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A PRIORITIZATION PROCESS FOR ACCESS MANAGEMENT IMPLEMENTATION IN UTAH

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract

Appropriate access management techniques can improve the safety and efficiency of arterial roads. To determine which roads can most benefit by the implementation of access management techniques, a prioritization process was developed to recommend various access management treatments. To serve as the basis for the performance index, a database was created including identifying features, characteristics, and crash history for 175 arterial road segments on Utah state routes. Stepwise linear regression was applied to the data collected to determine which characteristics of the roads were correlated with crash rate, crash severity, and specific collision types. Recommendations for access management treatments were given in the form of a decision tree to classify existing or future road segments into subcategories based on volume, signal spacing, land use, and other criteria, with recommendations provided for each subcategory.

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Executive Summary

Transportation systems must be continually evaluated to ensure that people and goods can be moved as efficiently and as safely as possible given the financial constraints of the agency responsible for the system. Safety and performance indices provide a method to numerically measure given data about a system so that comparisons and rankings can be made as objectively as possible. Because traffic volumes and congestion across the state of Utah have continued to increase in recent years, particularly on arterial roads, the safety and performance of arterial roads has become a concern for the Utah Department of Transportation (UDOT).

The purpose of this report is to present the results of a study conducted to develop a prioritization process for the implementation of access management techniques in the state of Utah. The study was part of a research project funded by UDOT and conducted by researchers at Brigham Young University (BYU) that began in March 2006.

Report Objectives

The objective of the research outlined in this report was to develop a prioritization process based on principles of performance indices that can be utilized to target arterial roads that would benefit from the implementation of various access management principles and techniques. This was accomplished by collecting existing characteristics and crash histories to determine the impact of access management on the safety of arterial roads. A performance-index-based prioritization process was created using these relationships as the basis for a decision tree that can be used to evaluate the need for access management on a given road segment. The results of this research can provide direction and guidance to UDOT personnel on the prioritization of corridors that could benefit from the implementation of access management principles and techniques.

Secondary objectives of this research were to determine how access management principles and techniques were related to crash severity, to expand the literature on the safety benefits of access management principles and techniques, and to show the specific relationship between access management and crash severity in the state of Utah.

Background

The American Association of State Highways and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (AASHTO Green Book) states "[a]rterials are expected to provide a high degree of mobility for the longer trip length. Therefore, they should provide a high operating speed and level of service. Since access to abutting property is not their major function, some degree of access control is desirable to enhance mobility" (AASHTO 2004). The increase in traffic volumes combined with the desire to provide access to adjacent properties can have a negative effect on the safety and operational characteristics of arterial roads. When unlimited access is provided to adjacent properties, the result oftentimes is a decrease in speed, level of service, and more importantly, safety. In an effort to combat the safety concerns associated with this access, specific principles and techniques have been implemented in an effort to control access and improve safety. These "access management" techniques are defined by the Transportation Research Board (TRB) as "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" (2003).

The implementation of access management principles and techniques has continued to be placed at the forefront of importance for state departments of transportation (DOTs) across the nation. UDOT has followed suit in this effort, having established state highway access management guidelines as part of the Administrative Rule R930-6, *Accommodation of Utilities and the Control and Protection of State Highway Rights of Way* (UDOT 2003). This document aims to provide guidance to DOT personnel in maintaining and preserving both existing and future capacity on the state roadway network. It also provides guidance for design, operations, and project management to better implement access management techniques in both existing and future projects.

The process of evaluating access management techniques in Utah, specifically raised medians, began by research completed at BYU (Saito et al. 2005). The results of this research established a procedure to guide state engineers through the evaluation process of identifying the need for a raised median section on a given highway. Further research has identified locations where access management techniques have been implemented throughout the state of Utah and identified the safety impacts of those installations (Schultz and Lewis 2006).

Facility Evaluation

A database of arterial roads was compiled to summarize state routes in the urbanized areas of six counties in Utah. The database was comprised of 175 segments of 49 different state routes totaling 207 miles of arterial roads. The three major components of the database included: 1) identifying features of each road segment, 2) independent variables, and 3) dependent variables.

Identifying Features

The identifying-features portion of the database included descriptive data to uniquely differentiate the segments from one another. Data in this section included the state route number, the county in which the segment was located, the street name, and the mile post numbers of the beginning and end points. Descriptions of the endpoints were also given, consisting of cross streets or other landmarks.

Independent Variables

Independent or explanatory variables include those characteristics of the road segments that had possible correlation with the safety or operational characteristics of the roadway. It was important to consider as many characteristics as possible at the onset to be able to properly account for any variables influencing the crash histories of the segments. Independent variables collected in this database included length, access category, number of lanes, median type, orientation, adjacent land use, posted speed limit, access density, average annual daily traffic (AADT), and signals per mile.

Dependent Variables

Dependent variables, or response variables, included those characteristics of a road segment that were believed to be the result of the various roadway characteristics discussed above. The dependent variables obtained for this database included the number of crashes aggregated by severity and collision type over the three-year period of 2002 to 2004. These crash histories included over 28,800 crashes.

Data Collection Methodology

Several web-based tools were used to collect the data used for this database including various UDOT documents and maps (UDOT 2004, 2006a), the UDOT Road Viewer Program (UDOT 2006b), Google Maps (Google 2006), and the UDOT web-based crash almanac (Anderson et al. 2005).

Safety Evaluation

Statistical analysis was performed on the data contained in the database to determine which characteristics were correlated to roadway safety aspects, including crash rate, crash severity, and collision type.

Statistical Methodology

Computer software SPSS® 14.0 was utilized to perform stepwise linear regression in order to determine which independent variables were related to each dependent variable analyzed (SPSS 2005). In addition to the stepwise linear regression, the “weight cases” option was also utilized to weight each individual segment by its length to ensure that short segments would not skew the data.

After the significant variables were identified from the stepwise procedure, multiple linear regression was used to identify the regression coefficients and their respective *t*-statistics and *p*-values. The null hypothesis was that the regression coefficients were zero. The intent of determining regression coefficients was not necessarily to predict crash rates, crash severities, or collision types, but to determine which characteristics were correlated with crash history. The regression equations should not be used to predict crashes but can be examined to see patterns in the data.

Crash Rate

Crash rates, in units of crashes per million vehicle miles traveled (MVMT), are a common method used in evaluating the safety of roads and intersections. They were calculated for each road section in the database as a function of the number of crashes, volume, and length. Stepwise linear regression showed statistically significant correlation of crash rates to signal spacing, adjacent land use, speed limit, and median type.

Crash Severity

Crash severity refers to the severity corresponding to the most severe injury of all those resulting from a given crash. According to the National Safety Council (1996), the five categories are fatal accident, incapacitating injury accident, non-incapacitating evident injury accident, possible injury accident, and non-injury accident. A common abbreviation for these severity levels is referred to as the KABCO scale, with each letter, “K” through “O”, representing fatal through non-injury levels of severity, respectively. In Utah, slightly different language is used to define these severity levels as identified in the report.

Five methods were developed to create crash severity scores for each road segment as a function of the quantities of each severity level of crash and weighting factors. The methods developed are as follows:

1. Federal Highway Administration (FHWA) Crash Costs Method,
2. Magnitudes of Ten Method,
3. Exponential Method,

4. Three Category Method, and
5. UDOT Crash Costs Method.

Each method was used to calculate a severity score and differed in the way that the different severity levels were weighted. Stepwise linear regression was completed on all five methods to determine the correlation of road characteristics and crash severity scores.

While multiple linear regression yielded different results for each method, many results were similar. Table ES.1 summarizes all of the variables identified with the stepwise linear regression as being correlated to the crash severity score of the segments in the database. A "+" symbol indicates positive correlation, while a "-" symbol indicates negative correlation. Blank cells indicate no correlation for the respective variable and method.

Table ES.1 Summary of Correlations of Independent Variables with Crash Severity

Variable	Method 1	Method 2	Method 3	Method 4	Method 5
Signals/Mile	+	+	+	+	+
AADT/Lane	+	+	+	+	+
Commercial	+	+	+	+	+
Residential					-
Speed Limit	+	+			+
TWLTL	+	+	+	+	
Access Density	+	+			+

Note: A "+" indicates positive correlation and a "-" indicates negative correlation.

Collision Type

Analyzing crashes by collision type has two apparent advantages: 1) it identifies specific geometric characteristics of the roadway, such as those that are related to access management, that may have caused or failed to prevent the crash, and 2) locations with high frequencies of certain crashes normally thought to yield more severe results are identified as hazardous, whether or not severe injuries occurred. The latter advantage is further magnified when sample sizes are lower and variability is higher.

For collision-type analysis, crash rates were determined for each type of collision and then compared with the respective crash rates of other locations. Statistical analysis included stepwise linear regression on the dependent variables of right-angle collisions, rear-end collisions, side-swipe collisions (in the same direction), single-vehicle collisions, and head-on and side-swipe collisions (from opposite directions).

Table ES.2 summarizes all of the variables identified with the stepwise linear regression as being correlated to various collision types of the road segments in the database. A "+" symbol indicates positive correlation, while a "-" symbol indicates negative correlation. Blank cells indicate no correlation for the respective variable and collision type.

Table ES.2 Summary of Correlations of Independent Variables with Collision Type

Variable	Right-Angle	Rear End	Side-Swipe	Opposite-Direction	Single-Vehicle	Other
Signals/Mile	+	+	+			
AADT/Lane	-	+			-	-
Commercial	+		+			+
Residential		-		+		-
Speed		-			-	-
Raised Median	-					
TWLTL				+		
Access Density			+			

Note: A "+" indicates positive correlation and a "-" indicates negative correlation.

Prioritization Process

A performance-index-based prioritization process was developed to make decisions regarding access management techniques that should be utilized on arterial roads. The primary method to develop this process was by utilizing a decision tree. The decision tree developed in this research was based on the results of statistical analyses performed on the data, as well as recommendations found in the literature. Decision criteria and cutoff values were determined by analyzing the data using statistical software programs CART™ and SPSS as well as utilizing recommendations from the literature.

Figure ES.1 shows the decision tree developed. Six steps can be followed to arrive at three different access management recommendations including limiting access density, installing raised medians, and future planning. Additionally, some segments are given no recommendation.

Conclusions and Recommendations

Conclusions

The purpose of this report was to develop a prioritization process based on principles of performance indices that can be utilized to target arterial road segments that would benefit from the implementation of various access management principles and techniques. This was accomplished by collecting existing characteristics and crash histories and determining the impact of access management on the safety of arterial roads. A performance-index-based prioritization process was created using these relationships as the basis for a decision tree that can be used to evaluate the need for access management on a given road segment.

A secondary purpose of this research was to determine how access management principles and techniques were related to crash severity and to expand the literature on the safety benefits of access management techniques. Statistical analysis showed that the lack of access management, such as high access density, numerous signals per mile, and lack of medians, were positively correlated with increased crash rates and increased crash severity. Certain collision types, such as right-angle, side-swipe, and opposite-direction crashes, were also more likely to occur when access was not effectively managed. Furthermore, land use plays a significant role in the safety of arterials. Road segments with adjacent commercial land use tended to have higher crash rates and severity scores.

Finally, this research shows that in addition to the safety benefits well established in the literature, access management positively benefits safety in the state of Utah.

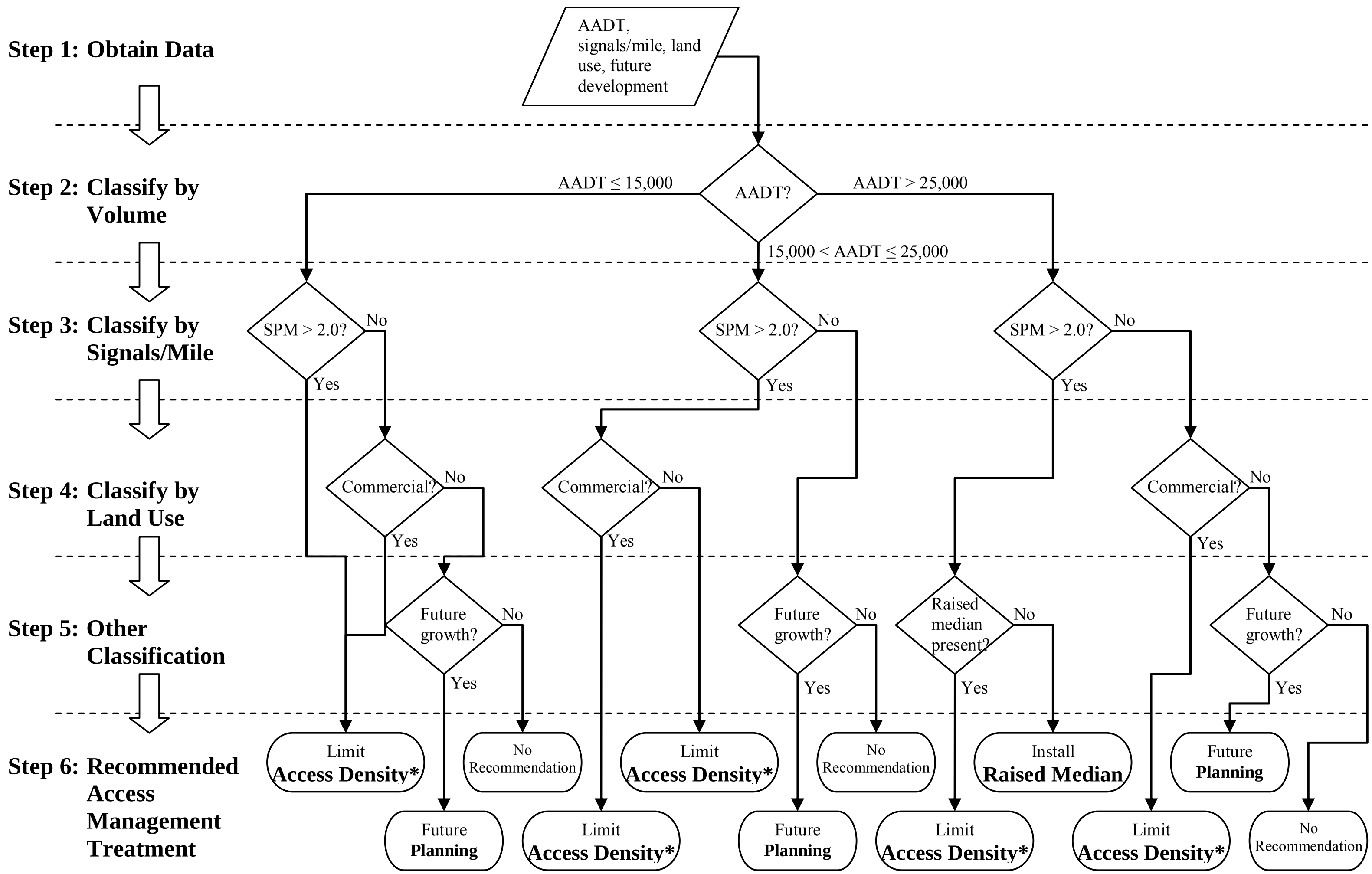
Recommendations

Based on the conclusions of this research, it is recommended that access management be continually implemented on arterial roads in the state of Utah. A decision tree was outlined that can assist UDOT personnel in determining which arterial roads might benefit the most from various access management techniques. To use the decision tree, information about AADT, signals per mile, adjacent land use, and future growth is needed to classify arterial road segments. Possible recommendations include limiting access points, installing raised medians, and planning for future growth by implementing standards for adequate signalized and unsignalized access spacing and obtaining sufficient right-of-way for future medians.

Future Research

Further research is recommended in the areas of safety and access management. A crash prediction model should be developed to assist planners in understanding the impact of future growth on state routes. Empirical Bayesian methodology has been developed in the literature and would be an effective means of conducting this analysis. Access management should be a key component in this model to show the effect it has on the predicted safety of state routes.

Other research recommended in order to study the effects of access management could include examining the relationship between crashes and the number of conflict points. Additionally, the effect of access in the vicinity of signalized intersections could be analyzed. Finally, a methodology could be developed to examine crashes most likely caused by access density instead of all crashes in general. This could more accurately show the benefits of access management on arterial roads.



*signalized or unsignalized

Figure ES.1 Decision tree for determining recommended access management techniques.

1 Introduction

Transportation systems must be continually evaluated to ensure that people and goods can be moved as efficiently and as safely as possible given the financial constraints of the agency responsible for the system. Safety and performance indices provide a method to numerically measure given data about a system so that comparisons and rankings can be made as objectively as possible. This report discusses an evaluation of the safety of arterial roads in Utah and makes recommendations to improve safety by utilizing access management principles and techniques.

1.1 Background

Traffic volumes and congestion across the state of Utah have continued to increase in recent years, particularly on arterial roads. The American Association of State Highways and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (AASHTO Green Book) states "[a]rterials are expected to provide a high degree of mobility for the longer trip length. Therefore, they should provide a high operating speed and level of service. Since access to abutting property is not their major function, some degree of access control is desirable to enhance mobility" (AASHTO 2004). The increase in traffic volumes combined with the desire to provide access to adjacent properties can have a negative effect on the safety and operational characteristics of arterial roads. When unlimited access is provided to adjacent properties, the result oftentimes is a decrease in speed, level of service, and more importantly, safety. In an effort to combat the safety concerns associated with this access, specific principles and techniques have been implemented in an effort to control access and improve safety. These "access management" techniques are defined by the Transportation Research

Board (TRB) as "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" (2003).

The implementation of access management principles and techniques has continued to be placed at the forefront of importance for state departments of transportation (DOTs) across the nation. The Utah Department of Transportation (UDOT) has followed suit in this effort, having established state highway access management guidelines as part of the Administrative Rule R930-6, *Accommodation of Utilities and the Control and Protection of State Highway Rights of Way* (UDOT 2003). This document aims to provide guidance to DOT personnel in maintaining and preserving both existing and future capacity on the state roadway network. It also provides guidance for design, operations, and project management to better implement access management techniques in both existing and future projects.

The process of evaluating access management techniques, specifically raised medians, began by research completed at Brigham Young University (BYU) (Saito et al. 2005). The results of this research established a procedure to guide state engineers through the evaluation process of identifying the need for a raised median section on a given highway. Further research has identified locations where access management techniques have been implemented throughout the state of Utah and identified the safety impacts of those installations (Schultz and Lewis 2006).

1.2 Problem Statement

The purpose of the research outlined in this report was to develop a prioritization process based on principles of performance indices that can be utilized to target arterial roads that would benefit from the implementation of various access management principles and techniques. This was accomplished by collecting existing characteristics and crash histories to determine the impact of access management on the safety of arterial roads. A performance-index-based prioritization process was created using these relationships as the basis for a decision tree that can be used to evaluate the need for access management on a given road segment. The results of this research provide direction and guidance to UDOT personnel on the prioritization of corridors that could benefit from the implementation of access management principles and techniques.

Secondary purposes of this research were to determine how access management principles and techniques were related to crash severity, to expand the literature on the safety benefits of access management principles and techniques, and to show the specific relationship between access management and crash severity in the state of Utah.

1.3 Report Organization

In Chapter 2, a literature review is presented summarizing general access management techniques, access management techniques used in the state of Utah, safety impacts of access management techniques in Utah, an overview of the UDOT web-based crash almanac, and safety and performance indices found in the literature. Chapter 3 discusses a database comprised of 175 segments of state routes in Utah including characteristics of the roads as well as their crash histories. Chapter 4 contains the methodology and results of statistical analysis conducted on the database in Chapter 3. A performance-index-based prioritization process developed utilizing the results of the statistical analysis and literature review is outlined in Chapter 5. The primary method for indexing arterials for their need of access management is through the use of a decision tree. Chapter 6 contains a summary of the results and recommendations. References are contained after Chapter 6 and are followed by eight appendices discussed later in this report.

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2 Literature Review

The purpose of this literature review is to outline and discuss the practice of access management techniques as well as the use of performance and safety indices. A comprehensive summary of common access management treatments is outlined in Section 2.1, followed by discussions of the requirements and impacts of access management in the state of Utah in Sections 2.2 and 2.3, respectively. This is followed by an overview of a crash evaluation tool maintained by UDOT in Section 2.4. Several methods for creating performance and safety indices are discussed in Section 2.5. Section 2.6 summarizes this literature review.

2.1 Summary of Access Management Techniques

Access management techniques and their potential benefits are well defined and established in the literature. The following sections provide brief overviews of each type of access management treatment as categorized by the *National Cooperative Highway Research Program (NCHRP) Report 420* (Gluck et al. 1999). The access management techniques outlined are as follows:

- Traffic signal spacing,
- Unsignalized access spacing,
- Corner clearance criteria,
- Median treatments,
- Left-turn lanes,
- U-turns as alternatives to direct left-turns,
- Access separation at interchanges, and
- Frontage roads.

2.1.1 Traffic Signal Spacing

Placing signalized intersections at uniformly spaced locations, with optimal frequency, improves the efficiency and safety of arterial roads. Negative effects of closely or irregularly spaced signals include increased delay, fuel consumption, and vehicular emissions, as well as an increase in crash rates (Gluck et al. 1999). Half-mile spacing is optimal. Spacing as close as a quarter mile is also acceptable for minor arterials or densely developed areas, although this will likely result in lower speeds and higher crash rates (TRB 2003).

2.1.2 Unsignalized Access Spacing

Increasing the number of driveways along a corridor has a negative impact on safety and progression because more conflict points are added to the road. Several studies correlate an increase in access density with an increase in crash rates and are discussed in detail in *NCHRP 420* (Gluck et al. 1999).

2.1.3 Corner Clearance Criteria

Corner clearance is defined as the distance from an intersection of a public or private road to the nearest driveway (TRB 2003). Because driveways should not be placed in the functional area of an intersection, the area defined as the perception-reaction distance, maneuver distance, and queue-storage distance of each leg (AASHTO 2004), providing proper corner clearance ensures that vehicles will not be required to enter or exit in critical areas near an intersection. Operationally, poor corner clearance results in blocked driveways, confusing movements at intersections, and inadequate weaving distances (Gluck et al. 1999). From a safety standpoint, conflicts are reduced because through traffic is allowed to move through the intersection without vehicles entering or exiting the roadway (TRB 2003). Recommendations for corner clearance as a function of speed are contained in the AASHTO Green Book (AASHTO 2004).

2.1.4 Median Treatments

In addition to a road being an undivided highway, two possible types of medians include two-way left-turn lanes (TWLTLs) and raised medians. TWLTLs have become popular especially in areas with high commercial development because access is not restricted for vehicles turning left into or left out of roadside developments. While studies have confirmed that TWLTLs are safer and more efficient than having no median at all, raised medians have proven even safer. Raised medians show particular success in improving safety in areas of high density because they limit the number of conflict points along a road segment. However, resistance to raised medians stems from perceived economic disadvantages as access to commercial establishments becomes more limited. Furthermore, rear-end collisions sometimes increase near median openings, and congestion and safety may deteriorate at nearby signalized intersections (Gluck et al. 1999).

2.1.5 Left-Turn Lanes

Providing left-turn lanes improves capacity by removing the vehicles from the through travel lanes and increases safety by improving site distance for opposite left turning vehicles, thus reducing right-angle collisions (Gluck et al. 1999).

2.1.6 U-Turns as Alternatives to Direct Left-Turns

By restricting left-turn egress and/or ingress to driveways along an arterial, the need for vehicles to make U-turns becomes apparent. Several methods exist to accommodate these movements, including dual left-turn bays at signalized intersections (with the inside lane allowing for U-turns), mid-block U-turn lanes, and “jughandles.” Studies show that crashes are reduced by restricting left-turns and providing for U-turns (Gluck et al. 1999).

2.1.7 Access Separation at Interchanges

Providing adequate distance between ramps at freeway interchanges and nearby access to developments and crossroads assists in the safety and operation in those areas. Potential problems associated with insufficient spacing are increased congestion, heavy weaving, increased crash rates, and the need for more complex signal timing (Levinson et al. 1998).

2.1.8 Frontage Roads

Frontage roads are an effective access management technique because they allow full access to development along a corridor while reducing the frequency of conflicts along the arterial. Several types of frontage roads exist, such as one-way and two-way roads that connect to the arterial by means of signalized intersections or by merging and diverging. Although increased right-of-way is often required, safety is increased due to decreased conflict points. Frequency and severity of collisions are reduced by utilizing frontage roads (Gluck et al. 1999).

2.2 Summary of Access Management Techniques in Utah

Access management techniques are currently being utilized in Utah. Although some aspects of access management have been implemented in limited measures for many years, a formal access management program was not initiated until 2003. Administrative Rule R930-6, *Accommodation of Utilities and the Control and Protection of State Highway Rights of Way*, was created, and a portion of the document was dedicated to access management (UDOT 2003). The stated purpose of that portion of Administrative Rule R930-6 was to "establish highway access management procedures and standards to protect Utah's State Highway system" (UDOT 2003).

According to Administrative Rule R930-6, "the policy of UDOT is to provide safe and efficient roadways to fully utilize the public's investment in the highway system, without compromising the rights of property owners of reasonable access to land uses" (UDOT 2003). Recognizing that not all state highways have the same purpose, access categories were set up to classify state roads according to their intended function. Each category has associated requirements for access spacing, including private driveways, public streets, traffic signals, and proximity to freeway interchanges. The nine categories and their associated requirements are shown in Table 2.1 (UDOT 2003).

Table 2.1 Access Category Descriptions and Minimum Spacing Requirements (UDOT 2003)

Category		Description	Minimum Spacing (feet)			Minimum Interchange to Crossroad Spacing (feet)		
			Signal	Street	Access	"A"[1]	"B"[2]	"C"[3]
1	I	Interstate/ Freeway	Interstate/Freeway Standards Apply					
2	S-R	System Priority Rural	5,280	1,000	1,000	1,320	1,320	1,320
3	S-U	System Priority Urban	2,640	Not Applicable		1,320	1,320	1,320
4	R-S	Regional Rural	2,640	660	500	660	1,320	500
5	R-PU	Regional Priority Urban	2,640	660	350	660	1,320	500
6	R-U	Regional Urban	2,640	350	200	500	1,320	500
7	C-R	Community Rural	1,320	300	150	Not Applicable		
8	C-U	Community Urban	1,320	300	150			
9	O	Other	1,320	300	150			

1. Standard "A" refers to the distance from the interchange off-ramp gore area (point of widening) to the first "right-in/right-out" driveway intersection.
2. Standard "B" refers to the distance from the interchange off-ramp gore area (point of widening) to the first major intersection.
3. Standard "C" refers to the distance from the last "right-in/right-out" driveway intersection to the interchange gore area (point of widening).

2.3 Safety Impacts of Access Management Techniques in the State of Utah

Research evaluating the effectiveness of access management techniques on a sampling of Utah's arterial roads was completed in 2005 and 2006 by BYU and UDOT

(Schultz and Lewis 2006). An observational study examined five corridors that had raised medians installed within the last 10 years by analyzing crash statistics before and after the raised medians were installed. The study showed that while crash rates did not necessarily decrease after the installation of the raised medians, fatalities and serious injury crashes did decrease. Total costs for the crashes were calculated using crash costs provided by UDOT. Comparing these comprehensive costs before and after the installation of raised medians showed a general decrease in costs associated with these crashes. This research showed that access management treatments, specifically raised medians, help decrease the severity of crashes in the state of Utah.

Similar research was also completed by Saito et al. (2005) on four corridors in central business districts (CBDs) in Utah and found that midblock right-angle crashes decreased, while rear-end crashes increased after raised median installation. Overall, severity also decreased both at midblock locations and at signalized intersections.

2.4 Summary of Web-Based Crash Almanac

Obtaining and analyzing crash data in Utah is a key step in the identification of corridors in need of access management treatments. To assist with this data collection, a web-delivered geographic information system (GIS) crash database, maintained by UDOT, can be used to access crash statistics and information for every road in Utah's state highway system. This system, known as the UDOT web-based crash almanac (Anderson et al. 2005), can also spatially represent the crash distribution using the GIS capabilities.

The interfaces for this almanac offer several benefits, including custom tables and reports containing only pre-specified parameters, geographic placement of crash locations on maps, and query tools allowing the consolidation of numerous data to answer focused research questions. Several parameters that are searchable using this tool include route number, date, time, location, crash type, crash severity, number of vehicles involved, and many others (Anderson et al. 2005). The use of this tool is discussed in greater detail in Section 3.4.

2.5 Safety and Performance Indices

In many fields of transportation engineering, a need to evaluate the quality of a given system exists. Whether it is a pavement, transit system, or intersection, transportation professionals must have a way to quantitatively rank the system against other peer systems. Indices provide a method to numerically measure given data about a system so that comparisons and rankings can be made as objectively as possible. Furthermore, as funds to improve failing transportation systems are usually limited, an effective ranking system helps planners more efficiently program needed treatments.

For example, one well established index is the present serviceability index (PSI) used in the design and maintenance of pavements. The PSI is a scale between 0 and 5, where 5 represents highest quality and 0 represents poorest quality. Each pavement is given a rating, called the present serviceability rating (PSR), somewhere between 0 and 5 based on the pavement's quality. When the PSR falls below a predetermined value called the terminal serviceability index (TSI), the quality of ride has become "unacceptable," and the road should be repaired (Fricker and Whitford 2004).

Although no such universally accepted index exists for evaluating the safety or operational performance of road segments or corridors, several types of safety and performance indices do exist and are currently utilized in the U.S. and abroad. These methods range in complexity and use both analytical and subjective tools. The following sections outline several of these indices, including the data needed and the method used to evaluate them. The methods discussed include standard crash history methods, critical rate methods, composite methods, predictive methods, and subjective methods.

2.5.1 Standard Crash History Methods

Standard crash history methods discussed in this section include crash frequency, crash rate, crash severity, collision type analysis, and benefit-cost ratio analysis.

