. Snow, Sleet, Hail Crash Rates and Traffic Signal Density

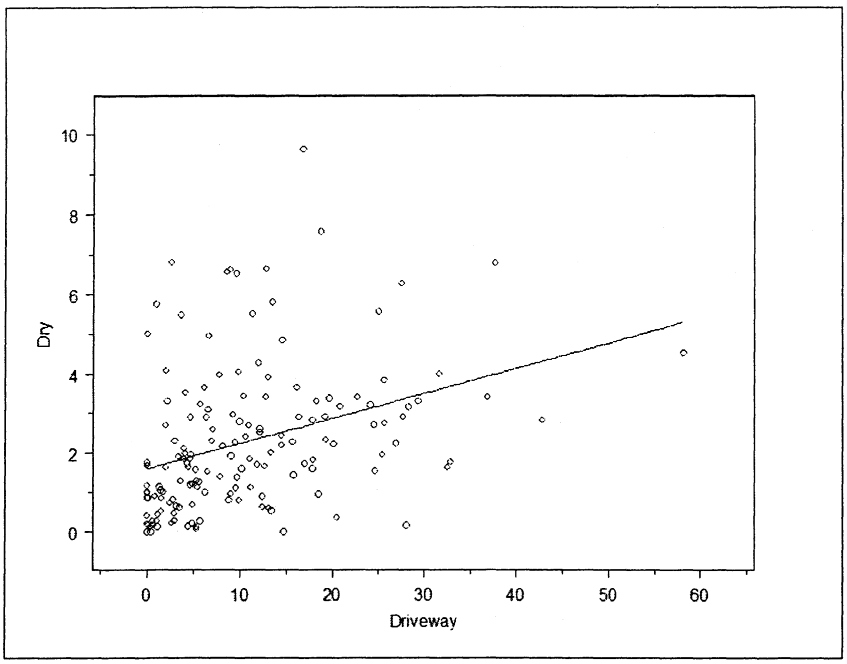

Figure C-7. Dry Surface Condition Crash Rates and Commercial Driveway Density

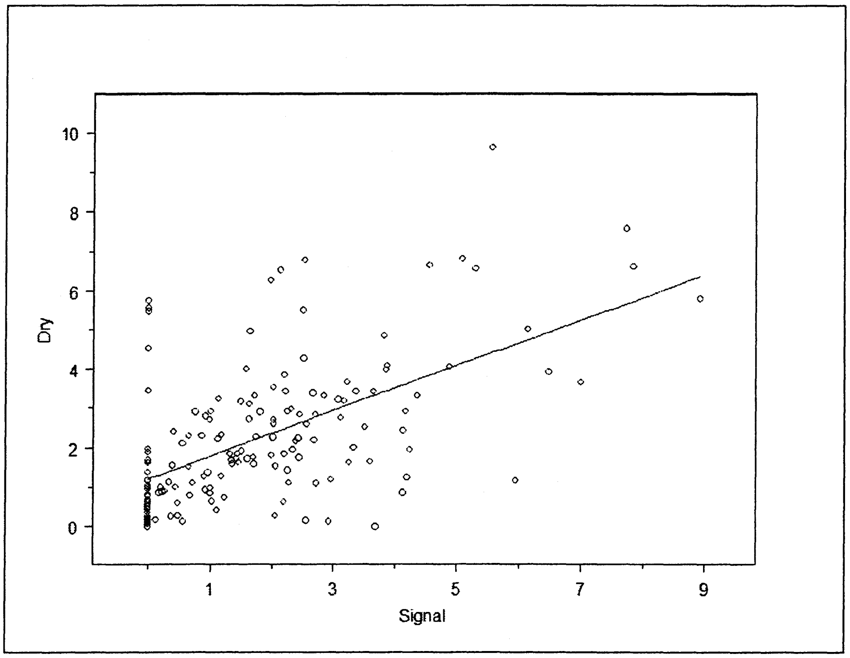