2.5.1.1 Crash Frequency

The simplest and least complex analytical method is the use of crash frequency. This is simply the number of reported crashes in a given area within a given time. The advantage to this approach is that it is intuitive and simple and therefore easy to understand. The major downfall of this method is that it does not account for the volume or exposure to potential conflicts. Furthermore, it fails to take into account the severity levels or types of crashes at the locations of interest (Hummer 2000).

2.5.1.2 Crash Rate

Adjusting the crash frequency for volume creates a crash rate. Crash rates for road segments are typically reported in crashes per million vehicle miles traveled (MVMT) or per hundred MVMT. Crash rates for intersections are typically reported in crashes per million entering vehicles (MEV) (Hummer 2000). Crash rates account for volume and are thus normalized to account for more crashes occurring at busier locations. Equation 2.1 shows the crash rate equation for a section of roadway.

$$CR_{\text{sec}} = \frac{N}{V_{\text{sec}} \times 365 * L} \times 10^6 \tag{2.1}$$

where: CR_{sec} = crash rate for section (in crashes per MVMT),
N = number of crashes per year,
V_{sec} = average annual daily traffic (AADT) of road section, and
L = length of section (in miles).

Equation 2.2 shows the crash rate equation for intersections.

$$CR_{\text{int}} = \frac{N}{V_{\text{int}} \times 365} \times 10^6 \tag{2.2}$$

where: CR_{int} = crash rate for intersection (in crashes per MEV), and
V_{int} = sum of average daily approach volumes of intersection.

2.5.1.3 Crash Severity

Crash rates can be weighted to reflect the severity of the individual crashes themselves. This is done by weighting the crashes using economic or comprehensive costs. Most indices using some form of crash severity in their method base the weights off of relative economic costs.

Methods for reporting the crash severity of a site vary. Schultz and Lewis (2006) and Plazak et al. (2004) summed the total dollar value of all crashes. Two different studies by the University of Utah (Cotrell and Mu 2004, 2005), as well as a study by Kar and Datta (2004), round off, divide all the dollar amounts by a common denominator, or in some other way manipulate the dollar amounts to obtain smaller, more manageable values. For example, the values used by Cotrell and Mu (2004, 2005) range as orders of magnitude from 0.1 for a property-damage-only (PDO) crash to 1,000 for a fatal crash. Kar and Datta (2004) use values from 1 to 150.

Gharaybeh (1991) weights the crashes by severity much more equally than the above methods. The factors for fatalities, injuries, and all others are 12, 3, and 1 respectively. These values are referred to as equivalent total accident numbers (ETAN), meaning that one fatal crash is the equivalent of 12 normal crashes, for example.

The Fourth Edition of the Institute of Transportation Engineers (ITE) *Traffic Engineering Handbook* recommends that serious injury and fatal crashes be combined because using cost to weight crashes by severity puts too much of an emphasis on fatalities (Wilson and Burtch 1992). Crash severity is discussed in greater detail in Section 4.3.

2.5.1.4 Collision Type Analysis

Because some crashes are more likely to occur because of access-related problems, analyzing only "access probable" crashes, such as right-angle crashes near driveways, may give a more realistic rating for a given road segment for which access management techniques are a desired countermeasure. The Des Moines Access Management Plan (Plazak et al. 2004) tabulated certain types of crashes that were more likely to be caused by access problems. Data for the whole state of Iowa was used to calculate crash frequency, crash rates, and crash costs for corridors in Iowa by using only crashes that were likely to have occurred because of access management problems. Additionally, the percentages of access-management-related crashes out of all crashes for each given corridor were calculated (Plazak and Souleyrette 2002).

2.5.1.5 Benefit-Cost Ratio

Thus far, the methods discussed for ranking road segments have been limited to those with high numbers of crashes or crash potential. However, California has used a “traffic safety index” based on the ratio of the benefit that can likely be seen from implementing countermeasures on a given road to the cost of implementing the countermeasures (Hanley et al. 2000). Therefore, if a “dangerous” road exists, but available countermeasures are not likely to provide much improvement, a less dangerous corridor might be selected that shows greater promise for improvement.

This method calculates the comprehensive costs of different types of crashes as outlined in Section 2.5.1.3 and then utilizes crash reduction factors (CRFs) to determine the magnitude of savings that could be realized by implementing a given countermeasure on a given segment of road.

In the state of Utah, Schultz and Lewis (2006) found that in three of six locations studied, the cost of constructing a raised median was recouped in less than one year. In two of the remaining locations, the capital costs were expected to be recouped in four and nine years, respectively.

2.5.2 Comparison to Critical Rates

Rose et al. (2005) recommends that crash rates for a given corridor be compared with rates in equivalent areas or with equivalent national rates. This method identifies potentially abnormal crash site areas relative to critical crash rates determined from existing data and trends. In addition to crash rates, other indicators such as severity scores, crash frequencies, or other indices discussed in further sections of this literature review can also be used.

Several methods exist for determining the critical rate or index. A predetermined percentage could be chosen. For example, an agency could determine that the locations with the top 10 percent of crashes are critical, so a critical rate is chosen so that 10 percent of locations will be above the critical rate. Alternatively, natural breaks in the range of crash rates could be found and a critical rate chosen where a break naturally occurs. Another method would be to arbitrarily assign a critical crash rate value based on tradition or other historical reasons (Hummer 2000). Statistical means can also be utilized to determine these critical rates as discussed in the next two sections.

2.5.2.1 Classical Statistical Method

The classical statistical method is a fairly objective method that utilizes statistics and assumes that the distribution of crash rates or other indices follow a standard normal distribution (Hummer 2000). The critical rate is calculated using Equation 2.3.

$$CR_{crit} = \bar{x} + (Z \times \sigma_s) \tag{2.3}$$

where: CR_{crit} = critical crash rate (or other index value),

$\bar{x}$ = mean crash rate (or other index value),

Z = Z-statistic corresponding to significance level, 1.645 for the 95 percent confidence level (upper tail only), and

σ_s = sample standard deviation.

Other levels of statistical significance can be chosen. Larger levels of statistical significance will include fewer “hazardous” locations than will lower levels of statistical significance.

2.5.2.2 Rate Quality Control Method

A similar method known as the rate quality control method (Hummer 2000, Gharaybeh 1991, FHWA 1981) can only be used for crash rates (not other index values), and it only compares a crash rate to those of similar road segments. Furthermore, the distribution of crash rates is assumed to follow a Poisson distribution, not a standard normal distribution as was the case with the classical statistical method. The rate quality control method is shown in Equation 2.4.

A variation of this method uses the crash rate of the road segment in question instead of the volume as shown in Equation 2.4 (Fricker and Whitford 2004). As with Equation 2.4, the crash rate of the road segment in question is still compared with the critical crash rate calculated to determine whether or not it is above the critical rate.

$$CR_{crit} = \bar{x} + Z\sqrt{\frac{\bar{x}}{V} + \frac{1}{2V}} \tag{2.4}$$

where: V = volume in MVMT (or MEV for intersections) of the location in question.

The setbacks to using the rate quality control method are the difficulty in finding similar locations and the need to recalculate the critical crash rate for every location in question.

2.5.3 Composite Indices

A composite index is a unitless index created by combining multiple indices or parts to create one composite index. The indices comprising the composite index can be weighted differently and can be obtained utilizing various methodologies, some of which have been discussed previously in this chapter. Several composite-type indices were found in the literature, and two of them are discussed in the following sections.

2.5.3.1 Michigan Safety Performance Index

Kar and Datta (2004) reported on a safety performance index for Michigan. Although this method was used to compare safety at a county-wide level, the principles of this method can be applied to the corridor or road segment level. In addition to crash frequency, exposure variables for this method included volume, population, and the number of registered vehicles. Based on the methodology developed by Kar and Datta (2004), the safety performance index value for a given location was calculated using Equation 2.5.

$$SPI = W_F + PRC + IRC + FRC + SRC \tag{2.5}$$

where: SPI = safety performance index,
W_F = weighted crash frequency,
PRC = PDO crash rate composite,
IRC = injury crash rate composite,

FRC	=	fatality crash rate composite, and
SRC	=	special focus crash rate composite.

The weighted crash frequency was calculated using Equation 2.6.

$$W_F = \frac{\left(w_1 \times N_p + w_2 \times N_i + w_3 \times N_f + w_4 \times N_s\right)}{1000} \tag{2.6}$$

where:

N_{PDO}	=	number of PDO crashes,
N_i	=	number of injury crashes,
N_f	=	number of fatal crashes,
N_s	=	number of "special focus" crashes, and
w_1, w_2, w_3, w_4	=	weighting factors.

The weighting factors (w_1, w_2, w_3, w_4) were given values of 1 for PDO crashes, 5 for injury crashes, 150 for fatal crashes, and 150 for special focus crashes. The method for obtaining these values is based on crash severity costs and is discussed in the literature (Kar and Datta 2004). These values are similar to those found in other studies outlined in Section 2.5.1.3.

Equation 2.7 shows how PRC is calculated. *IRC, FRC,* and *SRC* were calculated the same as *PRC* except with their respective crash frequencies.

$$PRC = \frac{\left(\dfrac{N_p}{P/1{,}000} + \dfrac{N_p}{RV/1{,}000} + \dfrac{N_p}{VMT/10{,}000{,}000}\right)}{3} \tag{2.7}$$

where:

P	=	population,
RV	=	number of registered vehicles, and
VMT	=	vehicle miles traveled.

The "special focus" category in this study referred to problems involving alcohol or lack of seatbelt use, as well as other specifically focused problems. The special focus crashes were given higher weights in order to determine locations with higher concentrations of these problems.

In summary, SPIs were calculated as a composite of several other calculations that were functions of population, number of registered vehicles, volume, and crashes. Areas with high SPIs were targeted for improvements.

2.5.3.2 Danger Index Composite Method

Gharaybeh (1991) summarized a method that determined a "danger index" by combining four different methods, including: 1) crash frequency, 2) crash rate, 3) crash seriousness (or severity), and 4) crash possibility (or rate quality control). The first three methods were summarized in Section 2.5.1, while the fourth method was summarized in Section 2.5.2.

Each site was ranked using each method individually. The four rankings were then added together to calculate the danger index as shown in Equation 2.8.

$$DI = R_F + R_R + R_S + R_{RC} \tag{2.8}$$

where:
- DI = danger index,
- R_F = rank using crash frequency method,
- R_R = rank using crash rate method,
- R_S = rank using crash seriousness method, and
- R_{RC} = rank using crash possibility method.

The lower the danger index, the more in need of improvement a site was determined to be. For example, a location that was ranked first in the categories of crash frequency, crash rate, crash severity score, and crash probability (i.e., it had the highest crash frequency, rate, severity score, and probability), would have a danger index of 4. This would be the worst location. Alternatively, a location with the lowest ranking for the above-mentioned criteria would have a very high danger index but would be considered the safest. While this method can be effective at comparing sites based on more than one criterion, the data for all locations must be known at the onset because the rankings are relative to one another.

2.5.4 Predictive Methods

The methods discussed in the following sections are those methods designed to predict future crashes as the basis for the indices.

2.5.4.1 Empirical Bayesian Model

The empirical Bayesian model is used to make estimates of crashes along corridors in the future (Persuad 1991). Because of a phenomenon known as regression-to-the-mean, using crash rates from the immediate past is not always a good estimator of future crash rates because of random variation in the number of crashes from year to year. An empirical study completed by Hauer and Lovell (1986) found that many locations with high numbers of crashes had lower numbers of crashes in preceding years, even though characteristics of the segments did not significantly change.

The empirical Bayesian model combines an estimate based on characteristics of the road, as well as actual observed past crash frequency, to predict a future number of crashes. Persuad (1991) showed that for a particular data set in Ontario, Canada, the empirical Bayesian model predicted future crashes much more precisely than past crash data or estimates based on road and traffic characteristics alone. Cheng and Washington (2005) conducted an experimental evaluation that showed that the empirical Bayesian model resulted in lower percentages of false-negative and false-positive identification of high-frequency crash locations.

An expected number of crashes using the empirical Bayesian methodology can be estimated using Equation 2.9 (Persuad 1991, Hauer et al. 2002).

$$N_p = w \times E\{N_p | T\} + (1 - w) \times x \qquad (2.9)$$

where:
- N_p = predicted number of crashes,
- w = weighting factor ($0 \leq w \leq 1$),
- T = set of traffic and/or geometric characteristics,
- x = observed crashes, and
- $E\{N_p | T\}$ = expected number of crashes, N_p, determined from regression analysis as a function of T.

The weighting factor, w, is determined by Equation 2.10. As the variance approaches zero, w becomes close to one. This causes the predicted value of crashes, N_p, to approach the expected value of crashes determined in $E\{ N_p \mid T\}$.

$$w = \frac{E\{N_p|T\}}{(E\{N_p|T\} + VAR\{N_p|T\})} \tag{2.10}$$

where: VAR = variance of N_p with respect to T.

2.5.4.2 Computer Simulation Method

Eisele and Toycen (2005) identified locations for possible safety improvements with the use of computer simulation. Characteristics were calculated for a given corridor, such as time-to-collision (TTC), which is the amount of time required for two vehicles to collide if their speeds and/or directions are not altered, and rate of deceleration, which is the rate of deceleration required by vehicles to avoid collisions. Locations that frequently exhibited low values of TTC were considered more dangerous because, as TTC decreases, the chance of drivers failing to avoid collisions theoretically increases. However, this method is limited to the accuracy of the simulation.

2.5.5 Subjective Safety Indices

While most of the methods for creating safety and performance indices discussed in the previous sections are fairly objective in nature, some subjective methods exist as well and are discussed in the following sections.

2.5.5.1 Pedestrian Safety Index

One subjective method for creating a safety index developed by Zegeer et al. (2006) analyzed pedestrian safety at intersections in three U.S. cities. Approximately 60 people were surveyed by allowing them to watch a 40-second video clip of a crosswalk at an intersection. The surveyors rated the crosswalk on a scale from 1 to 6 based on how likely they would choose to cross the street using that particular crosswalk. The mean ratings for each crosswalk were analyzed using linear regression with explanatory variables of type of control, number of through lanes, 85th percentile speed, main street volume, and land use type. Equation 2.11 was developed with an R-squared value of 0.83 to form a pedestrian safety index (I_p).

$$I_p = 2.3 - 1.9Sg - 1.8Stp + 0.34Lns + 0.018Spd + 0.006(V \times Sg) + 0.24LU_c \quad (2.11)$$

where:
- Sg = signal ($Sg = 1$ if signalized, otherwise $Sg = 0$),
- Stp = stop sign ($Stp = 1$ if stop controlled, otherwise $Stp = 0$),
- Lns = number of through lanes on street being crossed (both directions),
- Spd = 85th percentile speed of street being crossed in miles per hour (mph),
- V = volume in AADT for main street (in thousands), and
- LU_c = commercial land use ($LU_c = 1$ if adjacent land use is primarily commercial, otherwise $LU_c = 0$).

The higher the value of I_p, the more unsafe the crosswalk was reported to be. The regression was conducted with the ratings given by the observers as the dependent variables instead of crash statistics because Zegeer et al. believed that the number of crashes were too small to be significant (2006).

2.5.5.2 Decision Trees

Decision trees are tools utilizing a graphical approach to classify decisions based on their possible consequences, including chance event outcomes, resource costs, and utility (Wikipedia 2007, Haimes 2004). For example, decision trees have been utilized in pavement management to determine which preventative maintenance techniques should be used and when maintenance should occur based on characteristics of the road as well as predetermined goals for the facility (Wei and Tighe 2004). Effective decision trees should include enough information so that decision makers can make decisions without needing to do extra research.

Although decision trees can be subjective in nature, decision nodes and cutoff values can also be based on empirical data, thus making the decision trees more objective. One method to determine empirical values for decision trees relies on the procedure developed by Breiman et al. (1984) and is known as Classification and Regression Trees (CART). The computer program CART™ was developed using this statistical methodology to classify categorical data or use regression to classify continuous data with the use of decision trees (Steinberg and Colla 1997a). According to the CART™ program documentation, "CART's goal in a regression tree is to partition the data into relatively homogeneous (low standard deviation) terminal nodes…" (Steinberg and Colla 1997b). The use of CART™ for this research is discussed in Chapter 5.

2.5.6 Summary of Performance Indices

The previous sections outlined safety performance indices currently utilized, including standard crash history methods, methods using critical rates, composite indices, predictive methods, and subjective methods.

2.6 Summary of Literature Review

This chapter outlines currently utilized access management techniques and summarizes the impacts that access management has had on arterials in the state of Utah. The web-based crash almanac maintained by UDOT is also introduced. Finally, performance and safety indices utilized in various aspects of traffic and transportation engineering are summarized.

To begin the process of evaluating safety and developing a performance index for the state of Utah, a database compiled of arterial road segments in the state including their characteristics and crash histories was created. The following chapter discusses this database.

3 Facility Evaluation

The following sections describe a database of arterial roads that was compiled to summarize state routes in the urbanized areas of six counties in Utah. The database was comprised of 175 segments of 49 different state routes totaling 207 miles of arterial roads. The three major components of the database include: 1) identifying features of each road segment, 2) independent variables, and 3) dependent variables.

Section 3.1 discusses the methodology used to select the road segments. This is followed by a discussion of identifying features, independent variables, and dependent variables in Sections 3.2, 3.3, and 3.4, respectively. Included in these sections are the purposes for including each type of data as well as the methodology used to obtain the data contained in the three major components of the database. Section 3.5 summarizes the facility evaluation.

3.1 Selection of Road Segments

Principle and minor arterials located in six urbanized counties in Utah were divided into segments ranging from approximately one quarter mile to five miles long. The counties included Cache, Davis, Salt Lake, Utah, Washington, and Weber. The endpoints of the segments were determined by utilizing the UDOT *State Highway Access Category Inventory* (UDOT 2006a). Endpoints were selected such that each segment was comprised of roadway in only one access category. The various access categories are discussed in Section 2.2 and are shown again in Table 3.1 (UDOT 2003). Segments were also chosen such that the characteristics of each section were as homogeneous as possible throughout the entire segment of highway. For example, at the point a road changed from six lanes to four lanes, a new segment was created.

Table 3.1 UDOT State Highway Access Categories (UDOT 2003)

Category Assignment		Description
1	I	Interstate/Freeway
2	S-R	System Priority Rural
3	S-U	System Priority Urban
4	R-S	Regional Rural
5	R-PU	Regional Priority Urban
6	R-U	Regional Urban
7	C-R	Community Rural
8	C-U	Community Urban
9	O	Other

3.2 Identifying Features

The identifying-features portion of the database included descriptive data to uniquely differentiate the segments from one another. Data in this section included the state route number, the county in which the segment was located, the street name, and the mile post numbers of the beginning and end points. Descriptions of the endpoints were also given, consisting of cross streets or other landmarks (e.g., Bulldog Boulevard to University Parkway). Street names, cross streets, and city locations were identified using the web-based map program Google Maps (Google 2006).

Mile post numbers were obtained primarily using the UDOT web-based crash almanac by utilizing the "Points of Interest" utility located in the "Intersection" tab (Anderson et al. 2005). By inputting a state route number in the "Points of Interest" search, the number of crashes during the default years near every intersection was displayed. Each intersection was labeled with its respective mile post number. Further discussion on the UDOT web-based crash almanac is provided in Section 3.4. Additionally, mile post numbers could be cross-checked with those included in the *Traffic on Utah Highways: 2004* document (UDOT 2004), the UDOT *State Highway Access Category Inventory* (UDOT 2006a), as well as the web-based UDOT Road

Viewer program (UDOT 2006b). Mile post numbers matched in most cases to within one or two hundredths of a mile (or about 50 to 100 feet).

Figure 3.1 shows the breakdown of road segments from each county by percent, as well as the breakdown of road segments by county weighted by their lengths. Over 35 percent of the segments collected for the database were located in Salt Lake County. Most of the remaining locations were evenly distributed between Davis, Utah, and Weber counties, each containing approximately 15 to 20 percent of the segments. Segments in Cache and Washington counties only accounted for less than 10 percent of the data collected. Weighted by length, Salt Lake County accounted for almost 10 percent more of the data, while the remaining five counties accounted for slightly less, meaning that, on average, segments in Salt Lake County tended to be longer than in other counties. The identifying-features portion of the road segments is found in Appendix A.

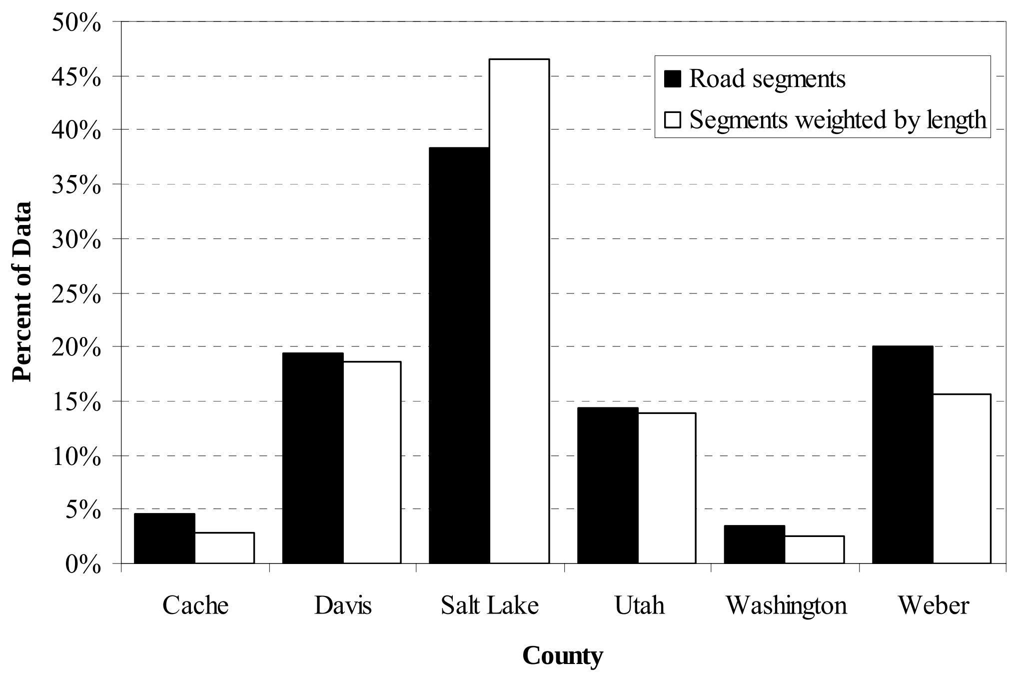


Figure 3.1 Percent of road segments located in each county.

3.3 Independent Variables

Independent variables, or explanatory variables, include those characteristics of the road segments that have possible correlation with the safety or operational characteristics of the roadway (or dependent variables). It was important to consider as many characteristics as possible at the onset to be able to properly account for any variables influencing the crash histories of the segments. Independent variables collected in this database included length, access category, number of lanes, median type, orientation, adjacent land use, posted speed limit, access density, AADT, and signals per mile. The following sections discuss the purpose for including each variable, the methodology used in obtaining each of the characteristics, and the range of data collected.

3.3.1 Length

The length of each section was obtained to determine the crash rate for each segment. The length can also be used to weight each segment to ensure that shorter sections do not skew the analysis because of abnormally low or high crash rates or other characteristics. Length was determined by calculating the difference between beginning and ending mile post numbers. Mile post numbers were obtained using the methodology described in Section 3.2.

Figure 3.2 shows the distribution of the road segments in percent by their lengths. Over 45 percent of the road segments in the database were between 0.5 and 1.5 miles long. However, almost 25 percent of the segments were less than 0.5 miles long, and more than 25 percent of the road segments were longer than 1.5 miles. The large variability in length shows the importance of weighting the segments by length.

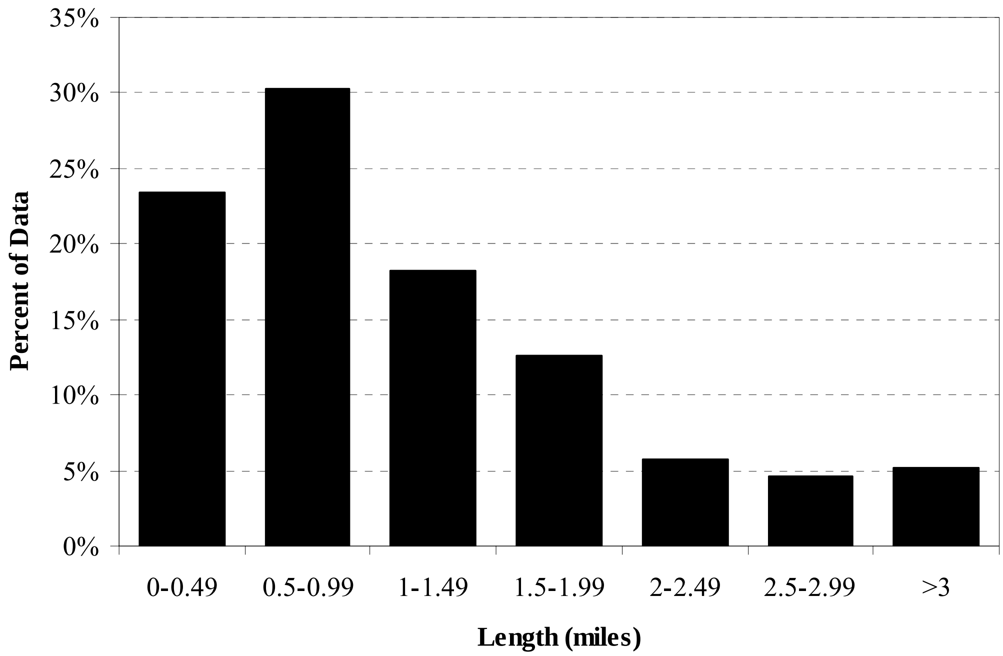


Figure 3.2 Percent distribution of road segments by length.

3.3.2 Access Category

The access management requirements and standards for a given portion of state highway in Utah are defined through the use of access categories. These categories were discussed previously in Sections 2.2 and 3.2. The access category for each road segment was obtained using the UDOT *State Highway Access Category Inventory* (UDOT 2006a).

Figure 3.3 shows the distribution of the road segments in percent by access category. The distribution weighted by length is also shown. The majority (approximately 70 percent) of the road segments were “Regional Priority Urban” highways. Approximately 20 percent of the road segments were “Regional Urban” highways. Less than 10 percent of the road segments were “System Priority Urban” highways, while less than 5 percent of the road segments were “Community Urban” highways.

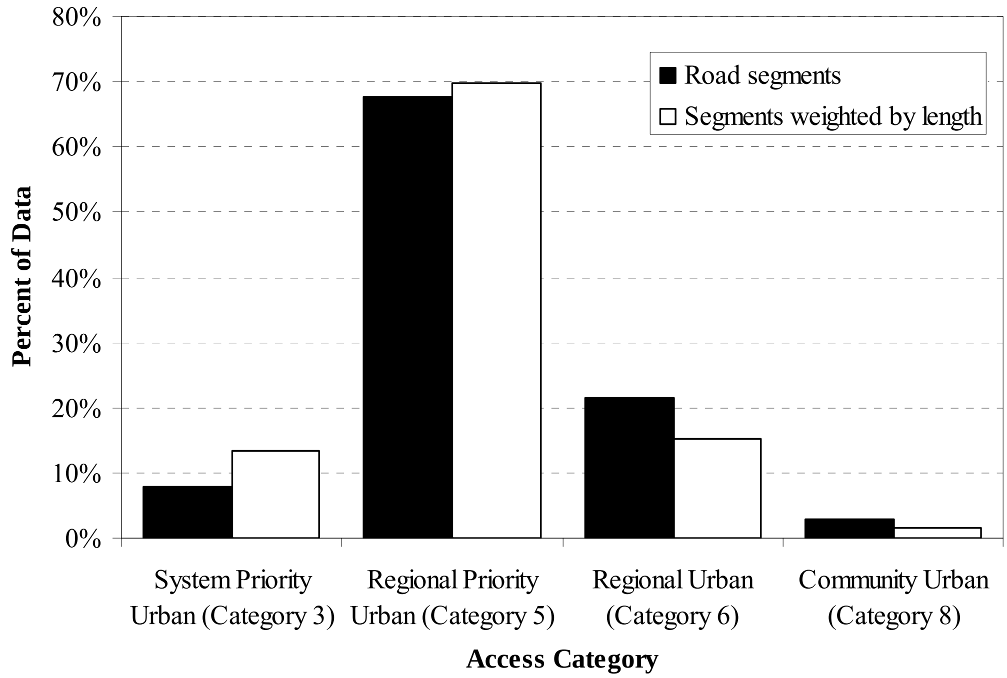


Figure 3.3 Percent distribution of road segments by access category.

3.3.3 Number of Lanes

The number of lanes within each road segment was included in the database to determine whether or not the number of lanes affected the safety of the road and to estimate the volume per lane. At unsignalized intersections and driveways, longer gap times are required to safely cross, turn left into, or turn left out of access points when more lanes are present. However, it is also possible that more lanes provide the ability for vehicles to avoid mid-block collisions by providing more through lanes to avoid conflicts with turning vehicles. The number of lanes for each segment in the database was determined by viewing the satellite images of the roads using Google Maps (Google 2006). Only through travel lanes were included (i.e., no TWLTLs, turning lanes, or parking strips were counted as lanes).

Figure 3.4 shows the distribution of the road segments in percent by the number of through lanes. The distribution weighted by length is also shown. Over 50 percent of road segments collected were four-lane roads. Approximately 30 percent of the sections were two-lane roads while, 10 percent were six-lane roads. A few road segments with three, five, and eight lanes were also contained in the database. Figure 3.4 shows that the distributions are fairly even between percentages of road segments and percentages of road segments weighted by length, meaning that, on average, none of the different categories of numbers of lanes had unusually long or short lengths.