Figure C-8. Dry Surface Condition Crash Rates and Traffic Signal Density

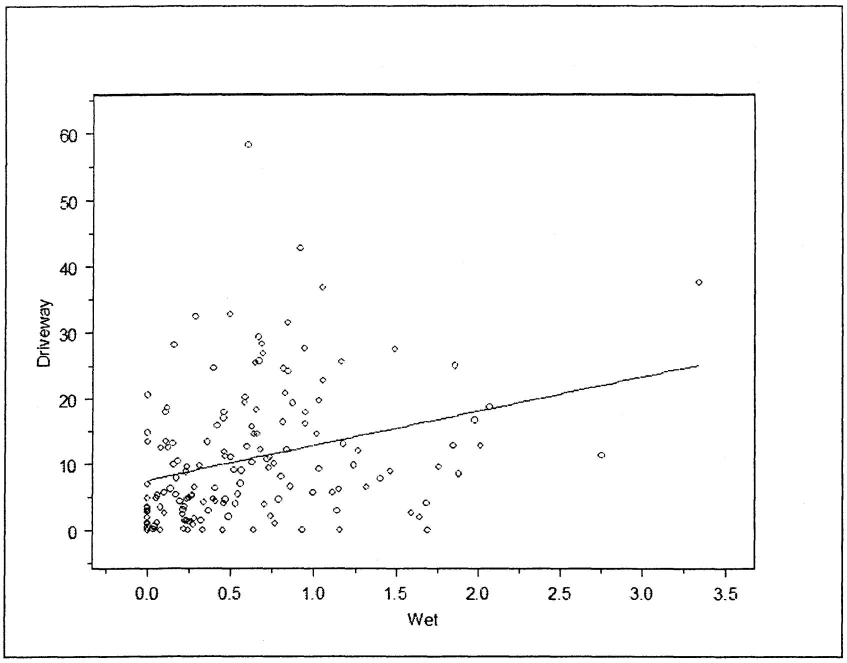

Figure C-9. Wet Surface Condition Crash Rates and Commercial Driveway Density

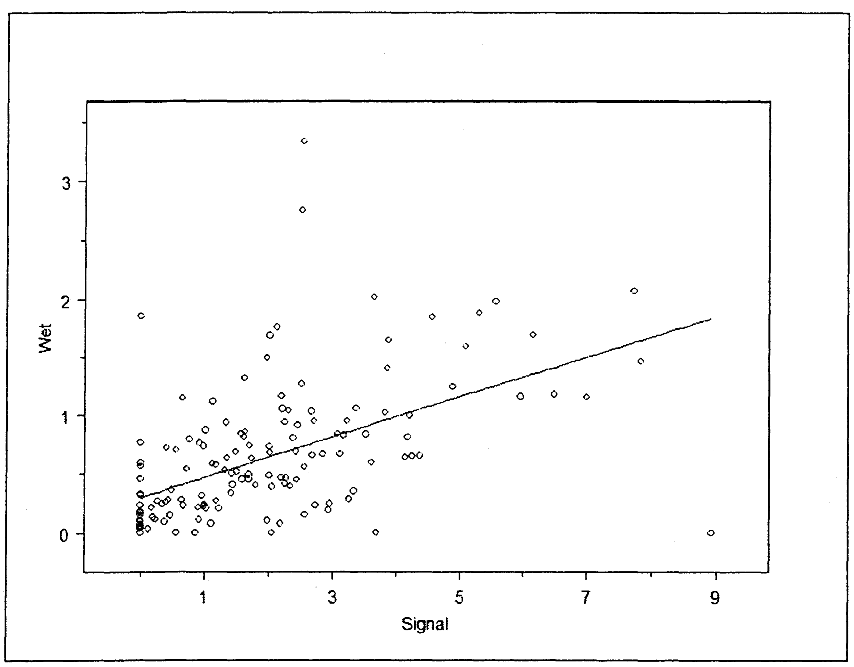

Figure C-10. Wet Surface Condition Crash Rates and Traffic Signal Density