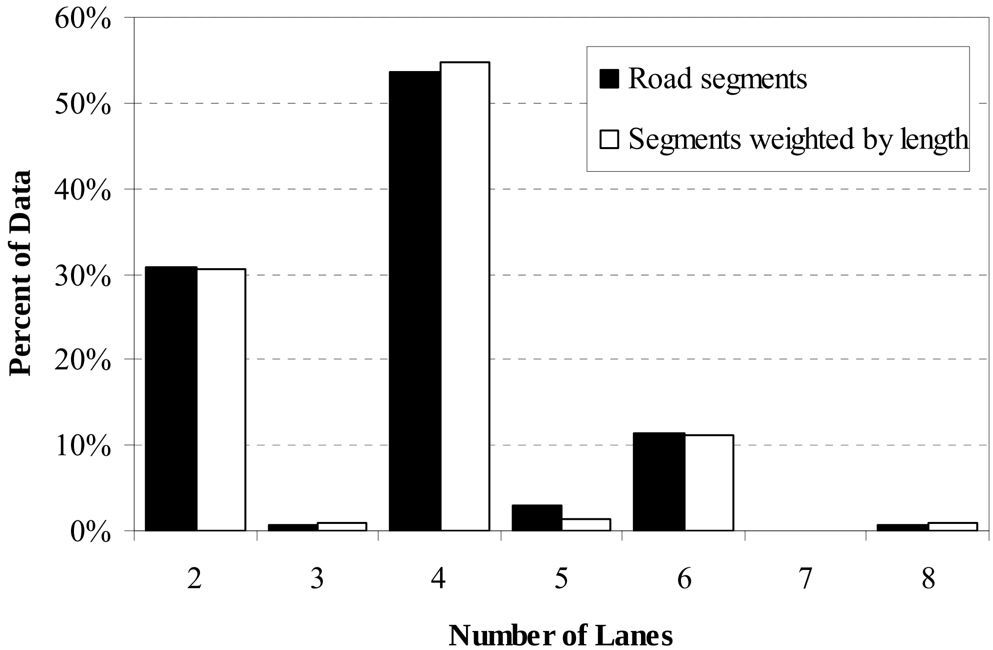


Figure 3.4 Percent distribution of road segments by number of lanes.

3.3.4 Median Type

Because the focus of this report was identifying road segments that can likely be improved using access management techniques, a key characteristic of each road segment was the type of median present. This characteristic is fundamental because it represents an access management treatment that can be implemented as a retrofit. Each road segment was viewed using the satellite imagery from Google Maps (Google 2006) to determine whether the segment had no median (i.e., undivided), a TWLTL, or a raised median. A fourth option was that the road segment was a divided highway, but these sections were counted as having raised medians. In addition to Google Maps, UDOT

Road Viewer imagery (UDOT 2006b) was used to confirm the median types during the analysis periods.

A road segment was allowed to have more than one median type if significant portions of the segment had different median types but was mixed too frequently to allow for dividing the initial segment into smaller segments. One example of this was SR 266 (4500 South) between State Street (SR 89) and 900 East in Salt Lake City. Although this road has a TWLTL, it also has raised medians near some of the intersections. However, splitting up this segment would result in very short segments. Therefore, this section of road was coded as having a TWLTL and a raised median.

Figure 3.5 shows the distribution of the road segments in percent by the type of median present. The distribution weighted by length is also shown. Over 70 percent of urban arterial state roads in Utah that were analyzed had TWLTL medians. Approximately 20 percent of roads analyzed were undivided, while only 10 percent had raised medians. Because some segments had more than one type of median, the percentages in Figure 3.5 add up to slightly more than 100 percent. The distribution of road segments weighted by length is very similar.

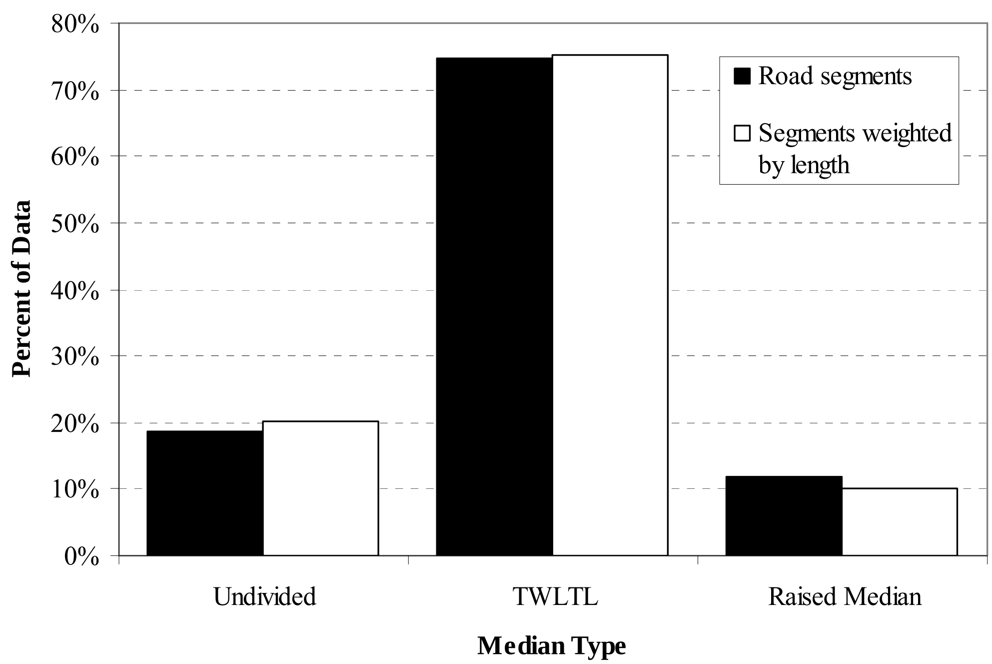


Figure 3.5 Percent distribution of road segments by median type.

3.3.5 *Orientation*

Most of the state roads analyzed were oriented from north to south or from east to west. A road segment's orientation was included to determine whether a difference in safety existed between the two types of orientation. If so, the orientation would serve as a confounding variable and need to be accounted for when estimating the safety of a given road segment. For example, drivers traveling east or west could be more susceptible to crashes because of decreased vision due to the sun rising or setting, respectively. The orientation of each segment was determined by viewing Google Maps (Google 2006). Segments not oriented east/west or north/south (e.g., northeast/southwest or northwest/southeast) were assigned as "other."

Figure 3.6 shows the distribution of the road segments in percent by orientation. The distribution weighted by length is also shown. Approximately 85 percent of the road segments had north/south or east/west orientations. This is intuitive, as much of urbanized Utah is laid out in a grid pattern. Also, the north/south segments were, on average, longer than the east/west segments.

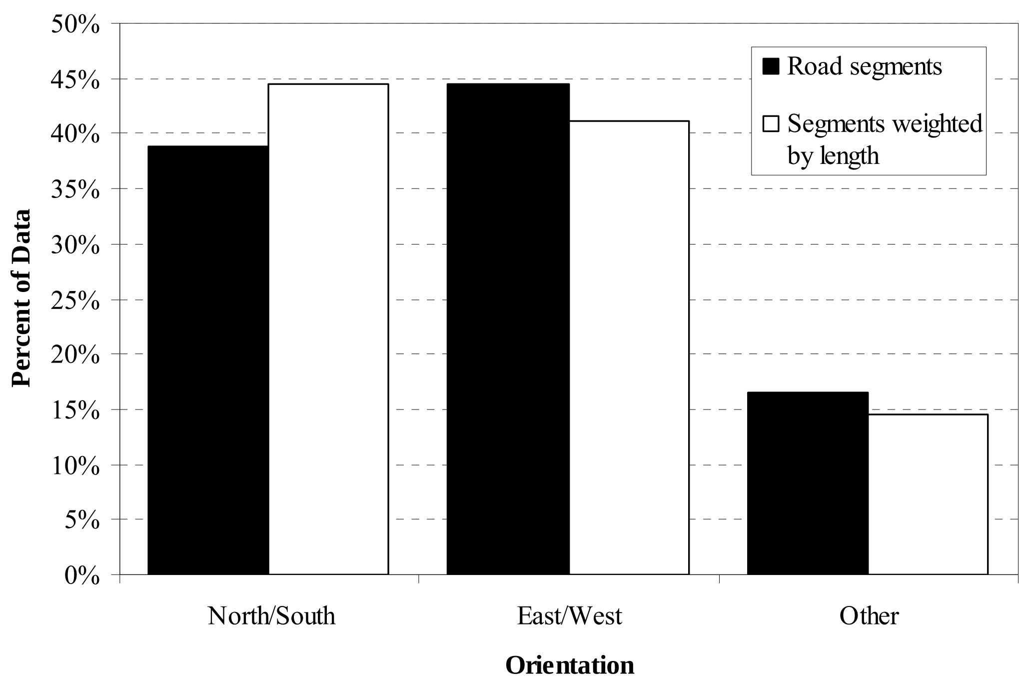


Figure 3.6 Percent distribution of road segments by orientation.

3.3.6 Adjacent Land Use

Adjacent land use affects the total volumes of vehicles that ingress and egress at access points along an arterial. The more vehicles that need to ingress or egress into or from a given driveway, the more potential exists for crashes. Because measuring these volumes for every driveway along every road segment analyzed would have been difficult, land use was used as a predictor of these volumes. For example, an arterial that had residential land use adjacent to it, especially single family dwelling units, would have had very high access density. Simply analyzing the road using the high access density as a predictor for crashes would have greatly overestimated the crash potential because residential driveways have very low volume. On the other hand, a commercial area with equivalent access density would have had much more volume present at the driveways, thus creating higher potential for crashes.

Each segment was assigned a predominant land use type using satellite imagery from Google Maps (Google 2006) as well as images from the UDOT Road Viewer program (UDOT 2006b). Possible land use types included commercial, residential, industrial, and agricultural. Because industrial and agricultural land use types comprised a relatively small portion of the data, and for simplicity in analysis, industrial and commercial land uses were combined into one land use type, and residential and agricultural land uses were combined to form a second land use type. Segments were allowed multiple land use types in areas with mixed land use.

Figure 3.7 shows the distribution of the road segments in percent by adjacent land use. The distribution weighted by length is also shown. The totals in Figure 3.7 do not add up to 100 percent because some road segments were adjacent to mixed land uses and were therefore assigned to more than one land use type. Over 60 percent of the road segments were adjacent to commercial land use. Almost 50 percent were adjacent to residential land use. Industrial land use accounted for approximately 10 percent of the road segments, while agricultural land use adjacent to the roadway accounted for less than 10 percent of the road segments. However, residential, industrial, and agricultural land uses all tended to have longer segments as is evident by their distributions being higher when weighted by length. Adjacent commercial land use tended to have shorter sections.

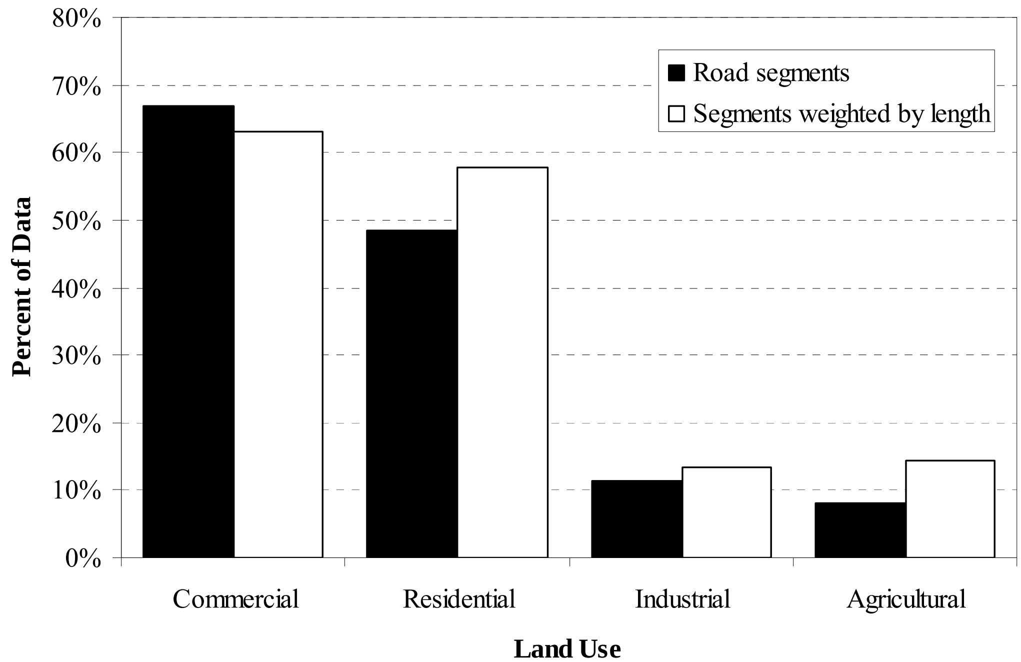


Figure 3.7 Percent distribution of road segments by adjacent land use.

3.3.7 Posted Speed Limit

While it is generally understood that speed plays a critical role in the severity of crashes, it is less apparent as to whether or not the posted speed limit on a given road segment affects the frequency or severity of crashes. However, because some correlation between speed limit and safety is likely, it is included as a possible independent variable.

Posted speed limits were obtained using the UDOT Road Viewer program (UDOT 2006b). While many changes in speed limit occurred at borders of access categories, and therefore at borders of the road segments, some speed limits did change within the segments themselves. When this occurred, both speed limits within the segment were recorded and averaged together. While this may not have been a precise indicator of the posted speed limit over a given segment, its purpose was only to be a general estimate of speeds in the segment since actual travel speeds were not being measured. Posted speed limit was the most difficult data to obtain for the road segments using the UDOT Road Viewer program and, consequently, the database was missing the speed limit data for some of the road segments.

Figure 3.8 shows the distribution of the road segments in percent by speed limit. The distribution weighted by length is also shown. Over 35 percent of the road segments had speed limits of 40 mph. Over 25 percent had speed limits of 45 mph. Close to 20 percent had speed limits of 35 mph. Figure 3.8 shows a fairly even distribution of speeds at around 25 to 35 percent each after weighting the segments by length. Speeds on the low and high ends accounted for less than 10 percent each of the road segments.

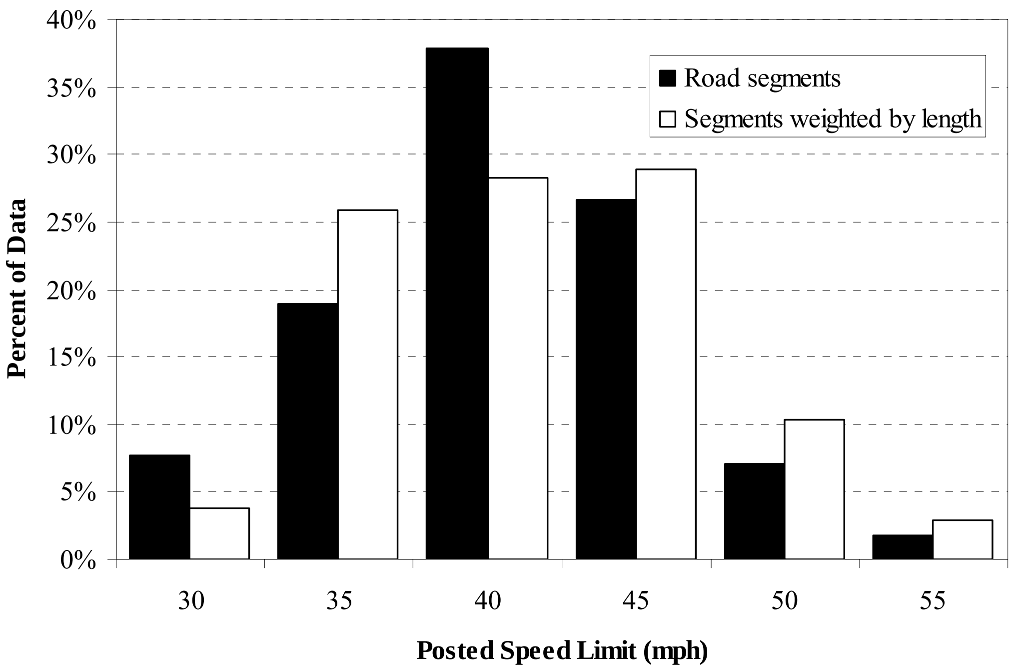


Figure 3.8 Percent distribution of road segments by posted speed limit.

3.3.8 Access Density

Access density served as a critical estimate of potential crashes because it measured the "friction" experienced along the arterial. As discussed in the literature, higher access densities correlate with higher crash rates (Gluck et al. 1999). As with median types, this variable had to be included, as it was directly related to access management.

Satellite imagery from Google Maps was inadequate in most cases to accurately count access points due to poor resolution at the levels needed to count driveways and due to the presence of trees blocking the satellite images. However, the UDOT Road Viewer program (UDOT 2006b) provided fairly clear images of the sides of the roads, allowing the number of driveways to be counted. Because of shadows and the angle of the pictures, the number of driveways counted could still only be considered as an estimate. More accurate counts would have required physically driving along each route. Because driveway density changes over time due to new developments and because of the impracticality of driving every state road, the UDOT Road Viewer estimates were considered adequate. Every attempt was made to use UDOT Road Viewer data from the same year as one of the analysis years. In most cases this was either 2002 or 2004. Google Maps (Google 2006) was utilized to count the number of cross streets, and the UDOT web-based crash almanac (Anderson et al. 2005) was utilized to count the number of signalized intersections. Access density was calculated as the sum of all driveways and streets divided by the segment's length as shown in Equation 3.1.

$$AD = \frac{NAP}{L} \tag{3.1}$$

where: AD = access density (access points per mile),

NAP = number of access points, and

L = length of road segment (miles).

Figure 3.9 shows the distribution of the road segments in percent by access density. The distribution weighted by length is also shown. Figure 3.9 shows a very even distribution of access densities for the road segments collected. Approximately 80 percent of the segments had access densities between zero and 80 access points per mile. The distribution was not as even for road segments over 80 access points per mile. Less than 15 percent of the road segments had between 80 to 100 access points per mile, and approximately 5 percent of the road segments had more than 100 access points per mile. Very few segments had more than 100 access points per mile, as that corresponded to approximately 100-foot spacing. Approximately 75 percent of the road segments with over 100 access points per mile corresponded to residential adjacent land use where driveways to single family dwellings were closely spaced.

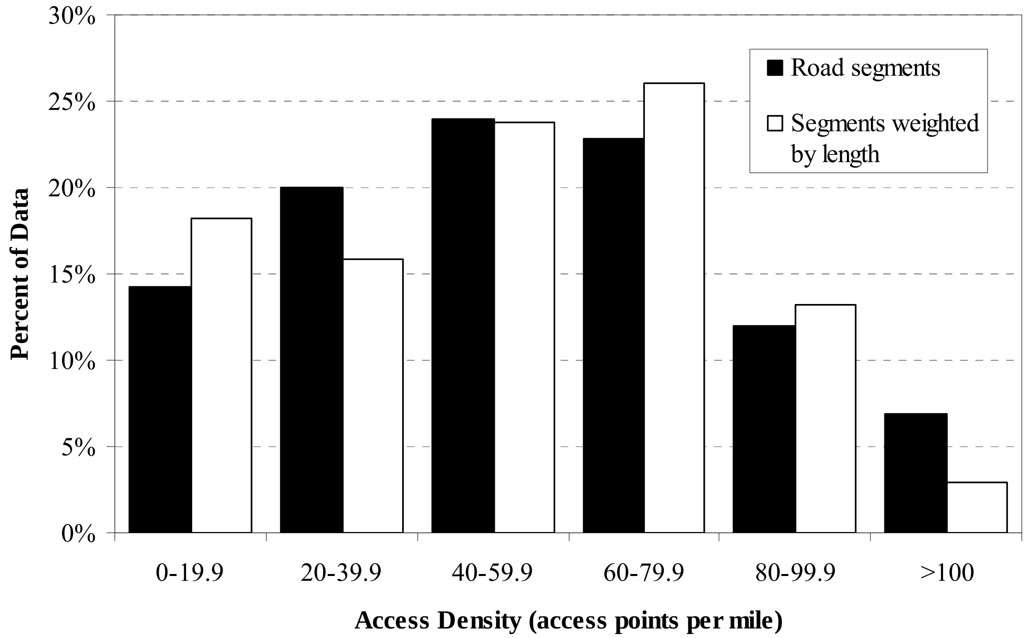


Figure 3.9 Percent distribution of road segments by access density.

3.3.9 AADT

AADT is necessary data to collect because it is needed to calculate the crash rate as will be discussed in Section 4.2. Using AADT is an accepted method for "normalizing" crash counts along road segments because the more vehicles that travel on a given segment, the more crashes will likely occur due to the added exposure of additional vehicles.

AADT values for the study corridors were obtained from *Traffic on Utah Highways: 2004* (UDOT 2004). This document contains AADT for each year from 2002 to 2004 for all state routes and is broken down by sections. A weighted mean was calculated for each road segment that contained more than one AADT section using Equation 3.2 (Schultz and Lewis 2006). The weighted averages for each time period were averaged to obtain an AADT value for each road segment for the entire time period.

Figure 3.10 shows the distribution of the road segments in percent by AADT. The distribution weighted by length is also shown. The majority of road segments collected for the database had AADT values between 10,000 and 30,000 vehicles per day (vpd). Approximately 30 percent were between 10,000 and 20,000 vpd, and almost 35 percent were between 20,000 and 30,000 vpd. Over 15 percent of the road segments had AADT values between 30,000 and 40,000 vpd. Approximately 10 percent were less than 10,000 vpd, and approximately 10 percent had AADT greater than 40,000 vpd.

$$AADT_{wt} = \frac{(AADT_1 \times L_1) + (AADT_2 \times L_2) + \ldots + (AADT_n \times L_n)}{L_1 + L_2 + \ldots + L_n} \tag{3.2}$$

where: $AADT_{wt}$ = weighted AADT for entire segment,

$AADT_n$ = AADT of each individual AADT section,

L_n = length of each individual AADT section, and

n = total number of AADT sections in segment.

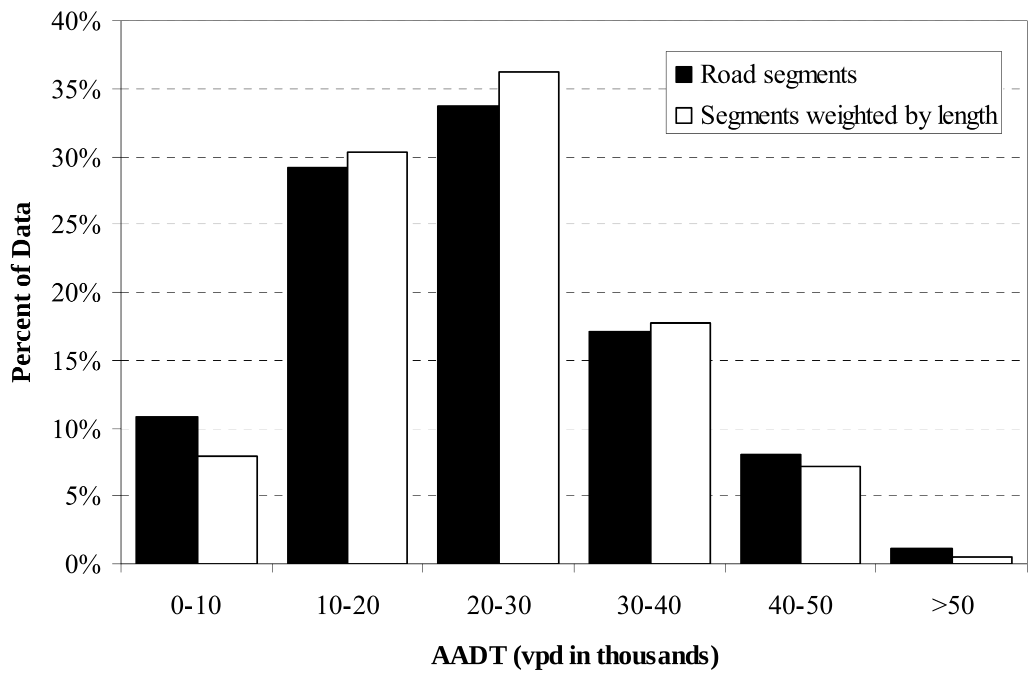


Figure 3.10 Percent distribution of road segments by AADT.

3.3.10 Signal Spacing

Signal spacing is an important characteristic of a road segment because arterials with optimum signal spacing generally provide more efficient and safer progression of traffic. Signal spacing can also be a confounding variable that must be identified to explain higher crash rates due to the presence of multiple large intersections. Signals per mile was calculated for each road segment by dividing the number of signalized intersections by the segment length as shown in Equation 3.3.

$$SPM = \frac{N_S + EP}{L} \tag{3.3}$$

where:
- SPM = signals per mile,
- N_S = number of signals within the segment (not including endpoints), and
- EP = endpoint condition (EP = 1 if both ends had a signal, EP = 0.5 if only one end had a signal, and EP = 0 if neither end had a signal).

Figure 3.11 shows the distribution of the road segments in percent by signals per mile. The distribution weighted by length is also shown. Over 50 percent of the road segments had fewer than 2 signals per mile. Additionally, almost 30 percent of road segments had between 2 and 4 signals per mile. Less than 20 percent of road segments had more than 4 signals per mile, which corresponds to a signal spacing of less than one quarter mile. Figure 3.11 also shows that those segments with short signal spacing (i.e., over 4 signals per mile) tended to have shorter lengths, while those segments that had longer signal spacing tended to be longer segments. This supports the need to weight the data by length because segments with inadequate signal spacing would have had a larger effect on the analysis than they would have had if they were not weighted.

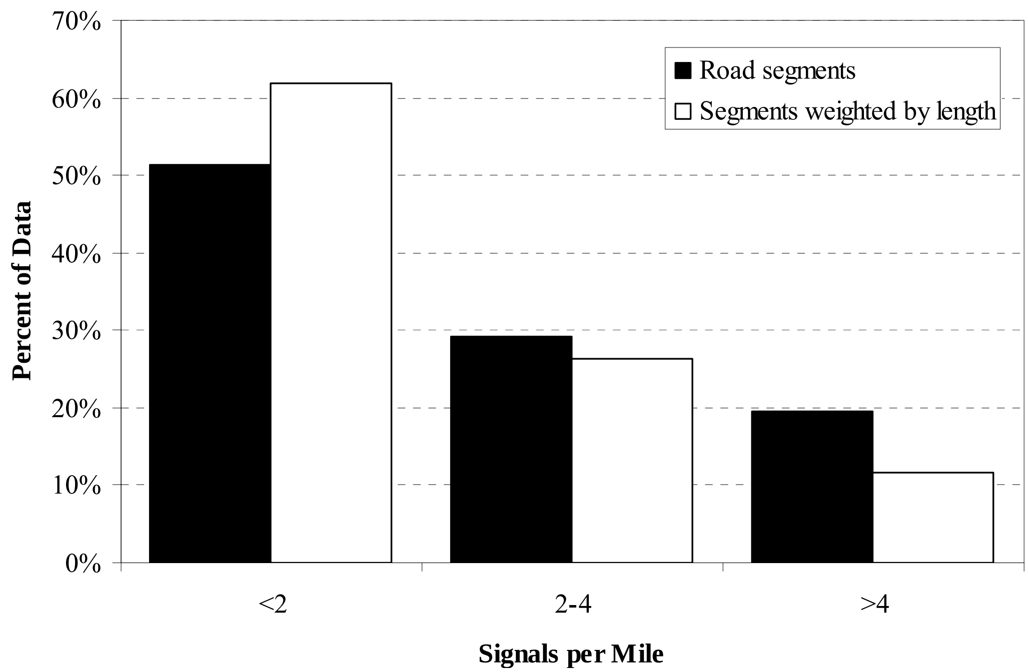


Figure 3.11 Percent distribution of road segments by signals per mile.

3.3.11 Correlation of Independent Variables

Because of the large number of independent variables identified in the database, correlation coefficients were calculated for each pair of variables to determine if the use of any variable was redundant. A correlation coefficient is a dimensionless number between negative one and one (inclusive) that describes the degree of linear association between a paired set of data. A value close to positive or negative one indicates high linear association, while a value close to zero indicates more random association. Table 3.2 shows the correlations between all of the independent variables collected.

None of the independent variables showed substantially high positive or negative correlation to each other. The closest correlation coefficient to positive or negative one occurred between the categorical variables for TWLTL and undivided median treatments and was only a value of -0.69, which is shown in bold-face font in Table 3.2 for emphasis.

The characteristics of all of the road segments that have been discussed in this section are located Appendix B and Appendix C. Appendix B contains all of the characteristics except for median type and land use, which are contained in Appendix C.