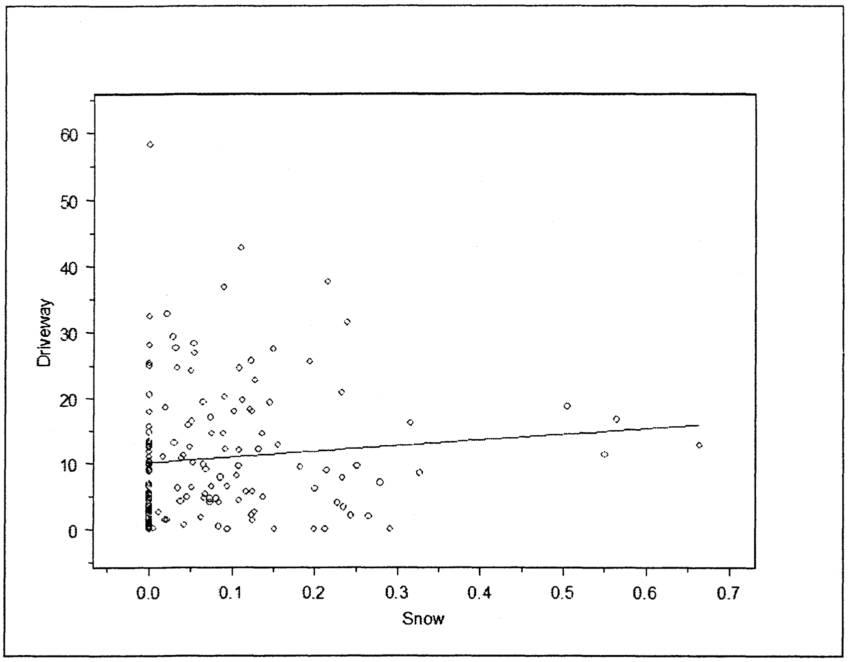

Figure C-11. Snow Surface Condition Crash Rates and Commercial Driveway Density

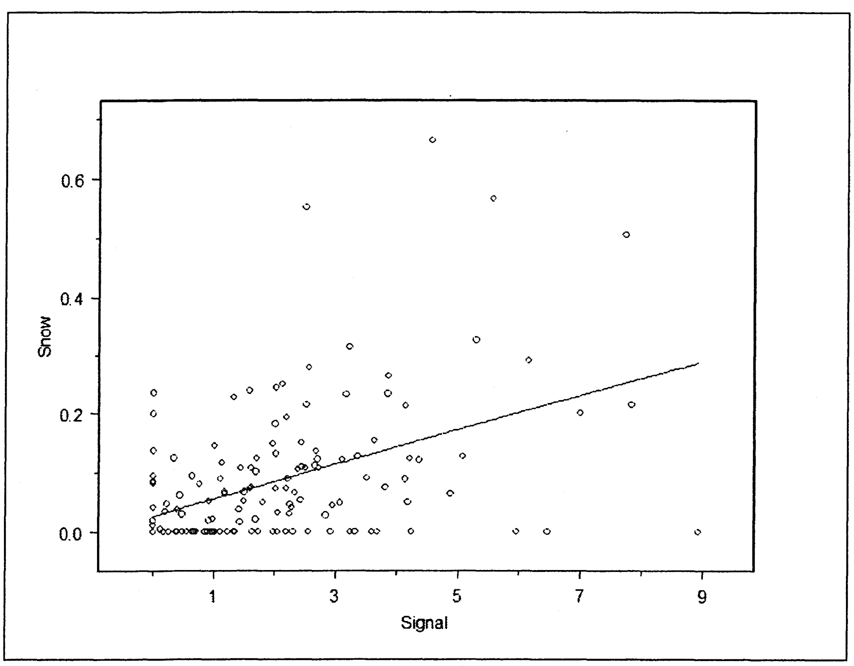

Figure C-12. Snow Surface Condition Crash Rates and Traffic Signal Density