Table 3.2 Correlation between Independent Variables

	Lanes	**Speed**	**Length**	**Raised Medians**	**TWLTL**	**Undivided**	**Commercial**	**Residential**	**Access Density**	**Signals/mile**	**AADT**
Lanes	1.00										
Speed	0.09	1.00									
Length	-0.01	0.35	1.00								
Raised Medians	0.46	-0.07	-0.06	1.00							
TWLTL	0.15	0.13	0.02	-0.43	1.00						
Undivided	-0.55	-0.08	0.05	-0.18	**-0.69**	1.00					
Commercial	0.36	-0.13	-0.08	0.10	0.34	-0.43	1.00				
Residential	-0.34	0.11	0.26	-0.13	-0.15	0.28	-0.47	1.00			
Access Density	-0.07	-0.38	-0.12	-0.18	0.17	-0.05	-0.02	0.26	1.00		
Signals/mile	0.52	-0.29	-0.28	0.39	0.00	-0.35	0.39	-0.46	-0.02	1.00	
AADT	0.66	0.03	0.01	0.25	0.18	-0.42	0.31	-0.34	0.02	0.48	1.00

3.4 Dependent Variables

Dependent variables, or response variables, include those characteristics of a road segment that were believed to be the result of the various roadway characteristics identified in Section 3.3. While a precise cause-and-effect relationship may not be known, a correlation can be shown between various characteristics of the data and the dependent variables. The dependent variables obtained for this database included the number of crashes aggregated by severity and collision type over a three-year period. Three years worth of data was recognized by Cheng and Washington (2005) to be the optimal amount of time to conduct safety analysis studies because it is long enough to average out random fluctuations likely to occur in short periods of time, but short enough to generally exclude consideration of data due to other changes to the road segments that occur over time, such as volume, land use, and demographic changes. Hanley et al. (2000) also recommend three years.

Dependent variables collected for this database included over 28,800 crashes that occurred on the road segments over the three-year study period. These crashes were aggregated by severity and collision type. The following sections discuss the methodology for collecting the two types of crash data.

3.4.1 Crashes by Severity

Crash severity refers to the severity corresponding to the most severe injury of all those resulting from a given crash. According to the National Safety Council, "there are five mutually exclusive categories of injury severity for classification of road vehicle accidents" (1996). The five categories are fatal accident, incapacitating injury accident, non-incapacitating evident injury accident, possible injury accident, and non-injury accident. A common abbreviation for these severity levels is referred to as the KABCO scale, with each letter, "K" through "O", representing fatal through non-injury levels of severity, respectively. In Utah, slightly different language is used to define these severity levels. Table 3.3 summarizes the descriptions of the severity levels according to the KABCO scale, UDOT (Anderson et al. 2005), and other descriptions.

Table 3.3 Crash Severity Terminology

	National Safety Council	Utah	Other Descriptions
K	Fatal	Fatal	Killed
A	Incapacitating injury	Broken bones or bleeding wounds	Major injury
B	Non-incapacitating evident injury	Bruises and abrasions	Minor injury
C	Possible injury	Possible injury	Unknown injury
O	Non-injury	No injury	Property damage only (PDO)

The five severity classifications are mutually exclusive because a crash is classified based on the most severe injury (e.g., a crash with a fatality and a minor injury is classified as a fatal crash, not a fatal crash and a minor injury crash). The following section discusses the methodology for tabulating crashes by severity.

3.4.1.1 UDOT Web-Based Crash Almanac

Crashes were tabulated by severity utilizing the UDOT web-based crash almanac (Anderson et al. 2005). First, filters were created selecting state routes to be analyzed during the analysis years of 2002 to 2004. The "Accidents" item was chosen from the drop-down menu in the upper right-hand corner of the screen, and then the "Filters" tab was selected. The "Create a Filter" button was clicked, bringing up a Filter Creator window as shown in Figure 3.12.

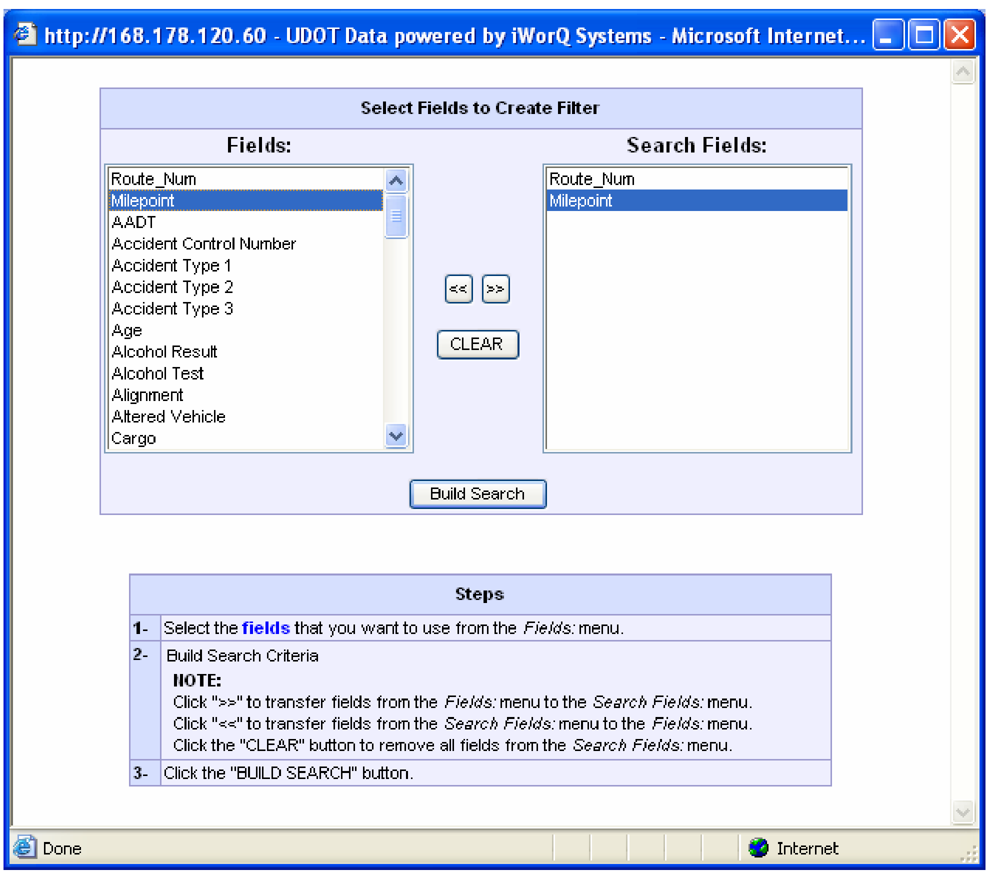


Figure 3.12 Filter Creator window.

The "Route_Num" and "Milepoint" fields were then selected and the "Build Search" button clicked. This opened another window allowing the filter to be named and the range of years, route number, and beginning and ending mile points to be selected. A filter was created in this manner for every state route analyzed.

Next, an "Advanced Search" was completed for each state route by using the filters previously created and selecting the appropriate crash severity. The "Advanced Search" tab was selected, thereby opening an Advanced Search window. The "Severity" field was selected, bringing up the Search window shown in Figure 3.13.

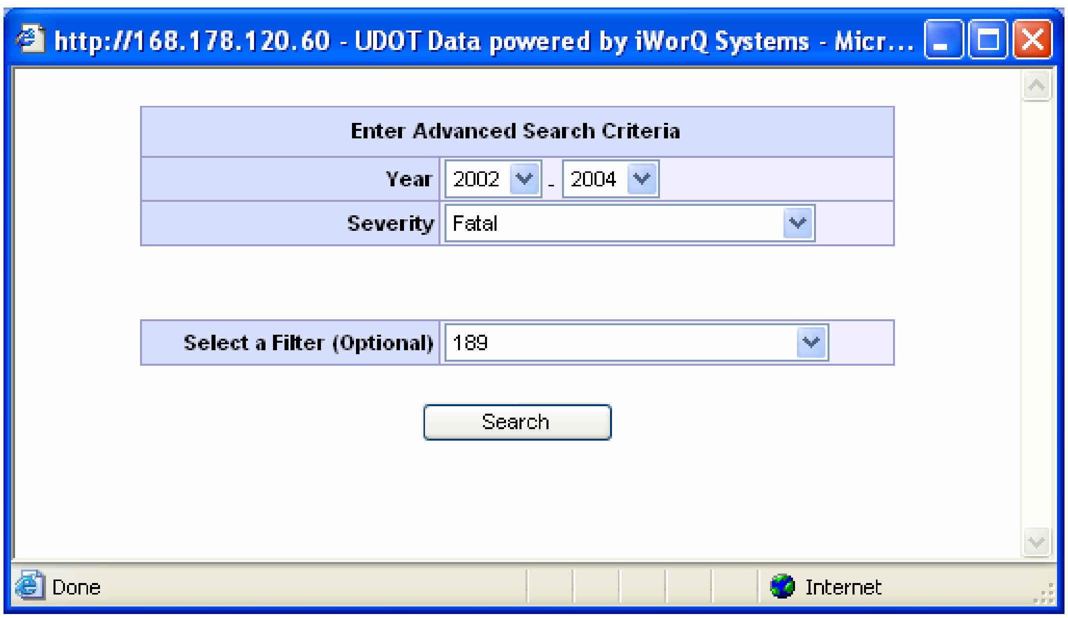
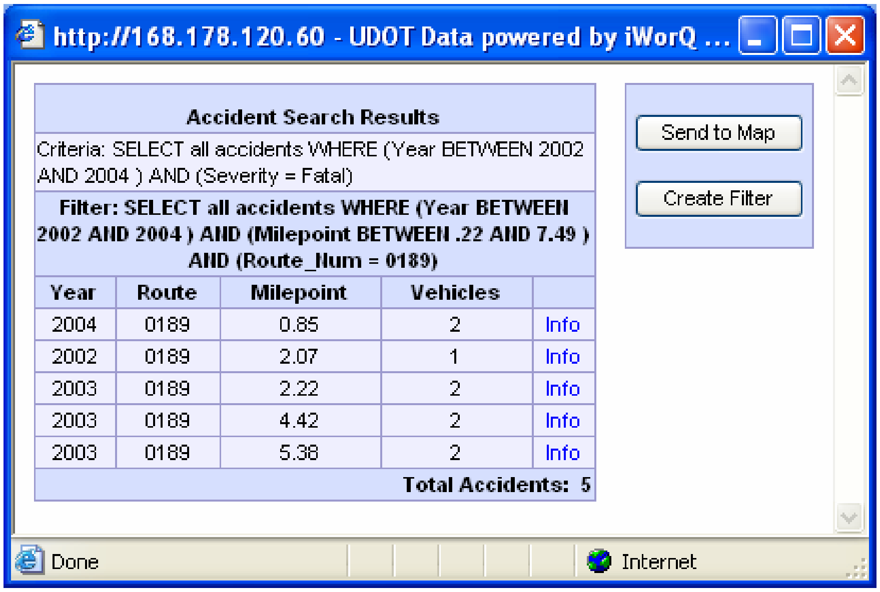


Figure 3.13 Search window showing "Fatal" and SR-189 selected.

After clicking the "Search" button, a window opened showing all crashes of the selected severity on the given route in the given time frame. Figure 3.14 shows a sample results window for fatal crashes on SR-189 in Provo, Utah. As is shown in Figure 3.14 five fatal crashes occurred on SR 189 between 2002 and 2004. The mile point of each crash and the number of vehicles involved is displayed. The window also contains links to more information about each crash.


http://168.178.120.60 - UDOT Data powered by iWorQ ...

Accident Search Results

Criteria: SELECT all accidents WHERE (Year BETWEEN 2002 AND 2004) AND (Severity = Fatal)

Filter: SELECT all accidents WHERE (Year BETWEEN 2002 AND 2004) AND (Milepoint BETWEEN .22 AND 7.49) AND (Route_Num = 0189)

Year	Route	Milepoint	Vehicles	
2004	0189	0.85	2	Info
2002	0189	2.07	1	Info
2003	0189	2.22	2	Info
2003	0189	4.42	2	Info
2003	0189	5.38	2	Info
			Total Accidents:	5

Send to Map

Create Filter

Done

Internet

Figure 3.14 Results window for a crash severity search showing fatal crashes on SR-189 between 2002 and 2004.

Data from each results window was selected and copied into an Excel spreadsheet and was saved for further analysis. This was done for each of the five severity levels: “no injury,” “possible injury,” “bruises and abrasions,” “broken bones and bleeding wounds,” and “fatal.”

For each severity, the crashes that occurred within the appropriate range of mile post markers for each road segment were then summed. This process was repeated for each state route analyzed.

3.4.1.2 Results of Crash Severity Search

The outcome of the process outlined in the previous subsection was the total number of crashes for each of the five severity levels over the three-year period for each road segment. The crashes by severity for each road segment are reported in Appendix D, and their distribution is summarized in Figure 3.15.

Almost 60 percent of crashes that occurred on the road segments were “no injury” crashes. Additionally, close to 30 percent of all crashes were categorized as “possible injury” crashes. Less than 10 percent were “bruises and abrasions” crashes, and approximately 5 percent were more serious injury crashes involving “broken bones or bleeding wounds." Of the road segments examined, 59 crashes were fatal, accounting for less than 0.25 percent of all crashes. Injury crashes as a whole, however, still accounted for close to 15 percent of all crashes, justifying the need to reduce the severity of crashes.

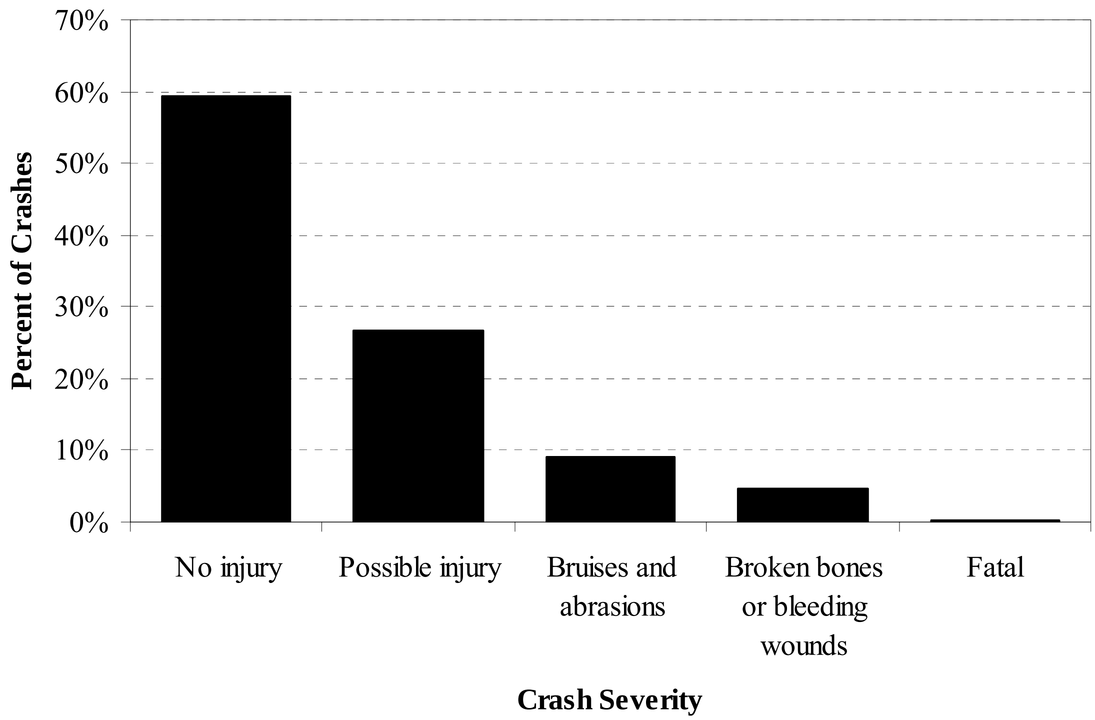


Figure 3.15 Percent of crashes by crash severity.

3.4.2 Crashes by Collision Type

Crashes by collision type were tabulated using the same procedure used to obtain crashes by severity that was outlined in Section 3.4.1.1, except the Advanced Search was done with collision type instead of severity. Because 25 different classifications of collision types exist under UDOT's system (Anderson et al. 2005), the collision types were consolidated into one of seven categories as shown in Table 3.4.

Figure 3.16 shows the percentage of crashes in the database that were in each category. Despite the relatively low number of injury crashes discussed in the previous section, almost 40 percent of all crashes that occurred on the road segments were right-angle crashes. However, the most common type of crashes were rear-end crashes, accounting for almost 45 percent of all crashes. All other collision types were relatively low, including same-direction side-swipe crashes and single-vehicle crashes that accounted for 5 and 7 percent of the crashes, respectively. Less than 1 percent of the crashes were opposite-direction crashes including side-swipe and head-on collisions. Detailed information on crashes by collision type for each road segment are contained in Appendix E.

Table 3.4 Collision Categories

Collision Categories	**UDOT Types of Collisions**
Right-Angle	Opposite directions, one vehicle straight, one vehicle turning left Both vehicles straight, approaching at an angle One vehicle straight, one coming from right turning right One vehicle straight, one coming from left turning left One vehicle straight, one come from right turning left Opposite directions, both vehicles turning left Approaching at an angle, both vehicles turning left Opposite directions, one turning left, one turning right One vehicle straight, one coming from left turning right Approaching at an angle, one turning left, one turning right
Rear-End	Same direction, both vehicles straight Same direction, one vehicle straight, one turning right Same direction, one vehicle straight, one turning left
Side-Swipe	Same direction, both straight, side swipe
Opposite-Direction	Opposite direction, both straight, side swipe Opposite directions, both vehicles straight
Single-Vehicle	Single vehicle
Other	Same direction, one vehicle straight, one turning right Same direction, one vehicle straight, one turning left Same direction, both vehicles turning left Same direction, both vehicles turning right Same direction, one vehicle turning left, one vehicle turning right One vehicle straight, one vehicle making a U-turn Backing

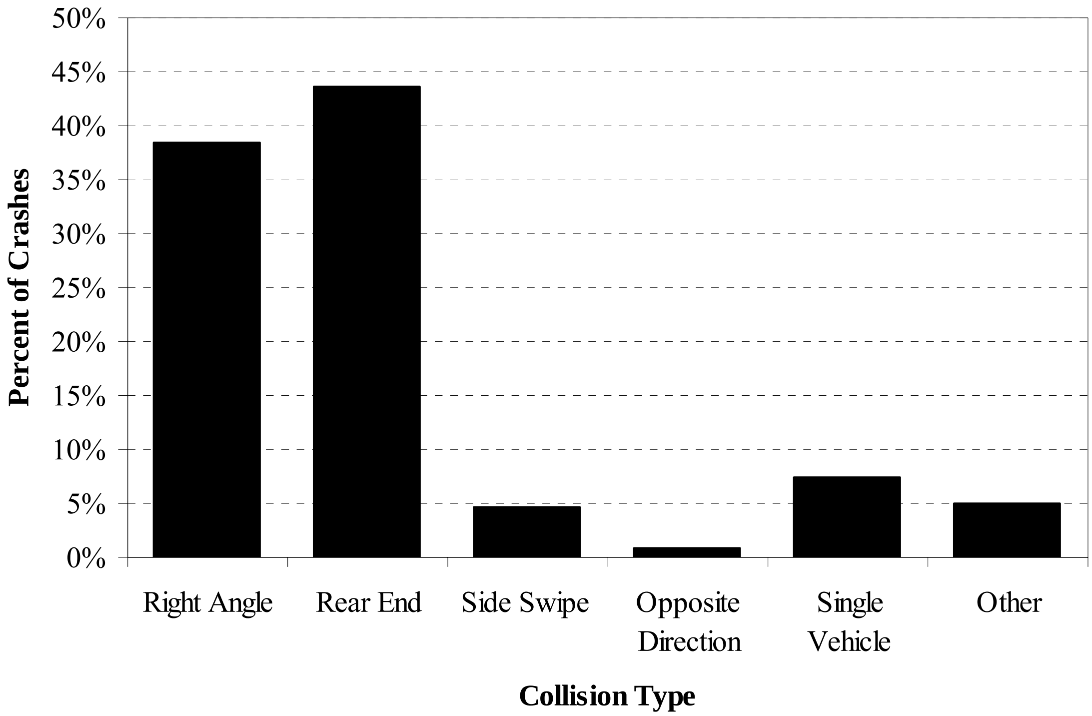


Figure 3.16 Percent of crashes by collision type.

3.5 Summary of Facility Evaluation

This chapter shows which data were collected to form a database of arterial segments of state roads in Utah. Data included identifying features, characteristics of each segment (independent variables), and crash histories (dependent variables). The methodology used to obtain these data, as well as the distribution of these data, is described.

The following chapter outlines statistical analyses performed on the data to correlate characteristics of the roadway and the crash histories obtained and discussed in this chapter.

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4 Safety Evaluation

The facility evaluation in Chapter 3 discussed the database containing dependent and independent variables for each segment of Utah arterial road studied in this research. This chapter discusses the statistical analyses performed on the data to determine which characteristics were correlated to roadway safety aspects, including crash rate, crash severity, and collision type. Section 4.1 discusses the methodology utilized to conduct the statistical analyses. Sections 4.2 through 4.4 discuss the specific methodologies utilized to examine crash rate, crash severity, and collision type, respectively. Section 4.5 summarizes the safety evaluation performed in this chapter.

4.1 Statistical Methodology

Since numerous independent variables were collected, including length, access category, number of lanes, median type, orientation, adjacent land use, posted speed limit, access density, AADT, and signals per mile, it was necessary to pare down the variables to only those with significant impact on the safety of the road. Variables with no statistically significant effect on crashes needed to be removed to eliminate the loss of precision associated with having too many explanatory variables in the model (Ramsey and Schafer 2002).

Computer software SPSS® 14.0 was utilized to perform stepwise linear regression in order to add and remove independent variables as necessary for each dependent variable analyzed (SPSS 2005). Independent variables analyzed included all those discussed in Section 3.3. Variables for median type, orientation, and adjacent land use were categorical variables and were assigned values of 1 or 0 in the analysis. For example, a road segment with a raised median was given a value of 1 to the categorical variable "raised median" and a value of 0 was given to the categorical variables of "TWLTL" and "Undivided Roadway".

Stepwise linear regression begins with the constant mean model (i.e., no explanatory variables to explain the dependent variables are in the model) and is altered with alternating steps of forward selection and backward elimination until no more variables can be added or removed (Ramsey and Schafer 2002). Forward selection consists of adding a variable with the highest extra-sum-of-squares *F*-statistic provided that the corresponding *p*-value is below a user-specified value. The default *p*-value in SPSS® for forward selection was 0.05. Backward elimination consists of removing a variable with the lowest extra-sum-of-squares *F*-statistic provided that the associated *p*-value is above a user-specified value. The default *p*-value used in SPSS® for removal was 0.10.

In addition to the stepwise linear regression, the "weight cases" option was also utilized to weight each individual segment by its length. This was done to ensure that short segments would not skew the data. For example, a segment one mile in length was given twice the weight in the regression analysis as a segment one half mile in length.

After the significant variables were identified from the stepwise procedure, multiple linear regression was used to identify the regression coefficients and their respective *t*-statistics and *p*-values. The null hypothesis was that the regression coefficients were zero. The intent of determining regression coefficients was not necessarily to predict crash rates, crash severities, or collision types, but to determine which characteristics were correlated with crash history. That is, the regression equations developed should not be used to predict crashes but can be examined to identify patterns in the data.

After completing a preliminary statistical analysis, many of the crash severity score methods and collision types were observed to be negatively correlated with the number of lanes of the road segments. This was counterintuitive because it was expected that as the number of lanes increased that there would have been more conflict points and thus more potential for crashes. This negative correlation was further investigated by dividing AADT by the number of lanes for each segment. It was hypothesized that this new variable would be a more accurate indication of the congestion of a given road because it would be an estimate of how many vehicles were in each travel lane. Figure 4.1 shows the AADT per lane versus the number of lanes for the data collected in Chapter 3.

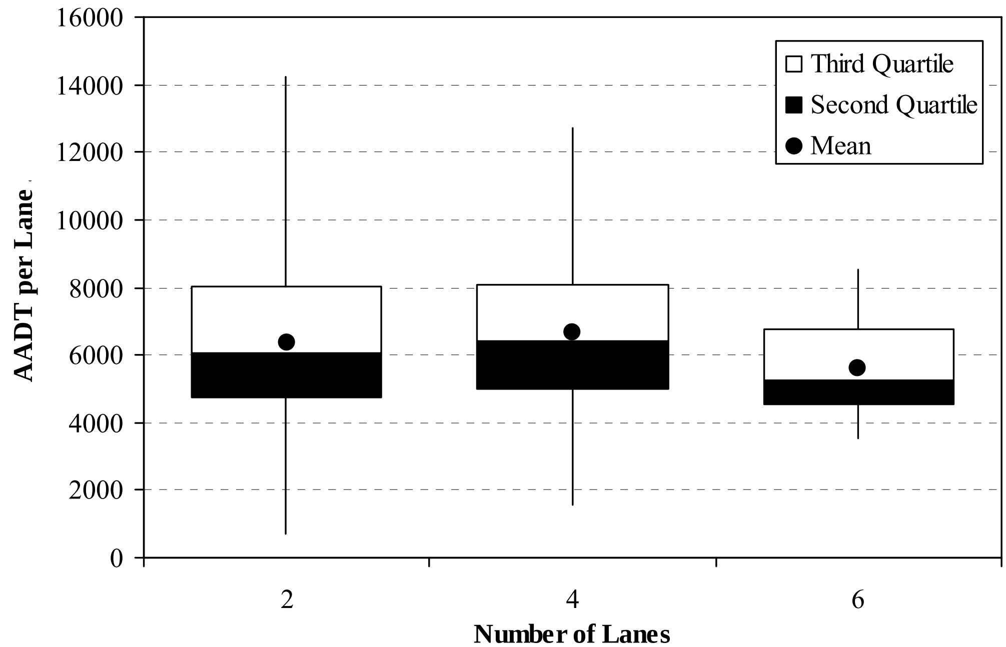

Figure 4.1 Box plot showing AADT per lane versus number of lanes.

As is shown in Figure 4.1, the mean and median AADT per lane of the six lane segments were lower than those of the two- and four-lane roads. The mean and median for six-lane road segments were both less than 6,000 vpd, while the means and medians of two- and-four lane road segments were both higher than 6,000 vpd. Because fewer vehicles were present in each lane on six lane segments, fewer conflicts would likely occur. Fewer conflicts could account for linear regression results, indicating that increased number of lanes correlated with decreased crash severity score.

As a result of this finding, AADT per lane was utilized in the statistical analysis instead of AADT and number of lanes because AADT per lane was a better indicator of conflicts than were the other variables.

4.2 Crash Rate Analysis

Crash rates (in units of crashes per MVMT) were calculated for each section as a function of the number of crashes, volume, and length as was shown in Equation 2.1 and is repeated in Equation 4.1.

$$CR_{\sec} = \frac{N}{V_{\sec} \times 365 \times L} \times 10^{6} \tag{4.1}$$

where: CR_{sec} = crash rate for section (in crashes per MVMT),

N = number of crashes per year,

V_{sec} = AADT of road section, and

L = length of section (in miles).

Figure 4.2 shows the distribution of crash rates by percent for the road segments. The distribution weighted by length is also shown. The highest quantity of crash rates was between two and five crashes per MVMT. The distribution takes on a more normal distribution after weighting these crash rates by length. Interestingly, the percentage of crashes rates above 10 became much smaller once the rates were weighted by length. This further justifies the decision to weight the crash data by length because of the numerous short sections with very high crash rates.

Stepwise linear regression showed statistically significant correlation of crash rates to signal spacing, adjacent land use, speed limit, and median type. Table 4.1 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. Crash rates were correlated with signals per mile such that every signal per mile present corresponded to approximately one crash per MVMT. Additionally, road segments with adjacent commercial land use had on average over one additional crash per MVMT than did segments with adjacent residential land use. Posted speed limit was found to be negatively correlated with crash rate, with a 10 mph increase corresponding to less than one additional crash per MVMT. However, the majority of locations analyzed had posted speed limits between 35 and 45 mph, suggesting that this correlation is not likely relevant for lower or higher speed limits. Finally, the presence of a raised median corresponded to a reduction of more than one crash per MVMT. Crashes rates for each road segment are provided in Appendix D.

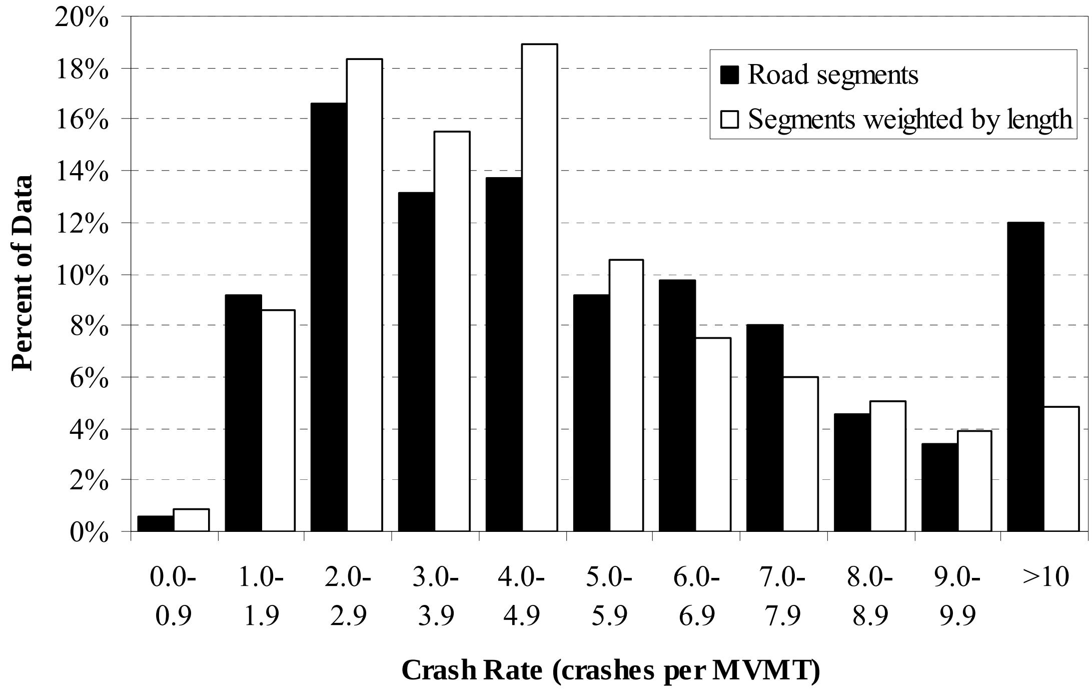

Figure 4.2 Distribution of crash rates for the road segments collected.