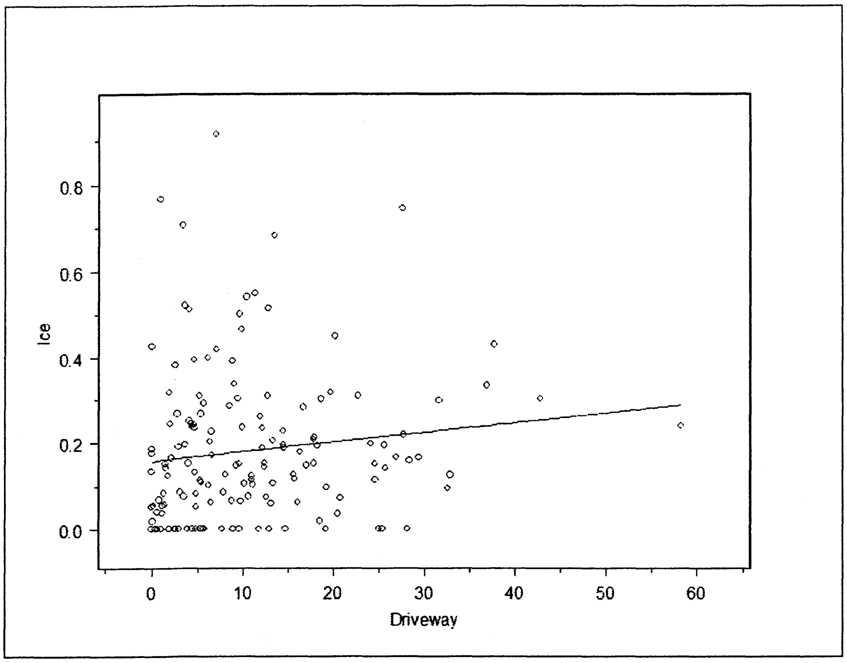

Figure C-13. Ice Surface Condition Crash Rates and Commercial Driveway Density

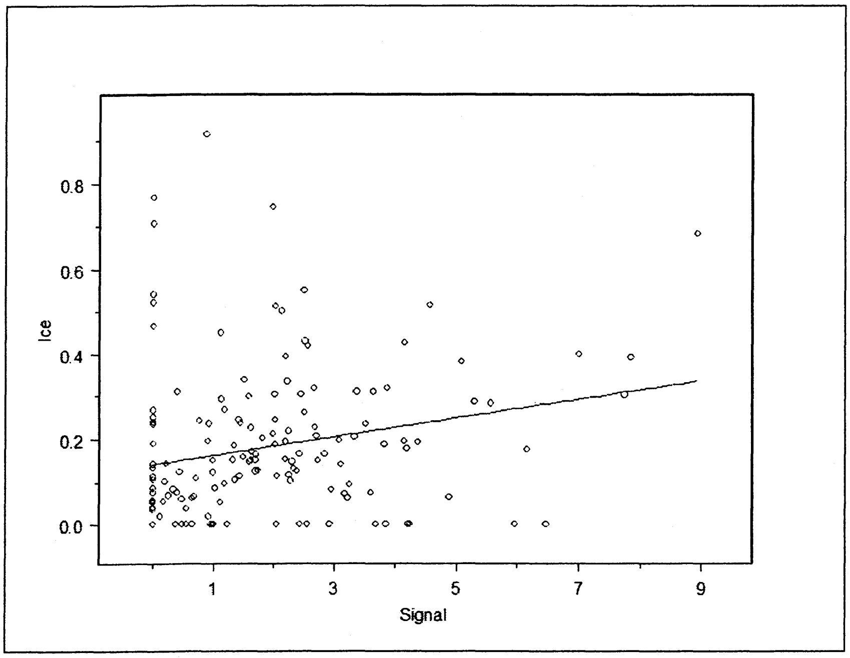

Figure C-14. Ice Surface Crash Rates and Traffic Signal Density

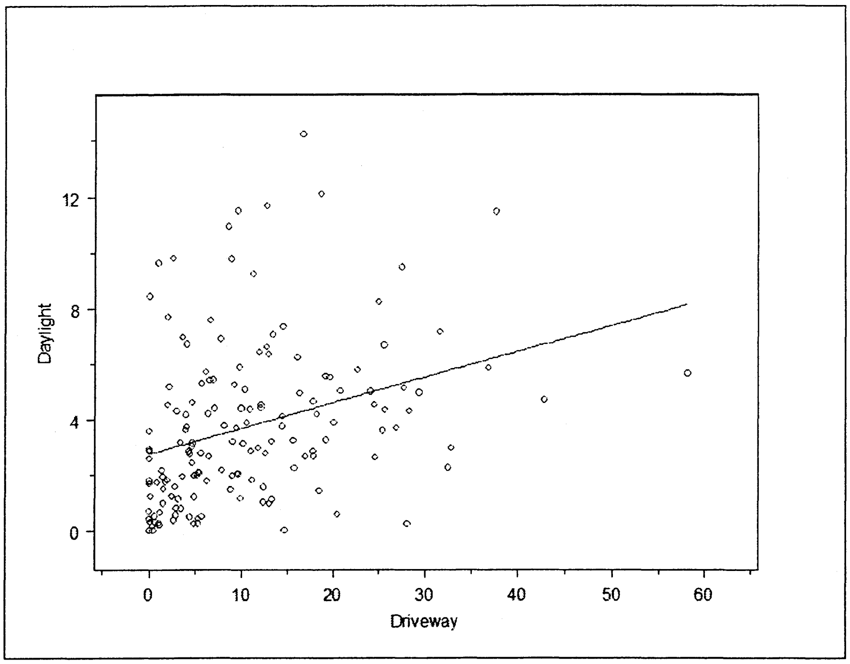

Figure C-15. Daylight Crash Rates and Commercial Driveway Density

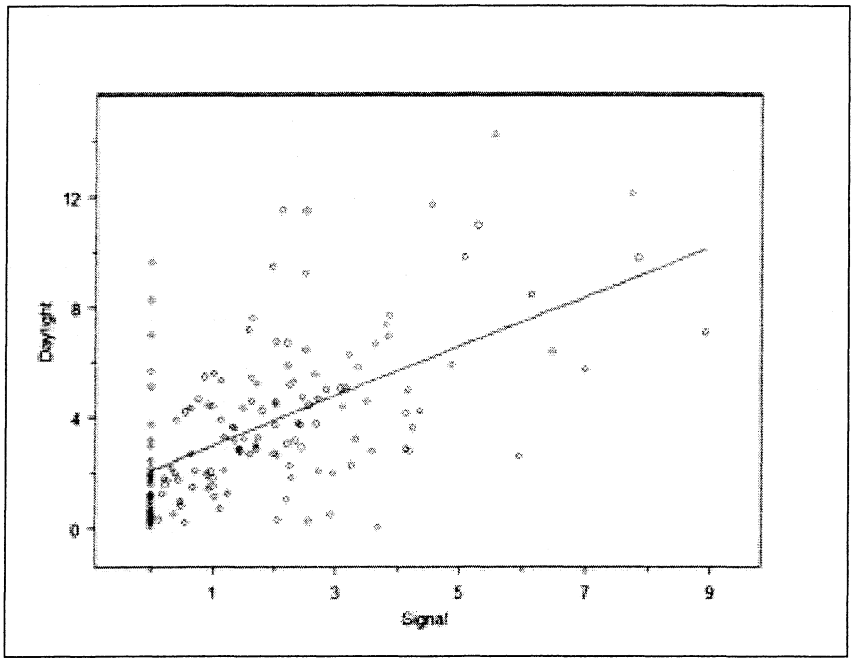

Figure C-16. Daylight Crash Rates and Traffic Signal Density

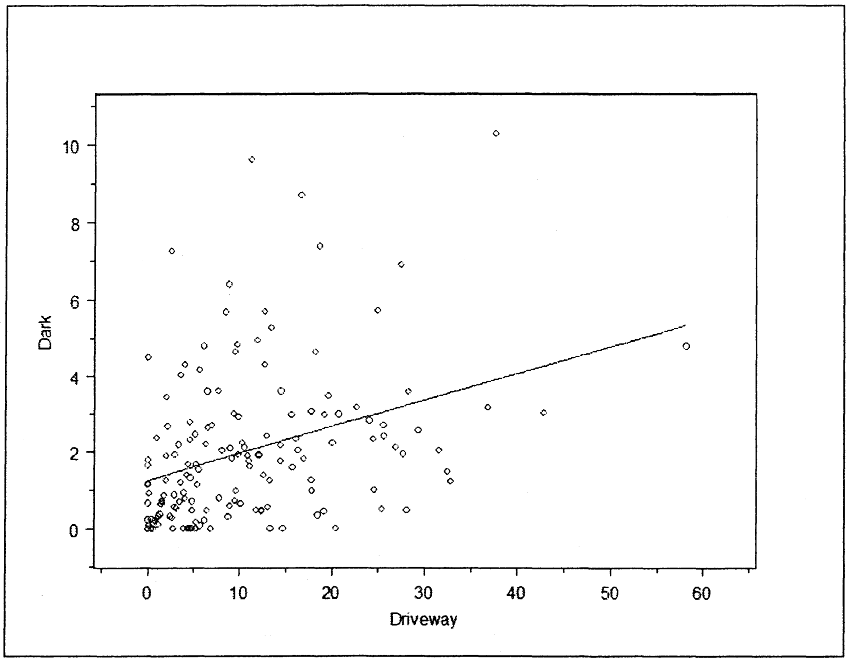