Table 4.1 Crash Rate Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	5.41	1.51	3.59	<0.01
Signals/Mile	0.919	0.136	6.77	<0.01
Commercial	1.23	0.377	3.26	<0.01
Speed Limit	-0.0709	0.0332	-2.13	0.03
Raised Median	-1.23	0.593	-2.08	0.04

4.3 Crash Severity Score Analysis

Crash severity refers to the resulting severity of the most severe injury of all those involved in a given crash and was discussed in greater detail in Section 3.4.1. A weighting method was utilized in order to quantify the net severity of crashes, or crash severity score, occurring on a given segment over a specified time period. As was discussed in Section 2.5.1.3, several methods exist to weight crash severity. Five methods were devised or adapted from those in the literature to calculate crash severity scores for this research. Because the segments contained in the database were of varying lengths, a preliminary step to all of the methods was to divide the number of crashes of a specific severity by the length of the segment in miles. This provided the number of crashes per mile for each segment (e.g., number of fatal crashes per mile, etc.).

The five methods developed to calculate crash severity scores were as follows:

1. Federal Highway Administration (FHWA) Crash Costs Method,
2. Magnitudes of Ten Method,
3. Exponential Method,
4. Three Category Method, and
5. UDOT Crash Costs Method.

These methods are outlined in the following sections along with the results of the statistical analysis completed to show correlation between the characteristics of the road segments and crash severity score. However, crash severity scores cannot be compared directly between methods, as the range of scores varies dramatically from one method to another.

4.3.1 Severity Score Method 1: FHWA Crash Costs Method

A technical advisory published in 1994 by the FHWA contains costs associated with each severity level of crashes. These values are shown in Table 4.2 in 1994 dollars (FHWA 1994) as well as 2006 dollars. The 2006 dollars were calculated using the gross domestic product (GDP) price deflator on the website of the Federal Reserve Bank of St. Louis (2006).

Table 4.2 FHWA Crash Costs by Severity Level

	Severity Level	1994 Dollars	2006 Dollars	Equivalent Non-Injury Crashes
K	Fatal	$2,600,000	$3,300,000	1,300
A	Incapacitating injury	$180,000	$230,000	88
B	Non-incapacitating evident injury	$36,000	$47,000	18
C	Possible injury	$19,000	$25,000	10
O	Non-injury	$2,000	$2,600	1

Each cost per crash in 2006 dollars from Table 4.2 was divided by $2,600 to obtain the approximate equivalent number of non-injury crashes. Crashes per mile of each severity type for three years were then multiplied by their respective proportion and then summed to obtain the total score for each road segment utilizing the relationship provided in Equation 4.2.

$$S_1 = O + (10 \times C) + (18 \times B) + (88 \times A) + (1{,}300 \times K) \quad (4.2)$$

where: S_1 = severity score for method 1 (FHWA crash costs method),
O = non-injury crashes per mile,
C = possible injury crashes per mile,
B = non-incapacitating evident injury crashes per mile,
A = incapacitating injury crashes per mile, and
K = fatal crashes per mile.

Figure 4.3 shows the distribution of severity scores by percent for the road segments using Method 1. The distribution weighted by length is also shown.

Stepwise linear regression showed correlation of crash severity score to signal spacing, volume, adjacent land use, speed limit, median type, and access density. Table 4.3 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. It is important to note that although the constant has a negative value, a negative crash severity score is not possible. Using the ranges of data for the characteristics discussed in Section 3.3, only positive severity scores existed. Signals per mile is correlated with crash severity score such that with each additional signal per mile, the severity score increases by approximately 400. AADT per lane is positively correlated with severity score, but for every additional 1,000 vpd per lane the severity score only increases by approximately 10. Land use is correlated to severity score, and those road segments with commercial land use tended to have severity scores approximately 350 points higher than residential arterials. Crash severity score was positively correlated with posted speed limit such that an increase in speed limit of 5 mph corresponded to a severity score over 200 points higher. The presence of a TWLTL corresponded to a severity score of over 300 points higher. Access density increased the severity score by approximately 75 points for every 10 additional access points per mile.

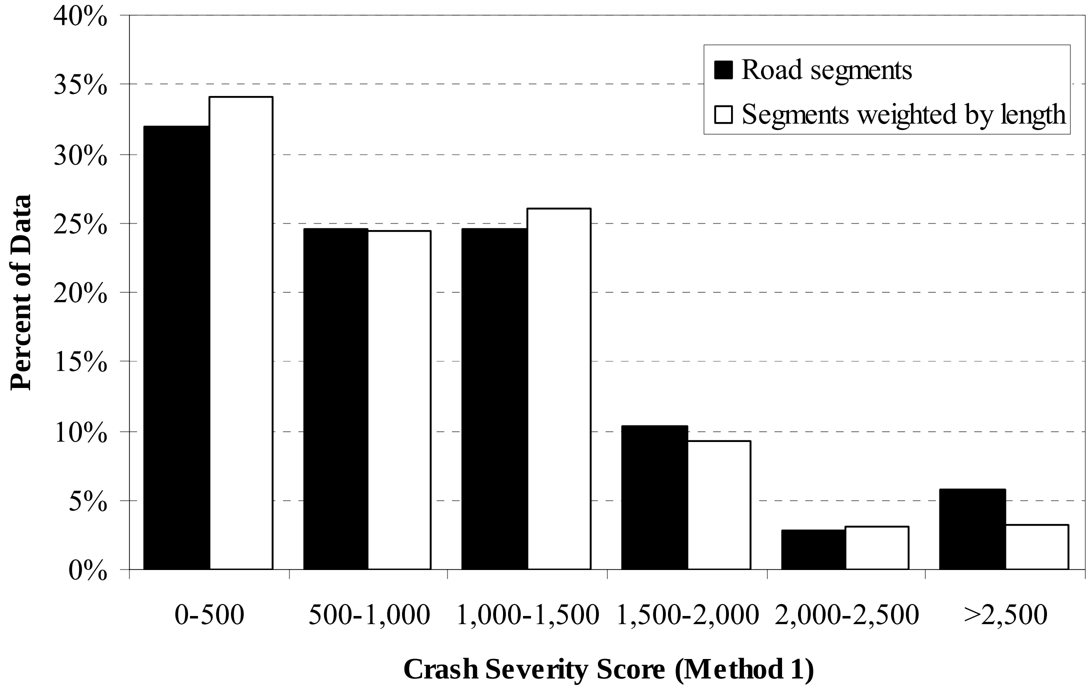

Figure 4.3 Distribution of severity scores for Method 1.

Table 4.3 Severity Score Method 1 Regression Coefficients

Variable	**Regression Coefficient**	**Standard Error**	***t*-statistic**	***p*-value**
(Constant)	-2840	645	-4.41	<0.01
Signals/Mile	437	43.4	10.1	<0.01
AADT/Lane	0.113	0.0257	4.39	<0.01
Commercial	359	147	2.45	0.02
Speed Limit	45.9	12.8	3.58	<0.01
TWLTL	321	156	2.05	0.04
Access Density	7.73	2.44	3.17	<0.01

4.3.2 Severity Score Method 2: Magnitudes of Ten Method

Research completed for UDOT by Cotrell et al. (2004 and 2005) used values ranging from 0.1 to 1,000 by factors of 10, to weight each crash severity type. Method 2 utilizes these values illustrated by the relationship provided in Equation 4.3.

$$S_2 = (0.1 \times O) + (1 \times C) + (10 \times B) + (100 \times A) + (1{,}000 \times K) \tag{4.3}$$

where: S_2 = severity score for method 2 (magnitudes of ten method).

This method places higher weight on fatal crashes than did Method 1 because it equates one fatal crash to 10,000 PDO crashes (1,000 for fatal crashes divided by 0.1 for non-injury or PDO crashes), compared to only 1,300 as was utilized in Method 1.

Figure 4.4 shows the distribution of severity scores by percent for the road segments using Method 2. The distribution weighted by length is also shown. Approximately 30 percent of the road segments had crash severity scores less than 500. Another 40 percent of the road segments had crash severity scores between 500 and 2,000. Less than 15 percent had crash severity scores greater than 2,000.

Stepwise linear regression showed correlation of crash severity score to signal spacing, volume, adjacent land use, speed limit, median type, and access density. Table

4.4 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. It is important to note that although the constant has a negative value, a negative crash severity score is not possible. Using the ranges of data for the characteristics discussed in Section 3.3, only positive severity scores existed.

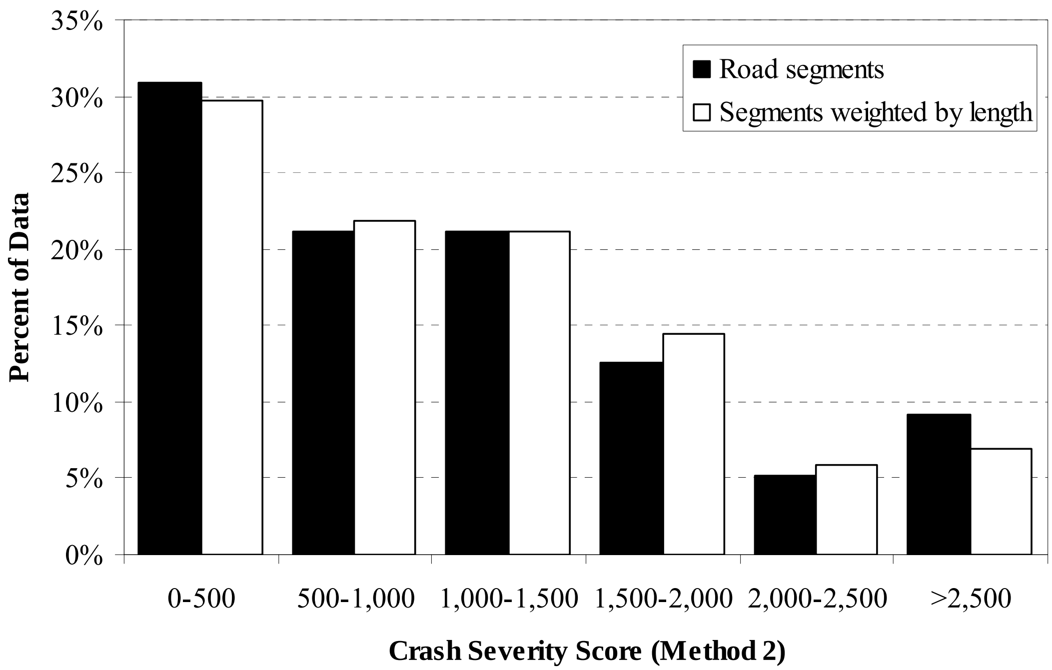

Figure 4.4 Distribution of severity scores for Method 2.

Table 4.4 Severity Score Method 2 Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	-2310	484	-4.77	<0.01
Signals/Mile	283	32.6	8.69	<0.01
AADT/Lane	0.0729	0.0193	3.78	<0.01
Commercial	253	110	2.30	0.02
Speed Limit	40.6	9.62	4.23	<0.01
TWLTL	230	117	1.96	0.05
Access Density	5.98	1.83	3.26	<0.01

The statistical results for Method 2 were very similar to the results of Method 1 likely due to the fact that the two methods had very high weight placed on fatal crashes. Each additional signal per mile increased the severity score by almost 300 points. AADT per lane was correlated to severity score such that an increase of 1,000 vpd per lane corresponded to an increase in severity score of less than 100 points. Commercial land use arterials corresponded to severity scores of approximately 250 additional points. Posted speed limits 5 mph higher corresponded to severity scores approximately 200 points higher. The presence of a TWLTL corresponded to severity scores 230 points higher. Access density was positively correlated to severity score such that an increase of 10 access points per mile corresponded to a severity score of nearly 60 points higher.

4.3.3 Severity Score Method 3: Exponential Method

The third method developed for this research places equal weight on non-injury or PDO crashes and possible injury crashes, while placing heavier weight on locations with repeated fatal crashes by using the exponential expression identified in Equation 4.4.

$$S_3 = O + C + (4 \times B) + (5 \times A) + (10^K) \tag{4.4}$$

where: S_3 = severity score for method 3 (exponential method).

Using this method, a location with only one fatal crash in the three-year time period had fatal crashes weighted as only 10 times worse than a PDO crash. However, with two or three fatal crashes, the fatal crashes became equivalent to 100 or 1,000 PDO crashes, respectively. This method placed high importance on identifying locations that experienced repeated fatal crashes. Locations with smaller numbers of fatal crashes were essentially filtered out.

Figure 4.5 shows the distribution of severity scores by percent for the road segments using Method 3. The distribution weighted by length is also shown. In contrast to Methods 1 and 2, approximately 90 percent of the severity scores using Method 3 are less than 500, whereas only 30 percent of severity scores using Method 1 and 2 are less than 500. Figure 4.5 shows that over 25 percent of road segments had scores less than

100, and approximately 30 percent had scores between 100 and 200. Less than 20 percent of road segments had scores between 200 and 300. The remaining 25 percent of road segments had scores greater than 300.

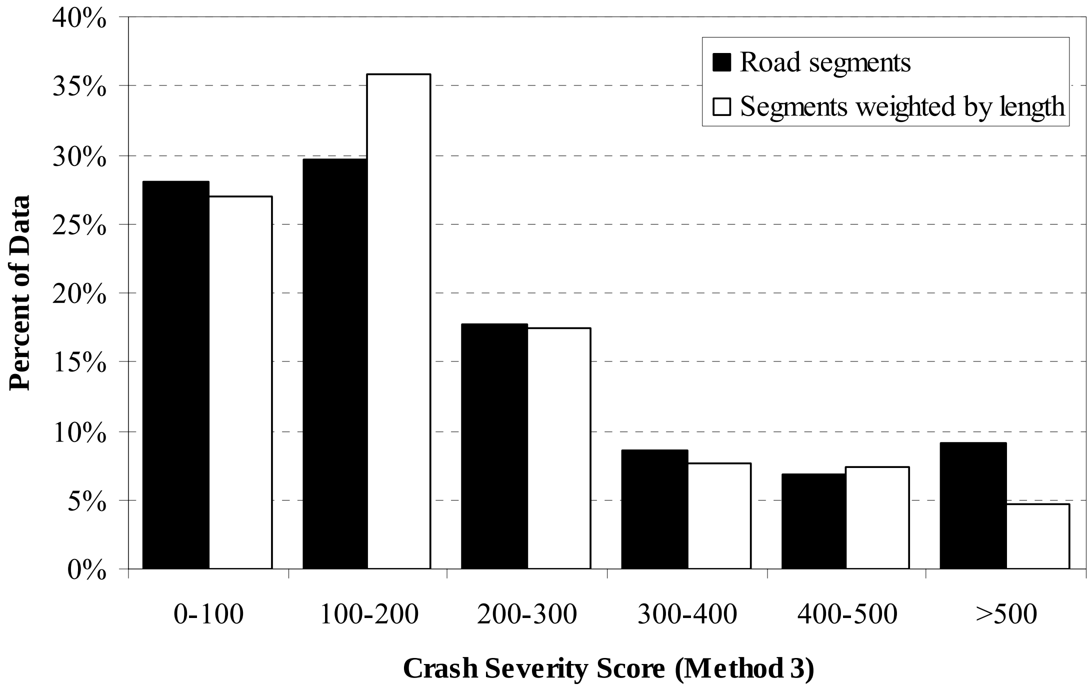

Figure 4.5 Distribution of severity scores for Method 3.

Stepwise linear regression showed correlation of crash severity score to signal spacing, volume, adjacent land use, and median type. Table 4.5 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. It is important to note that although the constant has a negative value, a negative crash severity score is not possible. Using the ranges of data for the characteristics discussed in Section 3.3, only positive severity scores existed. Table 4.5 shows positive correlation between signals per mile and crash severity score such that each additional signal per mile corresponded to an increase in severity score of approximately 60 points. However, 60 points in Method 3 was much more significant than 60 points in Methods 1 or 2. An increase in AADT per lane of 1,000 vpd per lane corresponded to an increase in severity score of approximately 20 points. Adjacent commercial land use corresponded to an increase in severity score of 45 points. The presence of a TWLTL corresponded to an increase in severity score of over 50 points.

Table 4.5 Severity Score Method 3 Regression Coefficients

Variable	**Regression Coefficient**	**Standard Error**	***t*-statistic**	***p*-value**
(Constant)	-99.5	25.5	-3.91	<0.01
Signals/Mile	59.1	5.27	11.2	<0.01
AADT/Lane	0.0171	0.00326	5.23	<0.01
Commercial	45.3	18.9	2.40	0.01
TWLTL	54.3	19.1	2.83	0.02

4.3.4 Severity Score Method 4: Three Category Method

The fourth method was based on the argument that the difference between a fatal crash and a major injury crash has less to do with the characteristics of the road or intersection and more to do with circumstances commonly considered outside of the control of transportation engineering. Hall (1998) cites a few examples:

- vehicle type,
- impact speed or timing,
- use (or lack) of restraint,
- age of the individuals involved,
- manner of collision, or
- matter of chance.

As with Method 3, Method 4 reduces the possibility of falsely identifying a location as extremely hazardous due to a fatality that may not have been caused by poor characteristics of the highway. Method 4 utilized only three categories of crash severity score, thereby applying equal weight to fatal and major injury crashes utilizing the relationship provided in Equation 4.5. The weights for the three severity levels used were adapted from similar weights obtained from the literature (Maze et al. 2005, Gharaybe 1991, Kar and Datta 2004).

$$S_4 = (O + C) + 4 \times (B) + 10 \times (A + K) \tag{4.5}$$

where: S_4 = severity score for method 4 (three category method).

All crashes were characterized as having a severity of non-injury (including PDO and possible injury), minor injury, or major injury (including major injuries and fatalities).

Figure 4.6 shows the distribution of severity scores by percent for the road segments using Method 4. The distribution weighted by length is also shown. The distribution of severity scores for Method 4 was very similar to the distribution of scores for Method 3. As was the case with Method 3, almost 90 percent of the road segments had severity scores less than 500, compared to Methods 1 and 2 having only 30 percent of their severity scores less than 500. Approximately 20 percent of the road segments had scores less than 100. Approximately 30 percent of the road segments had scores between 100 and 200. Less than 20 percent of the road segments had scores between 200 and 300, and less than 15 percent of the road segments had scores between 300 and 400. Approximately 20 percent of the road segments had severity scores greater than 400, although weighted by length the percentage was closer to 15.

Stepwise linear regression showed correlation of crash severity score to signal spacing, volume, adjacent land use, and median type. Table 4.6 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. It is important to note that although the constant has a negative value, a negative crash severity score is not possible. Using the ranges of data for the characteristics discussed in Section 3.3, only positive severity scores existed. The results for Method 4 were very similar to those of Method 3. While the severity score equations for those two methods may not appear to be similar, they both attempt to account for the same underlying principle, which is that randomness accounts for some crashes being fatal but that truly dangerous locations will have numerous fatal and major injury crashes. Table 4.6 shows positive correlation between signals per mile and crash severity score such that each additional signal per mile corresponded to an increase in severity score of approximately 65 points. An increase in AADT per lane of 1,000 vpd per lane corresponded to an increase in severity score of approximately 20 points. Adjacent commercial land use corresponded to an increase in severity of over 50 points. The presence of a TWLTL corresponded to an increase in severity score of almost 65 points.

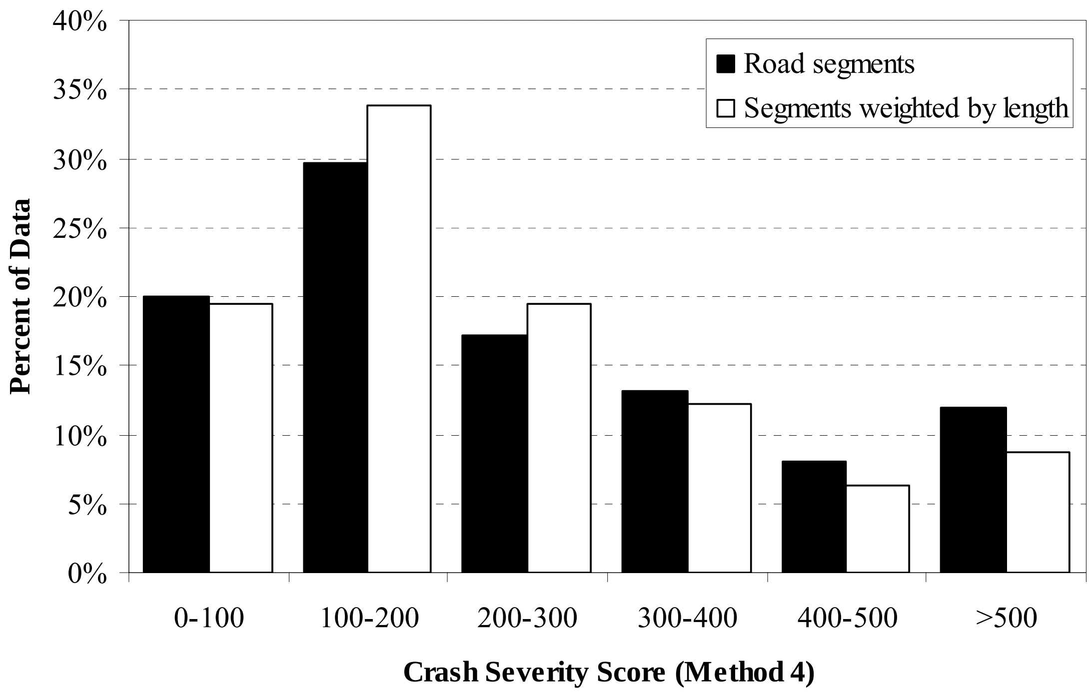

Figure 4.6 Distribution of severity scores for Method 4.

Table 4.6 Severity Score Method 4 Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	-113	28.6	-3.95	<0.01
Signals/Mile	66.4	5.91	11.2	<0.01
AADT/Lane	0.0197	0.00366	5.39	<0.01
Commercial	53.1	21.1	2.51	0.01
TWLTL	64.0	21.5	2.98	<0.01

4.3.5 *Severity Score Method 5: UDOT Crash Costs Method*

UDOT developed crash costs based on FHWA crash cost values for the UDOT Roadway Safety Improvement Program (UDOT 2006c). The methodology used to arrive at the UDOT crash cost values was based on prioritizing locations with major injury crashes and fatal crashes. These values are shown in Table 4.7.

Table 4.7 UDOT Crash Costs

	Severity Level	Cost/Crash	Equivalent Non-Injury Crashes
K	Fatal	$465,000	200
A	Incapacitating injury	$465,000	200
B	Non-incapacitating evident injury	$46,500	20
C	Possible injury	$23,200	10
O	Non-injury	$2,350	1

As with Method 1 discussed previously, costs were divided by the non-injury cost to obtain equivalent non-injury values (also shown in Table 4.7), multiplied by the number of each crash type, and summed to give an overall score utilizing the relationship provided in Equation 4.6.

$$S_5 = O + (10 \times C) + (20 \times B) + (200 \times A) + (200 \times K) \qquad (4.6)$$

where: S_5 = severity score for method 5 (UDOT crash method).

Figure 4.7 shows the distribution of severity scores by percent for the road segments using Method 5. The distribution weighted by length is also shown. The distribution of crash severity scores for Method 5 approximates a normal distribution with a mean around 1,000 to 1,500. As has been the case with the other methods, the higher scores have tended to be associated with road segments shorter in length, further justifying the decision to weight the crashes by length.

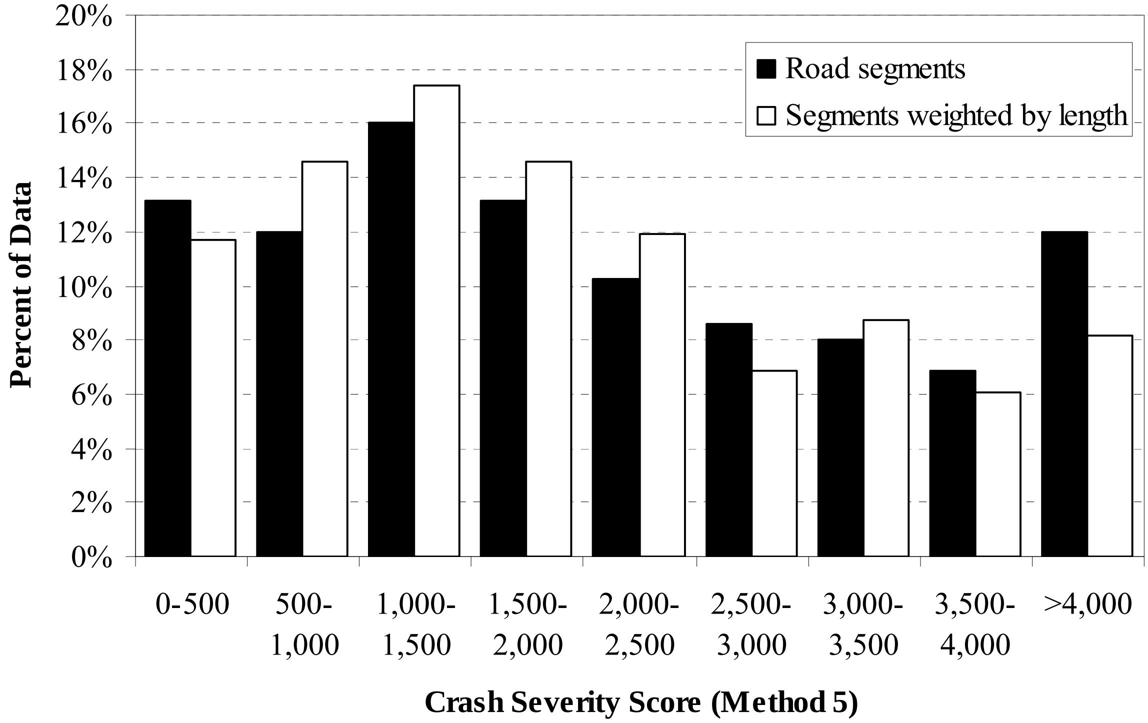

Figure 4.7 Distribution of severity scores for Method 5.

Stepwise linear regression showed correlation of crash severity score to signal spacing, volume, adjacent land use, speed limit, and access density. Table 4.8 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. It is important to note that although the constant has a negative value, a negative crash severity score is not possible. Using the ranges of data for the characteristics discussed in Section 3.3, only positive severity scores existed. The results from Method 5 were more similar to those of Methods 1 and 2 possibly due to the weights of the more serious crashes being orders of magnitude larger than PDO crashes, whereas, with Methods 3 and 4, fatal and major injury crash weights were much closer to the weights of PDO crashes. For Method 5, additional signals per mile increased the severity score by approximately 550 points. AADT per lane was correlated to severity score such that an increase in 1,000 vpd per lane corresponded to an increase in severity score of close to 200. Commercial land use arterials corresponded to severity scores of approximately 500 points higher, while residential land use arterials corresponded to severity scores of approximately 400 points lower. Crash severity score was positively correlated with posted speed limit such that an increase in speed limit of 5 mph corresponded to a severity score over 350 points higher. Access density was positively correlated to severity score such that an increase of 10 access points per mile corresponded to a severity score of approximately 100 points higher.

Table 4.8 Severity Score Method 5 Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	-3920	764	-5.13	<0.01
Signals/Mile	558	54.6	10.2	<0.01
AADT/Lane	0.180	0.0307	5.84	<0.01
Commercial	495	163	3.05	<0.01
Residential	-387	165	-2.34	0.02
Speed Limit	71.8	15.0	4.78	<0.01
Access Density	10.4	2.96	3.51	<0.01

4.3.6 Summary

Figure 4.8 compares the distribution of severity scores between the five severity score methods and shows the ranges of scores obtained using the various methods. As was discussed previously, Methods 1 and 2 were found to have similar results, as were Methods 3 and 4. Method 5 was most similar to Methods 1 and 2; however, the range of severity scores was much larger for Method 5.

Table 4.9 summarizes all of the variables identified with the stepwise linear regression as being correlated to the crash severity score of the segments in the database. A "+" symbol indicates positive correlation, while a "-" symbol indicates negative correlation. Blank cells indicate no correlation for the respective variable and method. Signal spacing and volume were significant in all five methods of determining severity score. Adjacent land use was significant in every method, with commercial land use being positively correlated with crash severity score in all five methods and residential land use being negatively correlated in one of the methods. Speed limit and access density were positively correlated with severity score in three of the methods, and TWLTL medians were positively correlated in four of the five methods.

Overall, the results of the statistical analysis were consistent with expectations, showing the importance of access management. Signal spacing, median treatment, and access density were all related to the severity score of the crashes on the road segments. Land use, volume, and speed limit, while not directly related to access management, were also related to the severity score. Crash severity scores for all five methods for each road segment are provided in Appendix D.

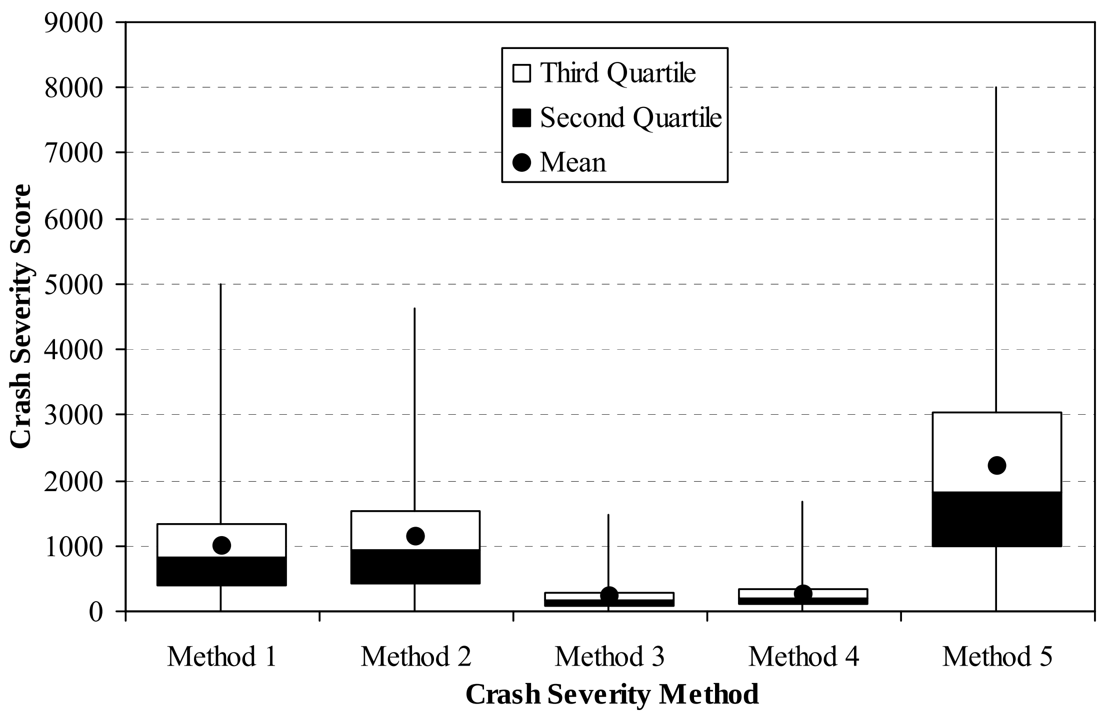

Figure 4.8 Box plot showing range of severity scores for each of the five methods.

Table 4.9 Summary of Correlations of Independent Variables with Crash Severity

Variable	Method 1	Method 2	Method 3	Method 4	Method 5
Signals/Mile	+	+	+	+	+
AADT/Lane	+	+	+	+	+
Commercial	+	+	+	+	+
Residential					-
Speed Limit	+	+			+
TWLTL	+	+	+	+	
Access Density	+	+			+

Note: A "+" indicates positive correlation and a "-" indicates negative correlation.

4.4 Collision Type Analysis

Analyzing crashes by collision type has two apparent advantages: 1) it identifies specific geometric characteristics of the roadway, such as those that are related to access management, that may have caused or failed to prevent the crash, and 2) locations with high frequencies of certain crashes normally thought to yield more severe results are identified as hazardous, whether or not severe injuries occurred. The latter advantage is further magnified when sample sizes are lower and variability is higher.

In analyzing collision type, a different approach was needed than was utilized in the crash severity score analysis. Crash severity scores provided logical rankings of crashes by injury severity whereas no easy method existed to rank collision types. For collision-type analysis, crash rates were determined for each type of collision and then compared with the respective crash rates of other locations. No cumulative score was given to include every type of collision in one comparison, but several different analyses were conducted to analyze each collision type. Analyses included examining right-angle collisions, rear-end collisions, side-swipe collisions (in the same direction), single-vehicle collisions, and head-on and side-swipe collisions (from opposite directions). Specific types of crashes that were categorized in each of these categories were discussed previously in Section 3.4.2. The following sections discuss the statistical analysis completed for each category of collision type.

4.4.1 Right-Angle Collisions

Right-angle collisions occur when two or more vehicles collide at approximately 90 degree angles. Often referred to as "T-bone" crashes, these collisions frequently occur at intersections because that is where vehicles cross paths at right angles.

Stepwise linear regression showed correlation of right-angle collisions to signal spacing, volume, adjacent land use, and median type. Table 4.10 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. The results of the stepwise linear regression indicated that right-angle crashes were positively correlated with commercial adjacent land use; however, a slight decrease in right-angle crashes was also observed with increasing volume per lane. As would be expected, raised medians were negatively correlated with right-angle crashes, validating the argument that raised medians prevent conflicts by restricting turning movements.

Table 4.10 Right-Angle Collision Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	1.20	0.255	4.72	<0.01
Signals/Mile	0.435	0.0597	7.28	<0.01
AADT/Lane	-7.3 E-05	3.43 E-05	-2.12	0.04
Commercial	0.571	0.173	3.29	<0.01
Raised Median	-0.808	0.277	-2.92	<0.01

4.4.2 Rear-End Collisions

Rear-end collisions occur near intersections and driveways when vehicles are slowing down or stopping for traffic signals or to turn into driveways. They also occur when vehicles exit driveways and are hit by vehicles already in the lane.

Stepwise linear regression showed correlation of rear-end collisions to signal spacing, volume, adjacent land use, and speed limit. Table 4.11 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. The results of the analysis show that corridors with residential land use tended to have lower numbers of rear-end collisions. This might have been caused by the relatively small number of vehicles entering and exiting residential driveways. A negative correlation between posted speed limit and rear-end collisions was also observed, suggesting rear-end collisions may have been more likely to occur in lower speed areas. Although the data do not show a decrease in rear-end collisions with access management treatments utilized, they also fail to show an increase.

Table 4.11 Rear-End Collision Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	2.54	0.954	2.66	0.01
Signals/Mile	0.398	0.0725	5.50	<0.01
AADT/Lane	9.52 E-05	4.19 E-05	2.27	0.02
Residential	-0.537	0.209	-2.57	0.01
Speed Limit	-0.0383	0.0190	-2.02	0.04

4.4.3 Side-Swipe Collisions (Same Direction)

A side-swipe collision between vehicles traveling in the same direction can occur when a vehicle changes lanes intentionally or inadvertently and strikes another vehicle that is already in the adjacent lane.

Stepwise linear regression showed correlation of side-swipe collisions to signal spacing, adjacent land use, and access density. Table 4.12 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. These data in Table 4.12 show that side-swipe collisions involving vehicles traveling in the same direction were more likely to occur in areas with commercial land use. Increasing access density was also linked with side-swipe-type collisions, likely due to the increase in conflicts with vehicles merging and diverging because of closely spaced access points.

Table 4.12 Side-Swipe Collision Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	-0.0162	0.0307	-0.529	0.60
Signals/Mile	0.0483	0.00844	5.72	<0.01
Commercial	0.0949	0.0271	3.49	<0.01
Access Density	0.00120	0.000449	2.68	0.01

4.4.4 Head-On Collisions and Side-Swipe Collisions (Opposite-Direction)

Head-on collisions and side-swipe collisions from the opposite direction were analyzed together because, although the resulting severity of the collisions may be drastically different, the cause of both types of collisions is likely the same; that is, one or both vehicles crossed the centerline of the road.

Stepwise linear regression showed correlation of opposite-direction collisions to adjacent land use, and median type. Table 4.13 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. Adjacent commercial land use was normally positively correlated with higher crash rates for most collision types and crash severities; however, for opposite-direction collisions, residential and agricultural type land uses tended to yield higher opposite direction collision crash rates. TWLTL medians were also correlated with opposite-direction collisions likely due to the fact that vehicles queued in TWLTLs are closer to oncoming traffic and would have a higher chance of being involved with a head-on or opposite-direction, side-swipe collision. Raised medians, however, would prevent most opposite-direction-type crashes.

Table 4.13 Opposite-Direction Collision Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	0.0212	0.00871	2.44	0.02
Residential	0.0206	0.00714	2.88	<0.01
TWLTL	0.0231	0.00818	2.82	0.01

4.4.5 Single-Vehicle Collisions

Single-vehicle collisions are defined as crashes that only involve one vehicle because they crash with non-vehicle objects on the side of the road.

Stepwise linear regression showed correlation of single-vehicle collisions to volume and speed limit. Table 4.13 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. While these results showed no direct relationship between the reduction of single-vehicle crashes and access management treatments, they also failed to show an increase in single-vehicle collisions due to access management techniques such as raised medians. This showed no apparent adverse safety side-effect to installing raised medians.

Table 4.14 Single-Vehicle Collision Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	0.928	0.131	7.09	<0.01
AADT/Lane	-2.7 E-05	6.44 E-05	-4.23	<0.01
Speed	-0.00808	0.00274	-2.95	<0.01

4.4.6 *"Other" Collisions*

All other types of collisions were analyzed together in an "other" category.

Stepwise linear regression showed correlation of these collisions to volume, adjacent land use, and speed limit. Table 4.15 shows the regression coefficient, standard error, *t*-statistic, and *p*-value for each independent variable. No apparent correlation between any of these "other" collision types and access management treatments were observed. This could be due to the fact that the types of collisions categorized together in this group were a wide variety of collision types. However, these results do continue to show the correlation between land use and crashes. Adjacent commercial land use was positively correlated with "other" collision types, while adjacent residential land use was negatively correlated with "other" collision types.

4.4.7 *Summary*

Table 4.16 summarizes all of the variables identified with the stepwise linear regression as being correlated to various collision types of the road segments in the database. A "+" symbol indicates positive correlation, while a "-" symbol indicates negative correlation. Blank cells indicate no correlation for the respective variable and collision type. As displayed in Table 4.16, there were fewer correlations between collision types and access management techniques as compared to the correlations between crash severity score and access management techniques shown previously in Table 4.9. Nevertheless, access management techniques such as signals per mile, TWLTLs, and access density were correlated with right-angle, rear-end, side-swipe, and opposite-direction collisions. Land use was also correlated in all but one of the collision types. Collision type rates for each road segment are provided in Appendix E.

Table 4.15 "Other" Collision Type Regression Coefficients

Variable	Regression Coefficient	Standard Error	*t*-statistic	*p*-value
(Constant)	0.810	0.125	6.49	<0.01
AADT/Lane	-2.2 E-05	5.98 E-06	-3.61	<0.01
Commercial	0.0640	0.0305	2.10	0.04
Residential	-0.0779	0.0294	-2.65	0.01
Speed	-0.00965	0.00256	-3.77	<0.01

Table 4.16 Summary of Correlations of Independent Variables with Collision Type

Variable	Right-Angle	Rear End	Side-Swipe	Opposite-Direction	Single-Vehicle	Other
Signals/Mile	+	+	+			
AADT/Lane	-	+			-	-
Commercial	+		+			+
Residential		-		+		-
Speed		-			-	-
Raised Median	-					
TWLTL				+		
Access Density			+			

Note: A "+" indicates positive correlation and a "-" indicates negative correlation.

4.5 Summary of Safety Evaluation

The previous sections outline the statistical analysis performed on the data contained in the facility evaluation outlined in Chapter 3. Increased crash severity scores were positively correlated with TWLTLs, greater signals per mile, and higher access density. Land use was also correlated with crash severity scores. Other factors not directly related to access management, such as volume and posted speed limit, were correlated to crash severity scores as well.

Some correlations existed between certain collision types and some access management techniques. Raised medians were negatively correlated with right-angle collisions, and TWLTLs were positively correlated with opposite-direction collisions. Increased access density was correlated with increased side-swipe crashes. Right-angle, rear-end, and side-swipe collisions were positively correlated with signals per mile. Other factors such as land use, volume, and posted speed limit showed various correlations with different collision types. The results of the analyses in this chapter are used as the basis for the performance-index-based prioritization process developed in the following chapter.

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5 Prioritization Process

Chapter 3 discussed the database containing segments of arterial roads in Utah, including their characteristics and crash histories, while Chapter 4 discussed the statistical analysis completed on the data showing correlations between many of the characteristics of the road segments and the crash severity scores and collision type. This chapter outlines the performance-index-based prioritization process developed to make decisions regarding access management techniques that should be utilized on arterial roads. The primary method to develop this process was by utilizing a decision tree. The decision tree developed in this research was based on the results of statistical analyses performed on the data, as well as recommendations found in the literature.

Section 5.1 discusses the selection of the crash severity score method utilized as the basis for the prioritization process. Section 5.2 outlines the components of the decision tree, while Section 5.3 discusses the specific access management principles of the decision tree. The decision tree, as well as the step-by-step process by which it can be utilized, is shown in Section 5.4. Sample recommendations using the decision tree are given in Section 5.5 and the prioritization process is summarized in Section 5.6.

5.1 Selection of Crash Severity Score Method

Although five methods were developed to score the severity of each road segment as outlined in Chapter 4, only one method was utilized to develop the prioritization process. To determine which method to use for the prioritization process development, the first step was to determine the correlation between the five methods. Table 5.1 shows the correlation coefficients between all five methods. The closer a correlation coefficient was to one, the more correlated the two methods were.

Table 5.1 Correlation Coefficients between Crash Rate and Severity Score Methods

	Crash Rate	Method 1	Method 2	Method 3	Method 4	Method 5
Crash Rate	1					
Method 1	0.62	1				
Method 2	0.49	0.97	1			
Method 3	0.81	0.88	0.76	1		
Method 4	0.80	0.88	0.78	1.00	1	
Method 5	0.68	0.91	0.87	0.93	0.95	1

Table 5.1 shows that all of the methods were generally highly correlated. Because high correlation existed between all five methods, it was not as important which method was used, as all would provide similar results. Method 5 was recommended for the process development because it utilized the severity ranking established by UDOT; therefore, it most closely corresponded to the goals of the agency (UDOT 2006c). It was also well correlated with the other four methods as is shown in Table 5.1.

5.2 Decision Tree Components

As was discussed in Section 2.5.5.2, decision trees can be effective tools to visually determine appropriate countermeasures for safety problems based on known characteristics and crash histories of given segments. However, to create decision trees, the data must be classified into smaller categories using decisions and cutoff values.

In order to classify the data into smaller subsets, road segments were separated into groups with similar characteristics and crash histories. Characteristics by which the data could be classified needed to be determined, as well as cutoff values for those characteristics that had continuous values. Possible methods for determining these cutoff values included arbitrarily choosing values, identifying natural breaks in the data, searching the literature for commonly used cutoff values, and choosing cutoff values such that the standard deviation of dependent variables was at a minimum.

The computer program CART™, which was introduced in Section 2.5.5.2, was utilized to assist in determining which variables were most important in order to classify the data into smaller groups and to determine which cutoff values should be used. As with SPSS®, independent and dependent variables were entered into CART™ to perform this analysis. Figure 5.1 shows the Model Setup window, where each variable can be designated as a "Target" variable (or dependent variable), "Predictor" variable (or independent variable), "Categorical" variable, or "Weight" variable. As was done in the stepwise linear regression analysis in SPSS®, length was chosen as the "Weight" variable. The "Regression" tree option was chosen for the analysis because the target variable (crash severity score) was continuous and not categorical (Steinberg and Colla 1997b).

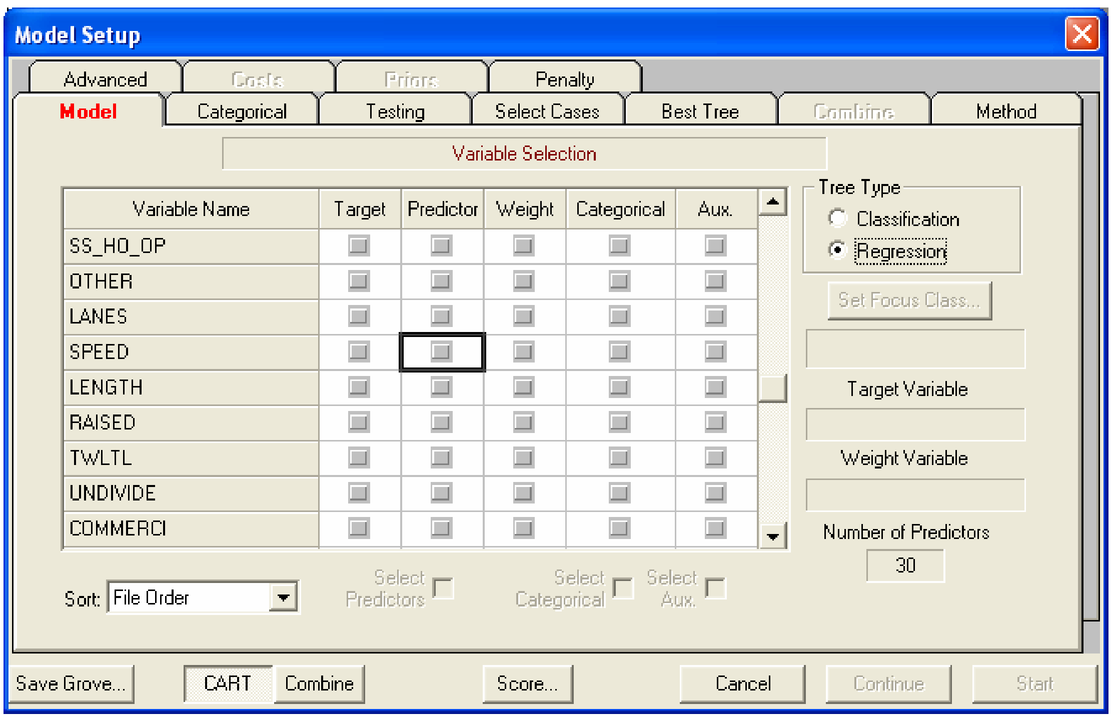

Figure 5.1 Model Setup window in CART™.

After completing the model setup, CART™ partitions the data into smaller groups of data with progressively smaller standard deviations utilizing a process known as "binary recursive" partitioning. "Binary" means that each "parent" node (or starting group of data) is split into exactly two "child" nodes (or subcategories of data), while "recursive" means that each "child" node then becomes a new "parent node." Instead of CART™ attempting to determine whether to stop partitioning data after each split, the process of splitting data into groups with smaller standard deviations is repeated until the data can no longer be split into more groups. CART™ then calculates the relative error (a measure of variance) for each possible decision tree and selects the tree with the smallest relative error to be the "best" tree (Steinberg and Colla 1997b).

Figure 5.2 shows a sample output of the CART™ process. The "best" tree from this particular analysis had three decision nodes and four terminal nodes as is shown in Figure 5.2. In the bottom of Figure 5.2, a plot showing relative error versus number of terminal nodes is shown. Figure 5.2 shows that the "best" tree has a relative error of 0.547.

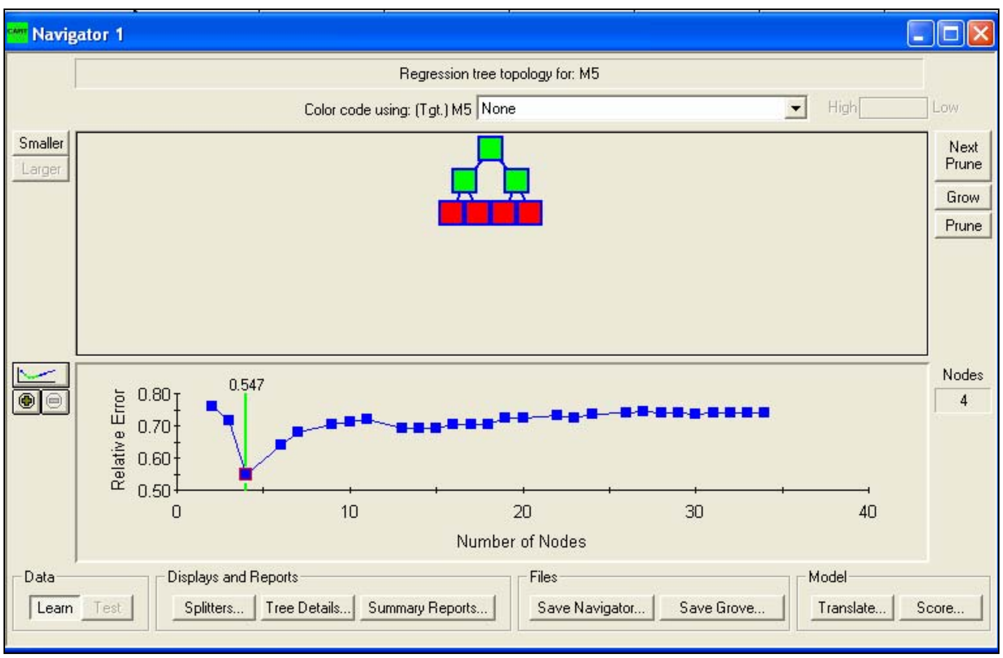

Figure 5.2 CART™ Navigator window showing decision tree and relative error.

Figure 5.3 shows the specific details for the decision tree from Figure 5.2. Each decision node (hexagon) states the decision to be made and the standard deviation, mean, and number of data points corresponding to the parent group's data. For example, the first decision node (Node 1) has 177 road segments corresponding to 208.8 miles in total length of data, with a mean crash severity score of 2,046 and a standard deviation of 1,506. The decision to make at this point is whether the AADT is less than or equal to 25,971. The next two nodes contain the data with AADT less than or equal to 25,971 (on the left) and AADT greater than 25,971 (on the right). The terminal nodes (squares) contain the data in groups with sufficiently low standard deviations to have the smallest relative error possible, as was shown in Figure 5.2.

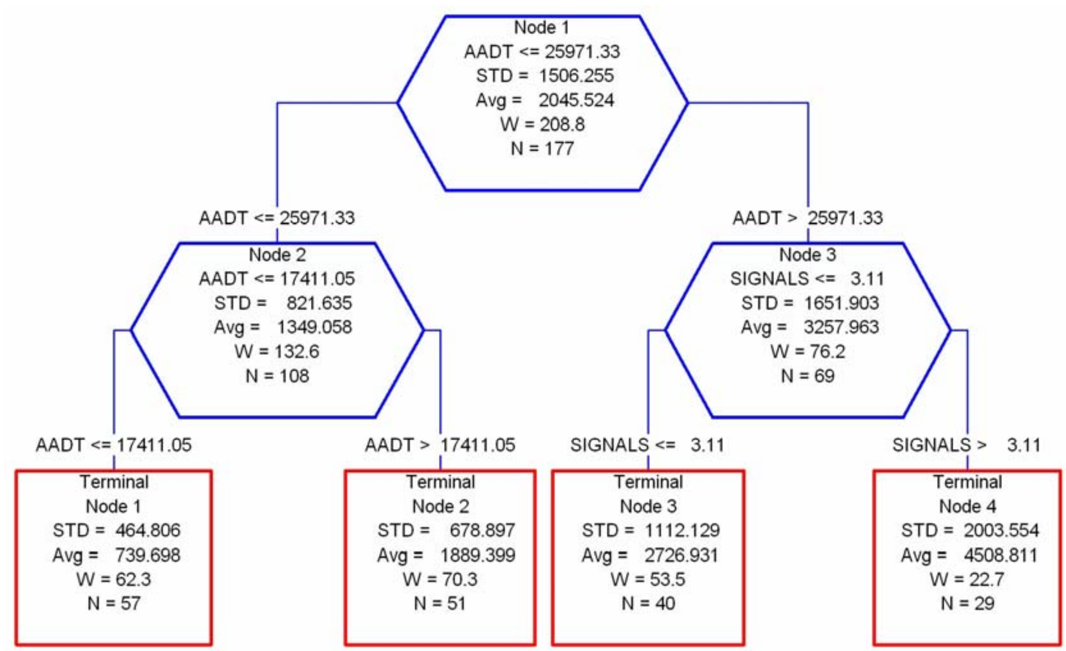

Figure 5.3 Details of CART™ decision tree.

Based on analysis from SPSS® and CART™, the two most important variables in determining crash severity score were volume and signal spacing. To illustrate the relationship that exists between crash severity score and volume and between crash severity score and signal spacing, the results of the relationships were plotted. Figure 5.4 shows the general relationship between volume and crash severity score, and Figure 5.5 shows the general relationship between signals per mile and crash severity score for all road segments for which data were collected.

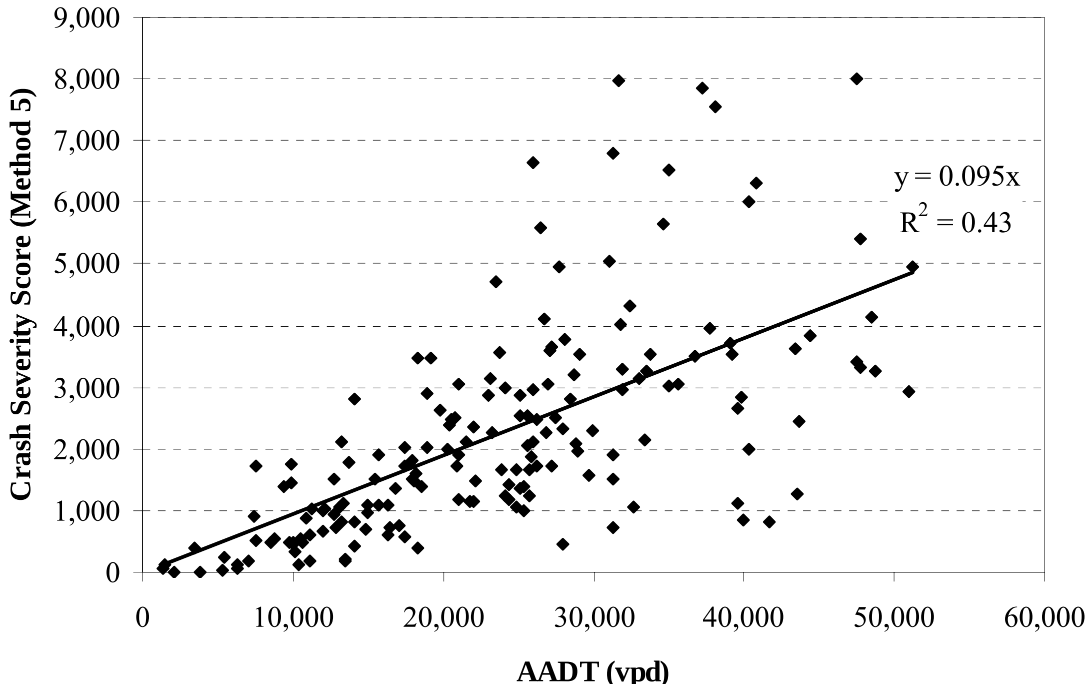

Figure 5.4 Crash severity score versus AADT.

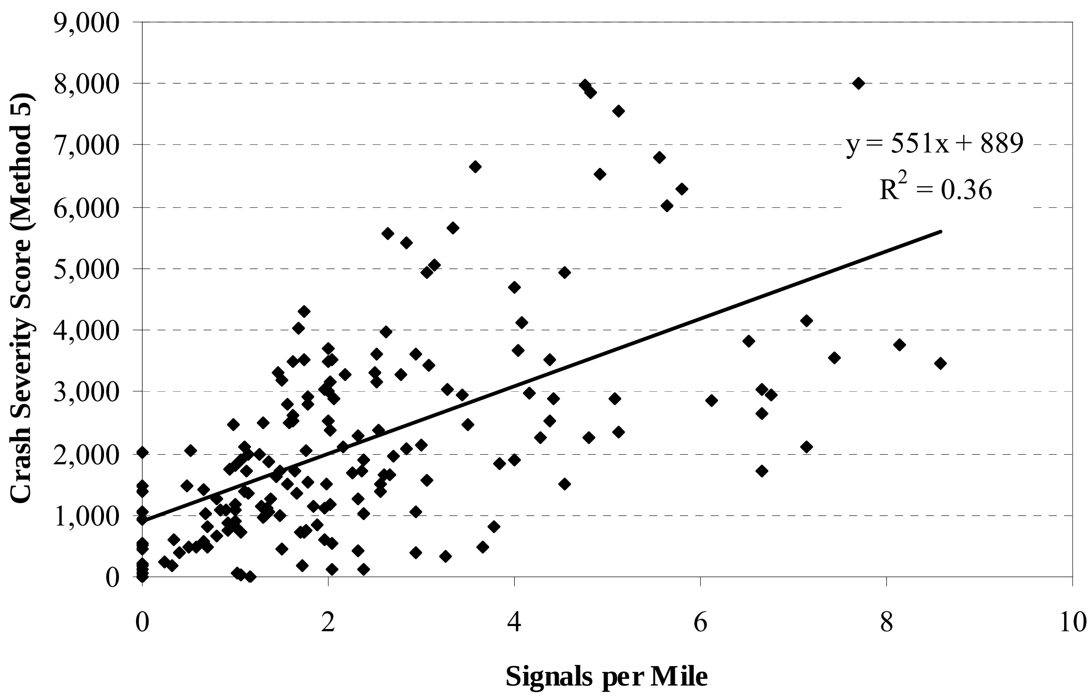

Figure 5.5 Crash severity score versus signals per mile.

Figure 5.4 and Figure 5.5 show the correlation of both volume and signal spacing with crash severity score. Figure 5.4 shows that crash severity score increased linearly with AADT with an R-squared value of 0.43. Figure 5.5 shows that crash severity score also increased linearly with signals per mile with an R-squared value of 0.36. Detailed statistical analyses were not completed on the data shown in Figure 5.4 and Figure 5.5. These figures are only presented to show the general relationship between these two characteristics and crash severity score. The following sections discuss how the cutoff values for volume and signals per mile were chosen to categorize the road segments into smaller subsets of data.

5.2.1 Volume

Potential cutoff values for AADT were chosen by examining the literature, the distribution of data collected for this research, and by using CART™. Sensitivity analyses utilizing descriptive statistics were then conducted to determine which of the potential cutoff values should be used.

According to the literature, the point at which raised medians become advantageous over TWLTLs is between 24,000 and 28,000 vpd (TRB 2003), therefore, the first potential cutoff value was 26,000 vpd.

Natural breaks in the data collected were found to be around 10,000 and 30,000 vpd. Therefore, the second potential cutoff values were 10,000 and 30,000 vpd.