Figure C-17. Dark Crash Rates and Commercial Driveway Density

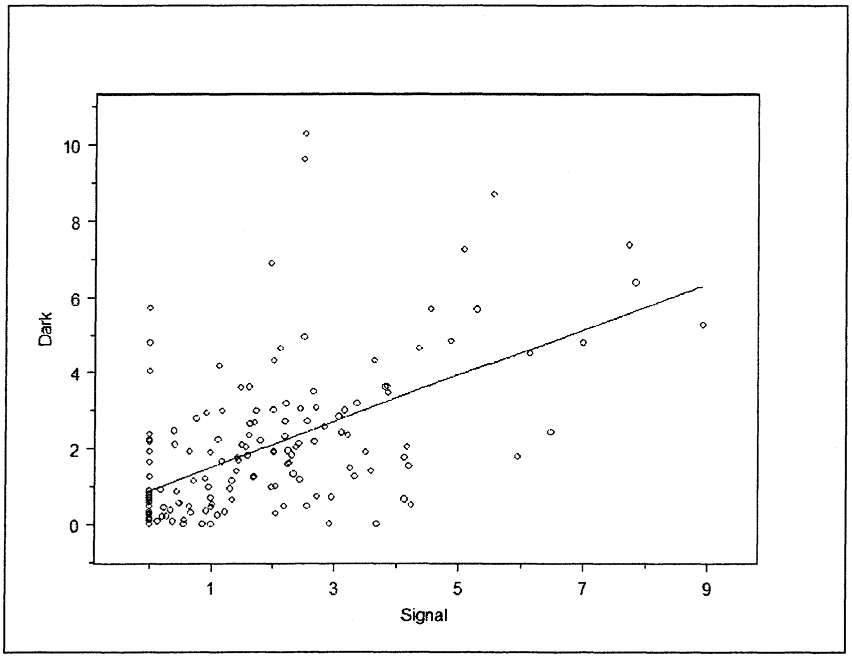

Figure C-18. Dark Crash Rates and Traffic Signal Density

APPENDIX D

This appendix contains additional figures and tables for chapter seven.