The third set of potential cutoff values was determined utilizing CART™. AADT was divided by CART™ into groups under 17,500 vpd, between 17,500 and 26,000 vpd, and over 26,000 vpd.

Finally, by dividing the data into exactly three sections (weighted by length), the potential cutoff vales were 18,000 and 27,000 vpd. Table 5.2 summarizes the four sets of potential cutoff values to split up the data.

Sensitivity analyses were completed by examining the means and standard deviations of the sets of data categorized by each of the potential cutoff values discussed above. The cutoff values obtained from the CART™ program yielded the overall lowest standard deviations.

Additional sensitivity analysis was conducted on the data by dividing the categories into the following groups: 1) under 15,000 vpd, 2) between 15,000 and 25,000 vpd, and 3) over 25,000 vpd, as is shown in Table 5.2. These rounded-off values yielded category standard deviations within 10 percent of the values obtained from the CART™ program. These values were therefore carried forward to the next categorization because they yielded sufficiently similar groups of data and because their cutoff values were within acceptable ranges based on the results in the literature.

Table 5.2 Potential Cutoff Values for AADT (vpd)

Source	Low AADT	Medium AADT	High AADT
Literature	< 26,000	-	> 26,000
Natural Breaks	< 10,000	10,000 - 30,000	> 30,000
CART™	< 17,500	17,500 - 26,000	> 26,000
Equal Groups	< 18,000	18,000 - 27,000	> 27,000
Rounded Values	< 15,000	15,000 - 25,000	> 25,000

5.2.2 Signal Spacing

As with AADT, potential cutoff values for signal spacing were chosen by examining the literature, the distribution of data collected for this research, and by using CART™. Sensitivity analysis was then conducted to determine optimal cutoff values.

According to the literature, 2 signals per mile is the optimal spacing for traffic signals (TRB 2003). Four signals per mile is also acceptable for minor arterials and densely developed areas where lower operating speeds are acceptable. Therefore, potential cutoff values of 2 and 4 were identified.

By examining the distribution of the data collected, additional potential cutoff values were identified as 2.02, corresponding to the weighted mean, and 1.69, corresponding to the weighted median.

Finally, potential cutoff values of 0.83, 1.99, and 3.11 were determined utilizing the CART™ program. Table 5.3 summarizes the seven identified potential cutoff values.

Table 5.3 Potential Cutoff Values for Signals per Mile

Source	Low Signals/mile	High Signals/mile
Literature	< 2	> 2
Literature	< 4	> 4
Mean	< 2.02	> 2.02
Median	< 1.69	> 1.69
CART™	< 0.83	> 0.83
CART™	< 1.99	> 1.99
CART™	< 3.11	> 3.11

Cutoff values selected for sensitivity analyses were 1, 2, 3, and 4 signals per mile, based on the potential cutoff values discussed above. The cutoff values of 3 and 4 yielded high standard deviations. The smallest standard deviation values were associated with the groups created by categorizing the road segments into groups less than, and greater than, 1 signal per mile. However, with a cutoff value of 1, some categories had very low numbers of road segments. While the standard deviations for the groups using 2 signals per mile were not as low as those associated with 1 signal per mile, the road segments were more evenly distributed. Furthermore, half-mile spacing (2 signals per mile) is recommended in the literature as being the optimal signal spacing for an arterial road (TRB 2003).

Six categories of road segments were created, as is shown in Table 5.4, by categorizing the road segments using the selected cutoff values for volume and signals per mile.

Table 5.4 Six Categories of Road Segments

AADT (vpd)	Signals per Mile
≤ 15,000	> 2.0
≤ 15,000	≤ 2.0
15,000 < AADT ≤ 25,000	> 2.0
15,000 < AADT ≤ 25,000	≤ 2.0
> 25,000	> 2.0
> 25,000	≤ 2.0

5.3 Access Management Techniques

Each set of road segments, as categorized using the methodology discussed in Section 5.2, was examined to determine which access management techniques were the most appropriate. The results of this analysis are contained in the following sections.

5.3.1 AADT Less than or Equal to 15,000

This section discusses arterial roads with AADT less than or equal to 15,000 vpd and is organized into subsections describing those segments with greater than 2 signals per mile and those with less than or equal to 2 signals per mile.

5.3.1.1 Greater than Two Signals per Mile

Because all but one of the road segments in this category had commercial adjacent land use, and because only approximately three miles of data was in this category, the data for this category was combined with the commercial land use arterials with less than 2 signals per mile discussed in the next subsection. No statistically significant correlations were identified between crash severity score and access management techniques for the data in this category.

5.3.1.2 Less than or Equal to Two Signals per Mile

The majority of road segments with under 15,000 vpd and less than or equal to 2 signals per mile had adjacent residential land use. However, those road segments that did have adjacent commercial land use were combined with the commercial land use arterials with greater than 2 signals per mile for this analysis. Linear regression performed on the data in this subcategory showed that crash severity score was positively correlated with access density at the 84 percent confidence level. This general upward trend is also seen in Figure 5.6. Therefore, limiting access density is the recommended access management treatment for arterials with AADT less than or equal to 15,000 vpd and adjacent to commercial land use.

Figure 5.6 shows that each additional access point corresponded to an increased severity score of approximately 25 points. However, one data point was omitted corresponding to a road segment that had over 100 access points per mile with a severity score of approximately 1,000. This road segment was removed because its access density of 100 access points per mile was uncharacteristic of the remainder of the data that fit into a domain of 15 to 60 access points per mile. Furthermore, two sections of road segment in Logan, Utah, each with AADT less than 2,000 vpd, were removed. Each had approximately 40 access points per mile but had severity scores of less than 200 points. These road segments were removed because their volumes were uncharacteristically low compared to the remainder of road segments that all had between 9,000 and 15,000 vpd.

The road segments with adjacent residential land use showed no correlation between crash severity score and access density as is shown in Figure 5.7. Furthermore, none of the road segments in the database contained in this subcategory had raised medians, so no recommendation for raised medians could be given. Figure 5.7 shows that residential arterial road segments with less than 15,000 vpd and greater than half-mile signal spacing tend to have severity scores of approximately 700 regardless of their access density.

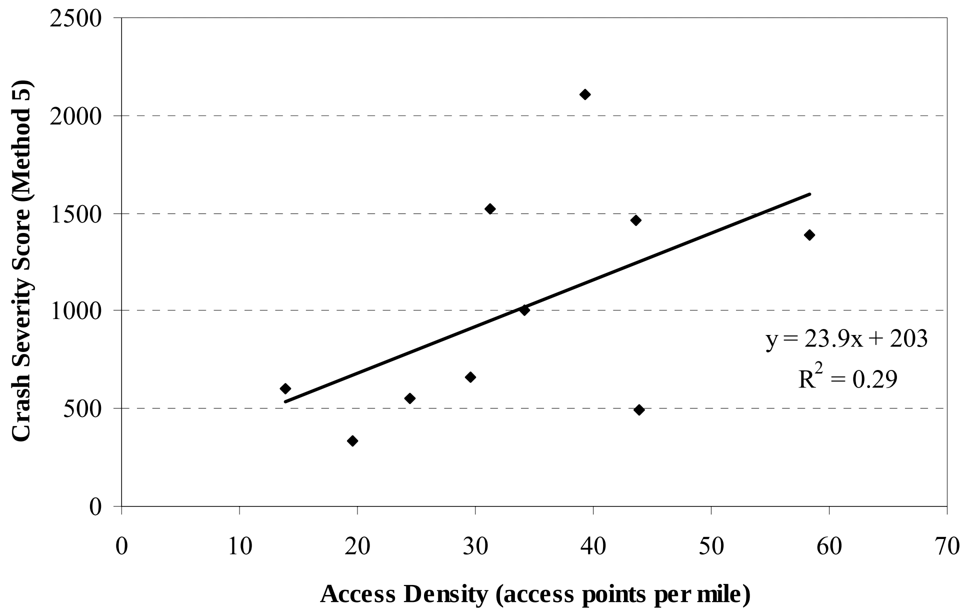

Figure 5.6 Crash severity score versus access density for commercial arterials with AADT under 15,000 vpd.

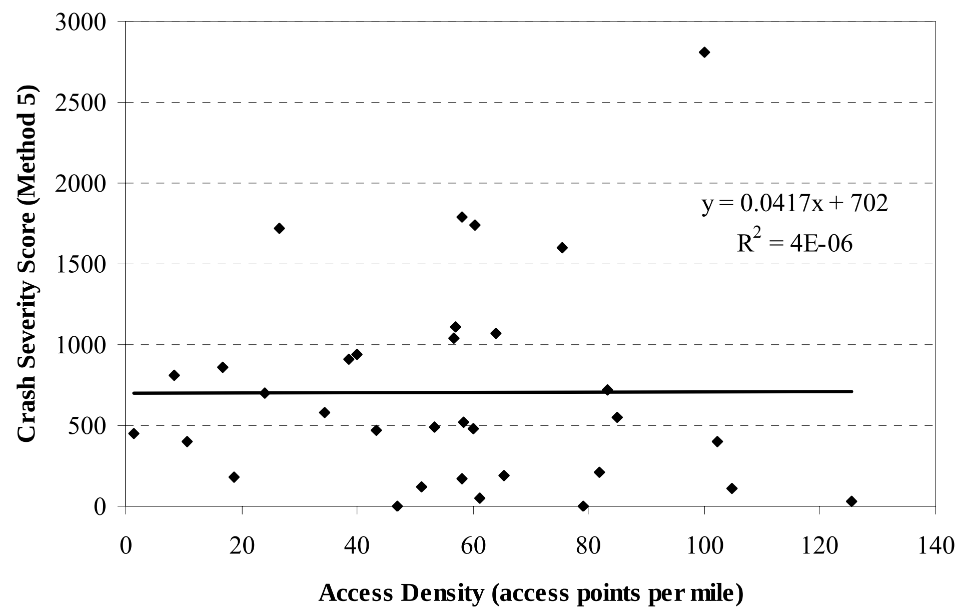

Figure 5.7 Crash severity score versus access density for residential arterials with AADT under 15,000 vpd.

The recommended access management techniques for low-volume roads with adjacent residential land use should focus on planning for road segments with potential for future growth. Future planning should include half-mile signal spacing, sufficient right-of-way for future medians, and access spacing guidelines to ensure that these low-AADT residential arterials with the potential for future development will grow appropriately. No recommendation for access management techniques is given for road segments in this subcategory without any potential for future growth.

5.3.2 AADT Greater than 15,000 and Less than or Equal to 25,000

This section discusses arterial roads with AADT greater than 15,000 and less than or equal to 25,000 vpd. The following two sections show that signal spacing is important for this range of AADT. Those sections with 2 or less signals per mile were far less sensitive to changes in access density compared to sections with greater than 2 signals per mile. This could be due to the fact that fewer access points were located near intersections because there were fewer intersections on those arterial segments.

5.3.2.1 Greater than Two Signals per Mile

The road segments with greater than 2 signals per mile were separated by adjacent land use. Figure 5.8 shows crash severity score plotted against access density for each land use. One road segment was omitted because it had abnormally low signal spacing. While the mean signal spacing for this group of road segments was approximately 1,400 feet, the omitted segment had a signal spacing of only 600 feet.

In addition to low R-squared values, as shown in Figure 5.8, linear regression revealed a significance level of only 69 percent for the independent variable of access density. However, a general trend of increasing crash severity score with increasing access density can be observed. For commercial arterials, the severity score increased by approximately 20 points per additional access point. Crash severity scores associated with residential arterials increased by only approximately 10 points per additional access point. This shows that access density was more significant for residential arterials when the AADT was higher. This is intuitive because, despite the residential land use, the number of conflicts is higher with added vehicles on the road. Median type was not significant in any of the analyses performed on the road segments in this category.

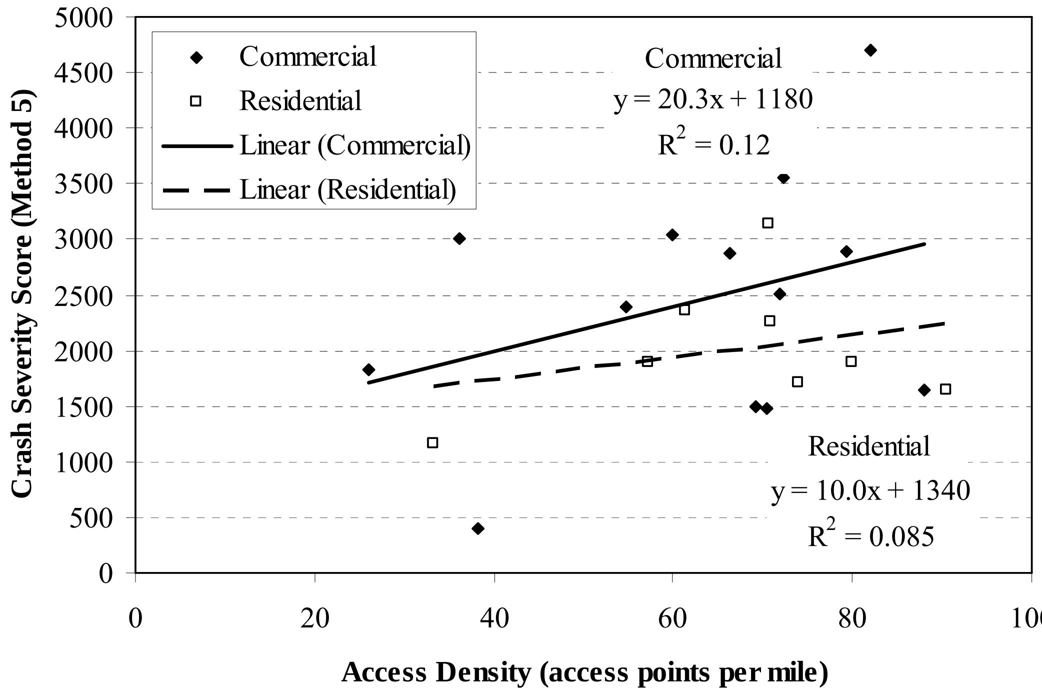

Figure 5.8 Crash severity score versus access density for commercial and residential arterials with AADT between 15,000 and 25,000 vpd and more than 2 signals per mile.

5.3.2.2 Less than or Equal to Two Signals per Mile

Road segments in this category were less sensitive to changes in access density as is shown in Figure 5.9. A fairly level trend line with a low R-squared value suggests that access density was not very well correlated with crash severity score. Linear regression also yielded a low significance level of approximately 85 percent. Furthermore, the mean value for the crash severity score in this category was approximately 1,500 compared to approximately 2,300 for segments with the same AADT but greater than 2 signals per mile.

The focus on planning for road segments in this subcategory should be placed on the potential for future growth. Future planning should include half-mile signal spacing, sufficient right-of-way for future medians, and access spacing guidelines to ensure that these arterials with the potential for future development will grow appropriately. Only one arterial road segment had a raised median, so no analysis was performed to determine whether median types were correlated to crash severity scores for this category of road segments.

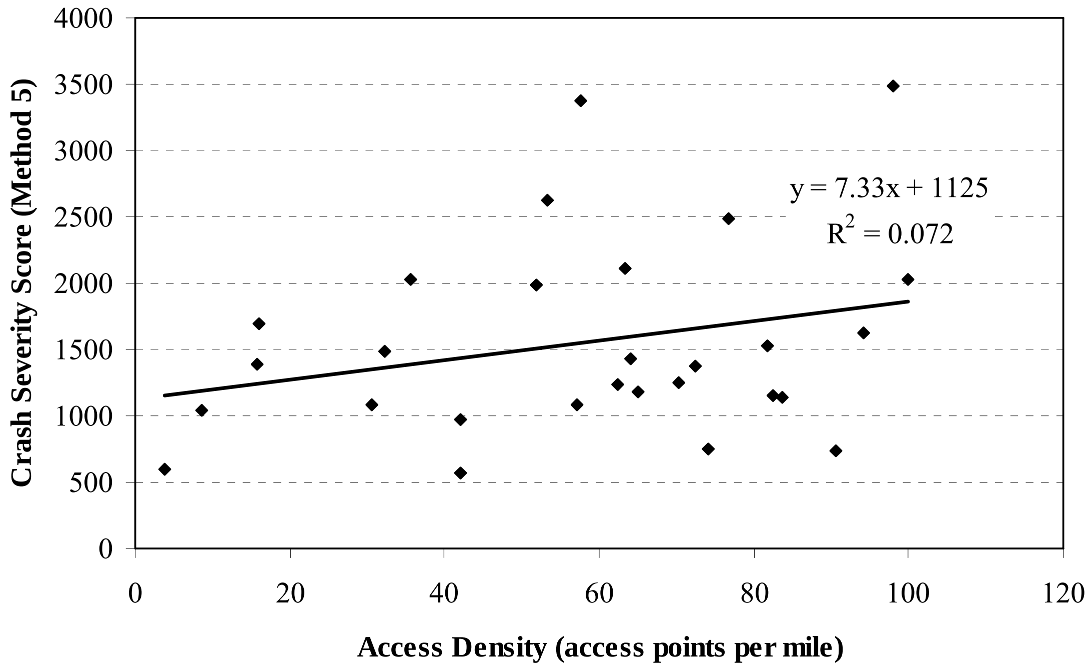

Figure 5.9 Crash severity score versus access density for arterials with AADT between 15,000 and 25,000 vpd and less than 2 signals per mile.

5.3.3 AADT Greater than 25,000

This section discusses arterial roads with AADT greater than 25,000 vpd and is organized into subsections describing road segments with greater than 2 signals per mile and those with 2 or less signals per mile.

5.3.3.1 Greater than Two Signals per Mile

Various regression models were tested for the data in this category with more than 2 signals per mile. Special attention was placed on determining how raised medians were correlated to severity scores, as the literature recommends installing raised medians when the AADT reaches 24,000 to 28,000 vpd (TRB 2003, Gluck et al. 1999).

The SPSS® analysis completed in this research showed that road segments with raised medians were correlated with severity scores approximately 1,000 points lower than road segments without raised medians. The linear regression model analyzed to come to this conclusion also included signals per mile. Therefore, given two road segments in this category with equivalent numbers of signals per mile, the segment with a raised median would have a severity score 1,000 points less than a segment without a raised median. The results of the linear regression analysis, including coefficients, *t*-statistics, and *p*-values, are shown in Table 5.5.

Interestingly, Table 5.5 shows that with only 2 additional signals per mile the safety benefits of adding a raised median are offset. That is, a raised median is correlated with a decrease in crash severity score of approximately 1,000 points, while 2 signals per mile correspond to an increase in severity score of approximately 1,000 points. Furthermore, for those road segments in this subcategory that already had raised medians, access density was positively correlated with crash severity score as is shown in Figure 5.10. Figure 5.10 shows that, for each additional access point added, the severity score was increased by approximately 25 points.

Table 5.5 Regression Coefficients for High AADT and High Signals per Mile

Variable	**Regression Coefficient**	**Standard Error**	***t*-statistic**	***p*-value**
(Constant)	1690	554	3.06	<0.01
Signals/Mile	585	146	4.00	<0.01
Raised Median	-1030	517	-1.99	0.05

5.3.3.2 Less than or Equal to Two Signals per Mile

For road segments with less than or equal to 2 signals per mile, the analysis results showed a positive correlation between access density and crash severity score in commercial areas but no correlation in residential areas. With respect to arterials with adjacent commercial land use, linear regression showed positive correlation between crash severity score and access management with an 81 percent confidence level. Figure 5.11 shows crash severity scores plotted against access density for arterials with adjacent commercial and residential land use.

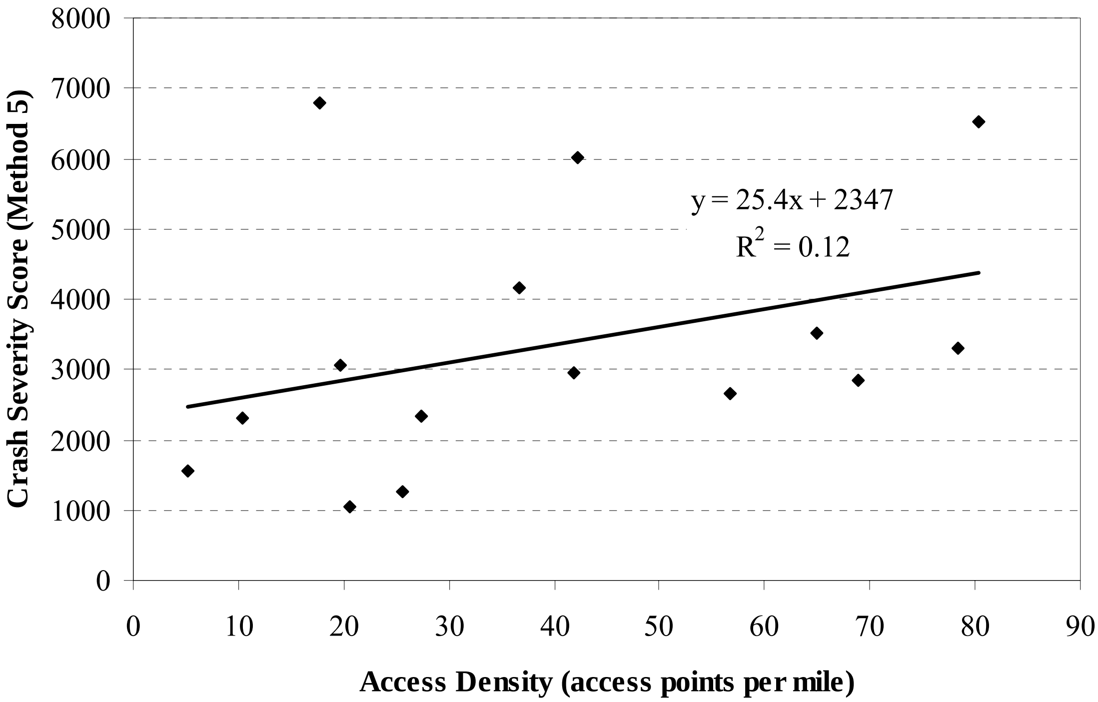

Figure 5.10 Crash severity score versus access density for arterials with AADT over 25,000 vpd, more than 2 signals per mile, and a raised median present.

Limiting access density is recommended for road segments with commercial adjacent land use because, for each additional access point, the crash severity score increased by approximately 15 points.

Figure 5.11 also shows that arterials were less affected in residential areas by high access density, most likely because the volumes at the driveways were insignificant compared to the volumes of a comparable number of driveways in commercial areas.

The focus on planning for road segments in this subcategory should be placed on the potential for future growth and volumes. Future planning should include half-mile signal spacing, sufficient right-of-way for future medians, and access spacing guidelines to ensure that these arterials with the potential for future development will grow appropriately.

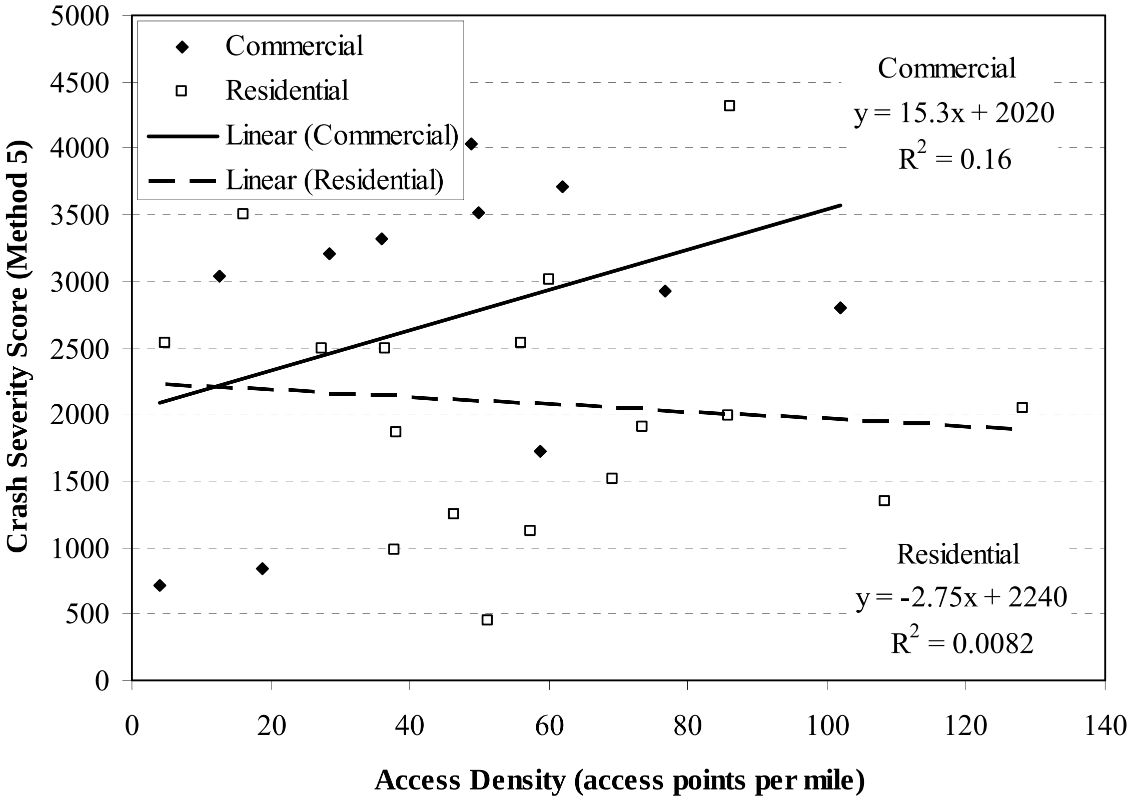

Figure 5.11 Crash severity score versus access density for commercial and residential arterials with AADT over 25,000 vpd and less than 2 signals per mile.

5.4 Decision Tree

Figure 5.12 shows the decision tree created based on the analysis discussed in the previous sections. It is presented in a step-by-step procedure to arrive at recommendations for access management treatments on Utah arterial road segments. The six steps are discussed in the following sections.

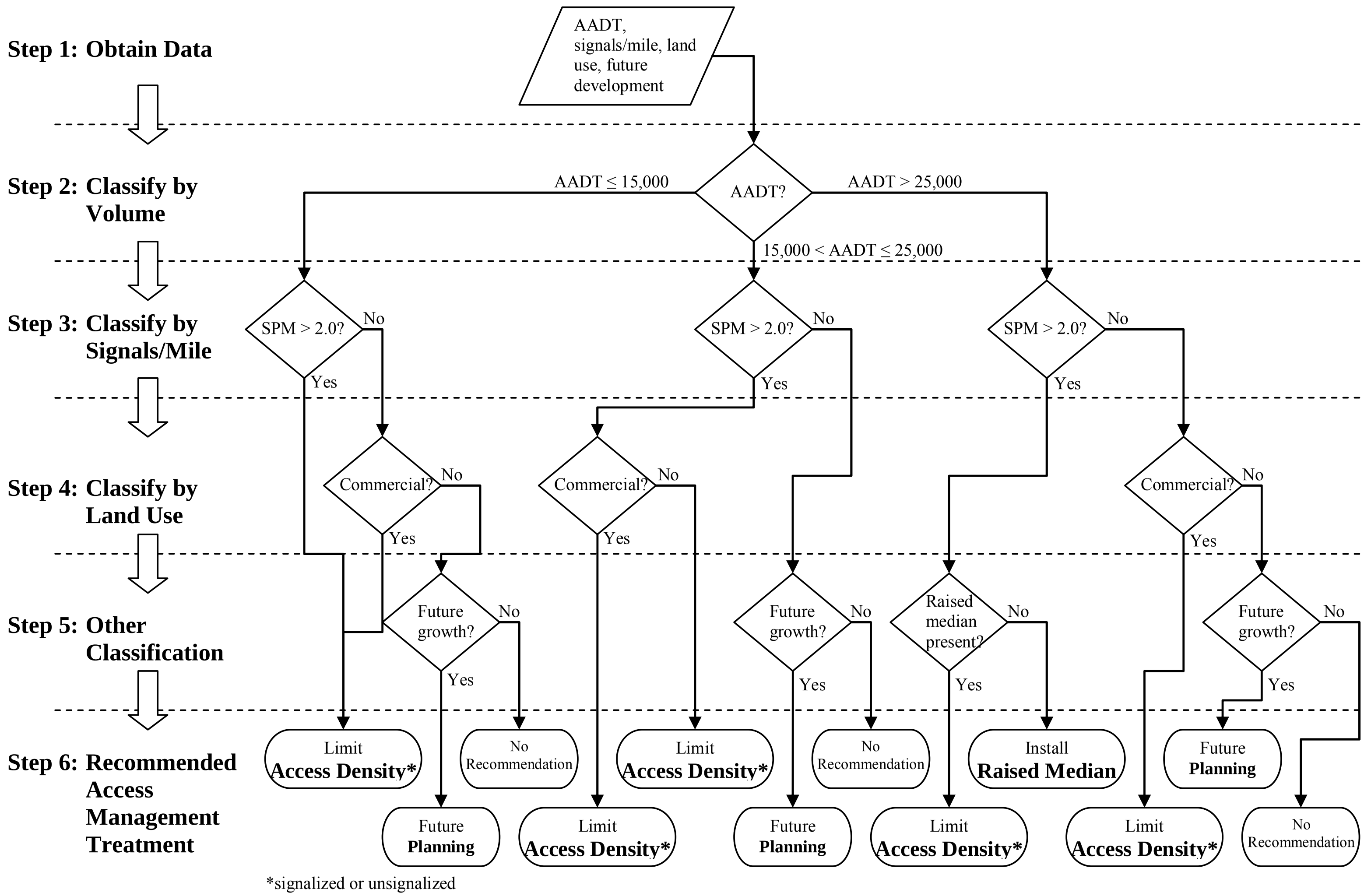

Figure 5.12 Decision tree for determining recommended access management techniques.