Table D-1. Expected Crash Rates under Clear Weather Conditions

Clear Weather Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.47	0.60	0.74	0.87	1.00
	2	1.06	1.19	1.33	1.46	1.59
	4	1.65	1.79	1.92	2.05	2.19
	6	2.25	2.38	2.51	2.64	2.78
	8	2.84	2.97	3.10	3.24	3.37

E(Y)=*0.4695+0.0266*cdd+0.2960*tsd*

Table D-2. Expected Crash Rates under Rain, Mist, and Foggy Weather Conditions

Rain, Mist, Fog Weather Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.09	0.13	0.17	0.21	0.25
	2	0.28	0.32	0.35	0.39	0.43
	4	0.46	0.50	0.54	0.58	0.62
	6	0.64	0.68	0.72	0.76	0.80
	8	0.83	0.86	0.90	0.94	0.98

E(Y)=0.0928+0.0078*cdd+0.0916*tsd

Table D-3. Expected Crash Rates under Snow, Sleet, and Hail Weather Conditions

Snow, Sleet, Hail Weather Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.19	0.21	0.23	0.25	0.27
	2	0.37	0.39	0.41	0.43	0.45
	4	0.55	0.57	0.59	0.61	0.63
	6	0.73	0.75	0.77	0.79	0.82
	8	0.91	0.93	0.95	0.97	1.00

E(Y)=0.1886+0.0042*cdd+0.0904*tsd

Table D-4. Expected Crash Rates under Dry Surface Conditions

Dry Surface Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.84	1.05	1.27	1.48	1.70
	2	1.89	2.10	2.32	2.54	2.75
	4	2.94	3.16	3.37	3.59	3.80
	6	4.00	4.21	4.43	4.64	4.86
	8	5.05	5.26	5.48	5.70	5.91

E(Y)=0.8352+0.0431*cdd+0.5267*tsd

Table D-5. Expected Crash Rates under Wet Surface Conditions

Wet Surface Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.20	0.26	0.32	0.37	0.43
	2	0.52	0.58	0.63	0.69	0.75
	4	0.84	0.89	0.95	1.01	1.06
	6	1.15	1.21	1.27	1.32	1.38
	8	1.47	1.53	1.58	1.64	1.70

E(Y)=0.2024+0.0113*cdd+0.1584*tsd

Table D-6. Expected Crash Rates under Icy Surface Conditions

Icy Surface Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.13	0.14	0.14	0.15	0.16
	2	0.17	0.18	0.18	0.19	0.20
	4	0.21	0.22	0.22	0.23	0.24
	6	0.25	0.26	0.26	0.27	0.28
	8	0.29	0.30	0.30	0.31	0.32

E(Y)=0.1282+0.0015*cdd+0.0200*tsd

Table D-7. Expected Crash Rates under Snowy Surface Conditions

Snow Surface Condition		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.03	0.03	0.03	0.03	0.03
	2	0.09	0.09	0.09	0.09	0.09
	4	0.14	0.14	0.14	0.14	0.14
	6	0.20	0.20	0.20	0.20	0.20
	8	0.26	0.26	0.26	0.26	0.26

E(Y)=0.0271+0.0000*cdd+0.0293*tsd

Table D-8. Expected Crash Rates under Daylight Conditions

Daylight Conditions		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	1.55	1.86	2.16	2.46	2.76
	2	3.21	3.51	3.82	4.12	4.42
	4	4.87	5.17	5.48	5.78	6.08
	6	6.53	6.83	7.13	7.44	7.74
	8	8.19	8.49	8.79	9.09	9.40

E(Y)=1.5546+0.0605*cdd+0.8289*tsd

Table D-9. Expected Crash Rates under Dark Conditions

Dark Conditions		**Commercial Driveway Density (per mile)**				
		0	**5**	**10**	**15**	**20**
Traffic Signal Density (per mile)	**0**	0.48	0.72	0.96	1.21	1.45
	2	1.57	1.82	2.06	2.30	2.54
	4	2.67	2.91	3.15	3.40	3.64
	6	3.76	4.01	4.25	4.49	4.74
	8	4.86	5.10	5.35	5.59	5.83

E(Y)=0.4760+0.0486*cdd+0.5481*tsd

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