5.4.1 *Step 1: Obtain Data*

The first step in the decision tree is to collect data for the road segment being analyzed, including the AADT, signals per mile, adjacent land use, and potential for future development. AADT for all state routes in Utah can be obtained from UDOT (UDOT 2004). Signals per mile can be determined by using the UDOT Road Viewer program (UDOT 2006b), the UDOT web-based crash almanac (Anderson et al. 2005), or site visits. A methodology for calculating signals per mile as a function of the number of signals and the length of the segment was discussed in Section 3.3.10. Adjacent land use can be determined from aerial photography such as Google Maps (Google 2006) or from site visits. Future development can be obtained from consulting the local government's general plan or zoning maps.

5.4.2 *Step 2: Classify by Volume*

Based on the analysis outlined previously in Section 5.2.1, the road segment being analyzed is categorized as having either low, medium, or high volume corresponding to less than or equal to 15,000 vpd, greater than 15,000 and less than or equal to 25,000 vpd, or greater than 25,000 vpd, respectively. Alternatively, a road segment could also be categorized by future expected volume in order to determine future needed access management treatments.

5.4.3 *Step 3: Classify by Signals per Mile*

Following classification by volume, the road segment is classified by its signal spacing. Roadways are classified based on whether the segment has 2 or less signals per mile or greater than 2 signals per mile.

5.4.4 *Step 4: Classify by Land Use*

Depending on the classification of the road segment according to its volume and signals per mile, some segments are further classified as having either adjacent commercial or residential land use.

5.4.5 *Step 5: Other Classification*

Some road segments are then classified as either having future potential growth or not. Additionally, high volume arterials with greater than 2 signals per mile are classified as having a raised median or not.

5.4.6 *Step 6: Recommended Access Management Treatments*

Access management treatments are recommended based on the classification from steps two through five, including limit access density, install raised median, future planning, and no recommendation. The justifications for each of these recommendations were discussed in detail in Section 5.3 and are summarized in the following subsections.

5.4.6.1 Limit Access Density

Limiting access density is recommended for five of the 12 subcategories shown in Figure 5.12. Limiting access density can include consolidating driveways, eliminating driveways, removing traffic signals or signalized driveways, or creating backage roads. This recommendation is given to subcategories where access densities were positively correlated with crash severity scores. While the degree to which these correlations were significant varied based on volume and signals per mile, the primary technique correlated with lower safety was limiting access density.

5.4.6.2 Install Raised Medians

As shown in Figure 5.12, installing a raised median is only recommended in one of the 12 subcategories, namely high-volume segments with more than 2 signals per mile. Statistical analyses discussed in Section 5.3.3.1 showed that raised medians corresponded to lower crash severities than did TWLTLs. This could be due to the fact that, as arterials become more congested, more conflict points exist. Furthermore, the more signals that are installed, the more likely these conflict points occur in the functional areas of the signalized intersections, thereby creating a larger need for raised medians.

5.4.6.3 Future Planning

Future planning is recommended for three of the 12 subcategories shown in Figure 5.12. Determining future growth and land use changes are critical in planning for good access management, especially for those roads that are adjacent to undeveloped land. Signal spacing, number of access points, and right-of-way sufficiently large enough for future median treatments are all aspects of a corridor that can be planned well in advance but may be too difficult or costly to change in the future. For example, once a road segment has multiple signals per mile, removing any of those signals would be very difficult. However, by planning the quantity and location of signals on a given corridor years before development is expected, good signal spacing can be achieved and maintained.

5.4.6.4 No Recommendation

Finally, three subcategories out of 12, as shown in Figure 5.12, are given no recommendation for access management treatments because no correlation between crash severity score and any access management treatment for the road segments contained in these subcategories was apparent. These road segments are those with low signals per mile and little expected future growth. As available funds for access management treatments are limited, other areas discussed above should be targeted instead of these road segments.

5.5 Sample Recommendations

The data collected for the database discussed in Chapter 3 were classified utilizing the decision tree outlined in Section 5.4 and given recommendations for possible access management treatments. Two important points are noted. First, the recommendations here are only limited to those road segments for which data were collected and analyzed in this report and are not comprehensive lists of sites recommended for access management treatments. Several more state routes exist that were omitted from the original data collection efforts because insufficient data were available for them. The analysis completed on this data could also be conducted on these other sites. Second, these recommendations merely represent those corridors for which in-depth analysis and feasibility should be conducted. The recommendations are meant to give guidance to UDOT on possible locations at which to consider implementing access management.

5.5.1 Limit Access Density

Limiting access density is recommended for 77 of the 175 segments analyzed using the methodology discussed for the decision tree. These segments are portions of 35 corridors approximately 75 miles in total length. The list of corridors is contained in Appendix F.

5.5.2 Install Raised Medians

A raised median is recommended for 37 of the 175 segments analyzed using the methodology discussed for the decision tree. These segments are portions of 21 corridors approximately 40 miles in total length. The list of corridors is contained in Appendix G.

Interestingly, one corridor on the list is St. George Blvd (SR-36) in St. George, Utah. After the analysis years of 2002 to 2004, a raised median has since been installed on this state route.

5.5.3 Future Planning and No Recommendation

Because data on the potential future growth was not obtained for the road segments in the database, the recommendations for “future planning” and “no recommendation” cannot be differentiated. Therefore, road segments in both of these categories are combined and reported in Appendix H.

5.6 Summary of Prioritization Process

This chapter discusses the prioritization process developed to recommend access management principles and techniques for state routes in Utah. A decision tree was utilized to classify road segments into smaller subcategories by determining appropriate characteristics and cutoff values to categorize the data. The goal of classifying the data was to find subcategories of road segments with similar characteristics and crash severity scores. Access management techniques were then recommended for each subcategory based on correlations between access management techniques and crash severity score. The decision tree was illustrated, and a step-by-step process for using the decision tree was outlined. Possible recommendations were given for the road segments collected for the database.

6 Conclusions and Recommendations

The preceding chapters have discussed a performance-index-based prioritization process for access management treatments for arterial roads in the state of Utah. Chapter 2 provided a literature review summarizing access management treatments currently being implemented both in and out of the state of Utah. Safety impacts of access management techniques in Utah were also reviewed, as well as a web-based crash almanac that has been proven effective in analyzing the safety of Utah roads, including those with access management techniques. Finally, the literature was reviewed to determine what safety and performance indices have been developed. Chapter 3 discussed an in-depth database created to evaluate the safety of 175 segments of arterial roads in Utah. Data included in the database were identifying features, characteristics of each segment, and crash histories. The methodology used to obtain this data was also discussed. Chapter 4 discussed statistical analysis, specifically stepwise linear regression, to determine correlations between access management techniques and crash histories including crash rate, crash severity score, and various collision types. Chapter 5 discussed a performance-index-based prioritization process, specifically a decision tree, which can be utilized to determine which arterial roads in Utah would best be improved by various access management treatments.

This chapter discusses the conclusions of this report in Section 6.1, recommendations in Section 6.2, and recommendations for future research in Section 6.3.

6.1 Conclusions

As stated in Section 1.2, the purpose of this report was to develop a prioritization process based on principles of performance indices that can be utilized to target arterial road segments that would benefit from the implementation of various access management principles and techniques. This was accomplished by collecting existing characteristics and crash histories and determining the impact of access management on the safety of arterial roads. A performance-index-based prioritization process was created using these relationships as the basis for a decision tree that can be used to evaluate the need for access management on a given road segment.

A secondary purpose of this research was to determine how access management principles and techniques were related to crash severity and to expand the literature on the safety benefits of access management techniques. Statistical analysis showed that the lack of access management, such as high access density, numerous signals per mile, and lack of medians, were positively correlated with increased crash rates and increased crash severity. Certain collision types, such as right-angle, side-swipe, and opposite-direction crashes, were also more likely to occur when access was not effectively managed. Furthermore, land use plays a significant role in the safety of arterials. Road segments with adjacent commercial land use tended to have higher crash rates and severity scores.

Finally, this research has shown that in addition to the safety benefits well established in the literature, access management positively benefits safety in the state of Utah.

6.2 Recommendations

Based on the conclusions of this research, it is recommended that access management be continually implemented on arterial roads in the state of Utah. A decision tree was outlined in Chapter 5 that can assist UDOT personnel in determining which arterial roads might benefit the most from various access management techniques. To use the decision tree, information about AADT, signals per mile, adjacent land use, and future growth is needed to classify arterial road segments. Possible recommendations include limiting access points, installing raised medians, and planning for future growth by implementing standards for adequate signalized and unsignalized access spacing and obtaining sufficient right-of-way for future medians.

6.3 Future Research

Further research is recommended in the areas of safety and access management. A crash prediction model should be developed to assist planners in understanding the impact of future growth on state routes. An empirical Bayesian methodology was identified in the literature that could be an effective means of conducting this analysis. Access management should be a key component in this model to show the effect it has on the predicted safety of state routes.

Other research recommended in order to study the effects of access management could include examining the relationship between crashes and the number of conflict points. Instead of only considering access points, the number of conflict points created by multiple lanes and turning movements could be correlated with crash rates, severity scores, or certain collision types. Additionally, the effect of access in the vicinity of signalized intersections could be analyzed. Finally, a methodology could be developed to examine crashes most likely caused by access density instead of all crashes in general. This could more accurately show the benefits of access management on arterial roads.

As additional corridors in Utah are reconstructed to include better access management, before-and-after analyses, such as those performed by Schultz and Lewis (2006), should be completed to track the safety benefits of the treatments.

Finally, as safety impacts of access management become more established in both the literature as well as in the state of Utah, the need will arise to show the economic impact of access management treatments to the communities in which access management treatments are implemented. For example, a financial analysis could be completed on businesses along arterial corridors before, during, and after construction of a raised median. The analysis could include objective data, including property values, vacancy rates, and sales, as well as subjective ratings given by customers and business managers. Similar research has been completed in other states (FHWA 2006).

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Appendix A. Identification of Road Segments

Table A.1 Identifying Features of Road Segments

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
101a	Main St	Cache	101	3.74	5.91	400 W to SR 165	7
218a	100N	Cache	218	7.77	8.2	300 W to SR 91	5
237a	800E	Cache	237	0	0.38	700 N to 1000 N	5
237b	800E	Cache	237	0.38	0.87	1000 N to 1400 N	5
238a	300 S	Cache	238	4.21	4.68	Main St to 400 E	7
239a	1400N	Cache	239	0	1.04	SR 91 to SR 237	5
288a	1200E	Cache	288	0	0.49	SR 89 to 1000 N	8
288b	1000N	Cache	288	0.49	0.98	1200 E to 800 E	8
105a	Parrish Lane	Davis	105	0	0.35	RR to 400 W	6
105b	Parrish Lane	Davis	105	0.35	0.69	400 W to Main (SR 106)	6
106a	2nd East	Davis	106	5.18	6.9	1700 S to 200 S	5
106b	200E/State	Davis	106	6.9	7.4	200 S to 100 N	6
106c	Main	Davis	106	7.4	8.29	100 N to SR 225	6
106d	Main	Davis	106	8.29	9.04	SR 225 to Sheppard Lane	5
106e	Sheppard Ln	Davis	106	9.04	9.43	Main St to SR 89	5
108a	Antelope Rd	Davis	108	0.2	0.62	I-15 to State (SR 126)	5
108b	Antelope Rd	Davis	108	0.62	2.92	State (SR 126) to 1000 W	5
108c	Antelope Rd	Davis	108	2.92	3.92	1000 W to 2000 W	5
108d	2000 West	Davis	108	3.92	4.45	1700 S to 1175 S	5
108e	2000 West	Davis	108	4.45	7.41	1175 S to SR 37	5
108f	2000 West	Davis	108	7.41	8.42	SR 37 to 6000 S	5
109a	Gentile St	Davis	109	0	0.44	Main St to Fort Lane	6
109b	Gentile St	Davis	109	0.44	0.76	Fort Lane to Chapel St	6
109c	Gentile St	Davis	109	0.76	1.19	700 E to Adamswood Rd	5
109d	Oak Hills Rd	Davis	109	1.36	2.96	Rosewood Lane to US 89	3
126a	Main St	Davis	126	0	3.21	900 S to Antelope Dr	5
126b	State St	Davis	126	3.21	4.45	Antelope Dr to SR 193	5
126c	State St	Davis	126	4.45	5.64	SR 193 to 300 N	5
126d	Main St	Davis	126	5.64	6.14	300 N to 800 N	5
126e	Main St	Davis	126	6.14	8.17	800 N to 6000 S	5
193a	700 South	Davis	193	0	0.7	SR 126 to I-15 NB ramp	5
193b	SR 193	Davis	193	0.7	5.67	I-15 NB ramp to US 89	3
227a	200 West	Davis	227	0	0.49	I-15 to State St	5
227b	State St	Davis	227	0.49	0.7	200 W to Main	6
232a	Hill Field Rd	Davis	232	0	0.27	SR 126 to Gordon Ave	5

Table A.1 Continued

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
232b	Hill Field Rd	Davis	232	0.27	2.26	Gordon to SR 193	5
273a	Main St	Davis	273	0	1.92	US-89 to 200 S	5
273b	Main St	Davis	273	1.92	2.48	200 S to 100 W	6
273c	Main St	Davis	273	2.48	2.87	100 W to I-15	5
37a	1800N	Davis	37	0	0.99	Main St to 1000 W	5
37b	1800N	Davis	37	0.99	2.42	1000 W to 2430 W	5
37c	1800N	Davis	37	2.42	2.76	2430 W to 2750 W	5
151a	S. Jord. Pkwy	SL	151	0	2.01	Bangerter to Redwood	5
171a	3500 S	SL	171	0	1.5	SR 111 to 7200 W	5
171b	3500 S	SL	171	1.5	3.53	7200 W to 5600 W	5
171c	3500 S	SL	171	3.53	7.03	5600 W to 2700 W	5
171d	3500 S	SL	171	7.61	8.05	2200 W to Redwood Rd	5
171e	3500S/3300S	SL	171	8.05	9.24	Redwood Rd. to 900 W	5
171f	3300 S	SL	171	9.24	9.85	900 W to 500 W	5
171g	3300 S	SL	171	10.14	10.75	300 W to State St.	5
171h	3300 S	SL	171	10.75	12.73	State to Highland Dr.	5
171i	3300 S	SL	171	12.73	14.11	Highland Dr. to 2300 E	5
171j	3300 S	SL	171	14.11	14.61	2300 E to 2700 E	5
171k	3300 S	SL	171	14.61	15.36	2700 E to 3300 E	5
173a	5400 S	SL	173	2.64	4.07	5600 W to 4460 W	-
173b	5400 S	SL	173	4.07	6.93	4460 W to 1900 W	-
173c	5400 S	SL	173	6.93	8.65	1900 W to 700 W	-
173d	5300 S/Spartan	SL	173	8.65	9.82	700 West to SR 89	-
181a	13th E	SL	181	0	2.81	SR-152 to 3300 S	5
181b	13th E	SL	181	2.81	3.44	3300 S to Crandall	5
181c	13th E	SL	181	3.44	4.12	Crandall to 2455 S	5
181d	13th E	SL	181	4.12	4.61	2455 S to 2100 S	3,6
181e	13th E	SL	181	4.61	5.17	2100 S to 1700 S	6
181f	13th E	SL	181	5.17	5.74	1700 S to 1300 S	6
181g	13th E	SL	181	5.74	6.89	1300 S to 500 S	6
184a	State/300N	SL	184	0	0.76	North Temple to Zane	6
186a	300 West	SL	186	4.35	5.09	North Temple to 400 S	6
186b	400 South	SL	186	5.09	5.54	300 W to Main Street	6
186c	400/500 South	SL	186	5.54	8.04	Main St to Guardsman	6
186d	Foothill	SL	186	8.04	9.02	Guardsman to Sunnyside	3
186e	21st East	SL	186	9.02	9.45	Sunnyside to Foothill	5
186f	Foothill	SL	186	9.45	9.98	2100 E to 2300 E	5
186g	Foothill	SL	186	9.98	11.25	2300 E to Stringham	5
190a	6200 S	SL	190	0.07	1.84	I-215 to Fort Union	3
195a	2300 E	SL	195	0	2.56	4500 S to I-80	3
209a	9000 S	SL	209	5.35	6.21	Redwood Rd to 1075 W	5
209b	9000 S	SL	209	6.21	7.14	1075 W to Sandy Pkwy	3
209c	9000 S	SL	209	7.14	7.85	Sandy Pkwy to State St	3,5
209d	9000 S	SL	209	7.85	8.84	State Street to SR 71	5
209e	9400 S	SL	209	10.18	11.74	1300 E to Quail Hollow	5
209f	Cottonwood	SL	209	11.74	12.79	2300 E to 3100 E	5
209g	Cottonwood	SL	209	12.79	13.33	3100 E to Wasatch Blvd	5

Table A.1 Continued

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
209h	Cottonwood	SL	209	13.33	14.57	Wasatch Blvd to SR 210	5
266a	4700 S	SL	266	0.27	0.77	2200 W to Redwood Rd.	5
266b	4700 S	SL	266	0.77	2.63	Redwood Rd to 500 W	3
266c	4500 S	SL	266	2.63	3.53	500 W to State	5
266d	4500 S	SL	266	3.53	4.73	State to 900 E	5
266e	4500 S	SL	266	4.73	6	900 E to Highland	5
266f	4500 S	SL	266	6	8.02	Highland to I-215	5
269a	600 S (EB)	SL	269	0	0.9	500 W to State (EB)	5
269b	500 S (WB)	SL	269	0.9	1.8	State to 500 W (WB)	5
270a	West Temple	SL	270	0.15	0.75	800 S to 400 S	6
48a	7800 S	SL	48	8.13	10.11	Bangerter to Redwood	5
48b	7000S	SL	48	10.11	10.6	Redwood Rd to 1300 W	5
48c	7200 S	SL	48	12.12	12.69	400 W to SR 89	5
68a	Redwood Rd.	SL	68	40.18	45.21	SR 140 to 104th South	5
68b	Redwood Rd.	SL	68	45.21	46.95	SR 151 to 90th South	5
68c	Redwood Rd.	SL	68	46.95	50.75	SR 209 to I-215	5
68d	Redwood Rd.	SL	68	51.47	56.13	5400 S to 2320 S	5
68e	Redwood Rd.	SL	68	56.13	56.36	2320 S to SR 201	5
68h	Redwood Rd.	SL	68	57.31	58.88	1500 S to 400 S	5
68j	Redwood Rd.	SL	68	59.63	60.99	N Temple to 1100 N	5
71b	126th S	SL	71	0	2.92	Bangerter to 1300 W	5
71c	700 E	SL	71	6.02	8.22	123rd S to 106th S	5
71d	700 E	SL	71	8.22	8.85	106th S to Carnation Dr.	5
71e	700 E	SL	71	9.05	11.72	9950 S to 7800 S	5
71f	900 E	SL	71	11.72	12.7	7800 S to Fort Union	5
71g	900 E	SL	71	12.7	15.71	Fort Union to SR 152	5
71h	700 E	SL	71	16.52	18.28	4500 S to 3300 S	5
114a	Center St	Utah	114	0	0.45	500 W to 1000 W	8
114b	Geneva Road	Utah	114	1.43	4.87	Center to University Pk	6
114c	Geneva Road	Utah	114	4.87	5.19	University Pk to 1000 S	6
114d	Geneva Road	Utah	114	5.19	5.74	1000 S to 575 S	6
114e	Geneva Road	Utah	114	5.74	6.99	575 S to 400 N	6
114f	Geneva Road	Utah	114	6.99	8.5	400 N to 1600 N	5
114g	Geneva Road	Utah	114	8.5	10.52	1600 N to 700 S	5
114h	Geneva Road	Utah	114	10.52	10.77	700 S to SR 89	5
156a	Main Str	Utah	156	1.38	0	I-15 ref point 2 to 300 S	8
180a	500 E	Utah	180	0	1.04	I-15 to State	5
189a	University Ave	Utah	189	0.22	1.52	I-15 to 500 S	5
189b	University Ave	Utah	189	1.52	3.5	500 S to University Pk	6
189c	University Ave	Utah	189	3.5	5.8	University Pk to 4200 N	3
189d	University Ave	Utah	189	5.8	7.49	4200 N to SR-52	3
198a	State/100W	Utah	198	4.38	5.12	800 S to 200 S	5
198b	100W/100N	Utah	198	5.12	5.54	200 S to 200 E	8
198c	100N	Utah	198	5.54	6.26	200 E to 1000 E	6
198d	State	Utah	198	7.92	9.11	300 S to 400 N	6
52a	800 North	Utah	52	0	0.46	Geneva Road to I-15	6
52b	800 North	Utah	52	0.46	2.05	I-15 to Main St	6

Table A.1 Continued

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
52c	800 North	Utah	52	2.05	3.06	Main St to 800 E	6
52d	800 North	Utah	52	3.06	4.48	800 E to SR 189	6
73a	Main Street	Utah	73	39.35	40.43	780 W to 500 E	6
73b	Main Street	Utah	73	40.43	40.79	500 E to I-15	5
73c	Main Street	Utah	73	40.79	41.2	I-15 to SR 89	5
18a	Bluff St	Wash.	18	0.29	1.45	I-15 SB ramp to 400 S	5
18b	Bluff St	Wash.	18	1.45	1.98	400 S to Tabernacle St	5
18c	Bluff St	Wash.	18	1.98	3.17	Tabernacle to Sunset	5
212a	Telegraph St	Wash.	212	0.74	1.28	300 W to 300 E	5
34a	St George Bl	Wash.	34	0	0.57	SR 18 to Main St	5
34b	St George Bl	Wash.	34	0.57	1.74	Main St to 1000 E	5
104a	Wilson Lane	Weber	104	0	0.58	SR 126 to I-15 SB ramp	5
104b	Wilson Lane	Weber	104	0.58	1.85	I-15 to Begin Div Hwy	3
108g	3500W	Weber	108	8.42	9.92	6000 S to 4800 S	5
108h	Midland Drive	Weber	108	9.92	12.81	4800 S to 1900 W	5
126f	1900 West	Weber	126	8.17	8.66	6000 S to 5600 S	5
126g	1900 West	Weber	126	8.66	9.05	5600 S to 5300 S	5
126h	1900 West	Weber	126	9.05	9.65	5300 S to 4800 S	5
126i	1900 West	Weber	126	9.65	10.15	4800 S to 4400 S	5
126j	1900 West	Weber	126	10.15	11.14	4400 S to SR 79	5
126k	1900 West	Weber	126	11.67	13.27	Sr 108 to SR 104	5
203a	Harrison Blvd	Weber	203	1.84	2.3	4600 S to 4200 S	6
203b	Harrison Blvd	Weber	203	2.3	2.43	4200 S to 4100 S	6
203c	Harrison Blvd	Weber	203	2.43	3.08	4100 S to 3600 S	6
203d	Harrison Blvd	Weber	203	3.08	3.64	3600 S to 3200 S	6
203e	Harrison Blvd	Weber	203	3.64	4.21	3200 S to 2800 S	6
203f	Harrison Blvd	Weber	203	4.21	5.23	2800 S to 2100 S	6
203g	Harrison Blvd	Weber	203	5.23	5.37	2100 S to 2000 S	6
204a	Wall Avenue	Weber	204	0	0.92	SR 26 to 32nd	5
204b	Wall Avenue	Weber	204	0.92	1.35	32nd to 29th	5
204c	Wall Avenue	Weber	204	1.35	3.56	29th to 12th	5
235a	Washington	Weber	235	0	3.07	200 S (SR89) to 2550 N	3
26a	Riverdale Rd	Weber	26	0	0.67	SR 126 to 1500 W	5
26b	Riverdale Rd	Weber	26	0.67	1.5	1500 W to 900 W	3
26c	Riverdale Rd	Weber	26	1.5	2.53	900 W to 500 W	5
26d	Riverdale Rd	Weber	26	2.53	3.06	500 W to 40th	5
26e	Riverdale Rd	Weber	26	3.06	3.74	40th to SR 89	5
39a	1200 South	Weber	39	4.12	6	I-15 NB ramp to SR 204	3
39b	1200 South	Weber	39	6	6.57	SR 204 to Adams Ave	5
39c	1200 South	Weber	39	6.57	7.74	Adams Ave to SR 203	5
53a	MLK Jr St	Weber	53	0.5	0.95	G Ave to A Ave	5
53b	MLK Jr St	Weber	53	1.67	1.95	Lincoln to Washington	6
97a	5500 South	Weber	97	2.03	2.63	4300 W to 3800 W	5
97b	5600 South	Weber	97	2.63	3.08	3800 W to 3500 W	5
97c	5600 South	Weber	97	3.08	4.85	3500 W to 2100 W	5
97d	5600 South	Weber	97	4.85	5.32	2100 W to Park Dr	5

Appendix B. General Characteristics of Roadway Segments

Table B.1 General Characteristics of Roadway Segments

ID	Length	No. Lanes	Speed	N/S	E/W	Access Density	Sig/ Mile	AADT	AADT/ lane
101a	2.17	2	35/40	0	1	0.0	0.23	5492	2746
218a	0.43	2	30	0	1	79.1	1.16	3807	1903
237a	0.38	2	35	1	0	34.2	1.32	11948	5974
237b	0.49	4	40	1	0	24.5	2.04	8743	2186
238a	0.47	2	30	0	1	125.5	1.06	5283	2641
239a	1.04	4	45	0	1	26.0	3.85	17938	4485
288a	0.49	2	35	1	0	44.9	2.04	1436	718
288b	0.49	2	35	0	1	36.7	1.02	1387	693
105a	0.35	4	35	0	1	22.9	8.57	18278	4570
105b	0.34	4	35	0	1	38.2	2.94	18278	4570
106a	1.72	2	40	1	0	58.1	0.00	13543	6772
106b	0.50	2	30	0	0	82.0	0.00	13440	6720
106c	0.89	2	35	0	0	64.0	0.00	13072	6536
106d	0.75	2	40	0	0	1.3	0.00	10045	5023
106e	0.39	2	-	0	1	43.6	0.00	9895	4948
108a	0.42	4	40	0	1	35.7	4.76	31662	7915
108b	2.30	4	45	0	1	27.4	1.30	26287	6572
108c	1.00	2	40/45	0	1	65.0	1.00	24333	12167
108d	0.53	2	40	1	0	60.4	0.94	9943	4972
108e	2.96	2	45	1	0	53.4	0.51	9754	4877
108f	1.01	2	45	1	0	38.6	0.99	7428	3714
109a	0.44	2	35	0	1	70.5	4.55	18062	9031
109b	0.32	2	35	0	1	100.0	1.56	14058	7029
109c	0.43	2	40	0	1	102.3	2.33	14058	7029
109d	1.60	2	50	0	1	18.8	0.31	7038	3519
126a	3.21	4	40/45	0	0	63.2	1.09	21469	5367
126b	1.24	4	45	0	0	53.2	1.61	19842	4960
126c	1.19	4	40/45	0	0	70.6	2.52	23097	5774
126d	0.50	4	40	1	0	82.0	4.00	23506	5877
126e	2.03	4	45	1	0	37.9	1.48	25322	6331
193a	0.70	4	35	0	1	51.4	4.29	26823	6706
193b	4.97	4	50/55	0	1	15.9	1.11	18604	4651
227a	0.49	4	40	1	0	61.2	0.00	6310	1578
227b	0.21	2	35	0	1	104.8	2.38	6310	3155
232a	0.27	4	40	0	0	14.8	11.11	37800	9450

Table B.1 Continued

ID	Length	No. Lanes	Speed	N/S	E/W	Access Density	Sig/ Mile	AADT	AADT/ lane
232b	1.99	4	40/45	1	0	61.3	2.01	22027	5507
273a	1.92	4	40/45	0	0	42.2	1.30	15025	3756
273b	0.56	4	30	1	0	57.1	0.89	16313	4078
273c	0.39	4	40	0	1	69.2	2.56	15457	3864
37a	0.99	2	-	0	0	84.8	0.00	10522	5261
37b	1.43	2	-	0	1	60.1	0.70	8578	4289
37c	0.34	2	-	0	1	47.1	0.00	2143	1072
151a	2.01	2	35	0	1	51.2	1.49	28009	14005
171a	1.50	2	40	0	1	58.0	1.00	13747	6873
171b	2.03	2	45	0	1	76.8	0.99	20483	10242
171c	3.50	4	40/45	0	1	87.1	3.14	31036	7759
171d	0.44	6	40	0	1	111.4	4.55	51198	8533
171e	1.19	6	45	0	1	48.7	1.68	31757	5293
171f	0.61	6	45	0	1	19.7	3.28	26993	4499
171g	0.61	6	35	0	1	80.3	4.92	35015	5836
171h	1.98	4	35	0	1	90.4	4.04	27155	6789
171i	1.38	4	35	0	1	94.2	1.45	18152	4538
171j	0.50	4	35/40	0	1	98.0	2.00	19181	4795
171k	0.75	6	40	0	1	88.0	2.67	24815	4136
173a	1.43	4	40/45	0	1	86.0	1.75	32410	8103
173b	2.86	4	45	0	1	61.2	2.62	37775	9444
173c	1.72	4	45/50	0	1	10.5	2.33	29881	7470
173d	1.17	5	40	0	1	27.4	5.13	27904	5581
181a	2.81	2	40	1	0	81.9	1.78	17896	8948
181b	0.63	4	40	1	0	57.1	2.38	21045	5261
181c	0.68	6	40	1	0	20.6	2.94	32633	5439
181d	0.49	6	40	1	0	36.7	7.14	48541	8090
181e	0.56	2	35	1	0	101.8	1.79	28467	14233
181f	0.57	2	35	1	0	128.1	1.75	25627	12813
181g	1.15	4	35	1	0	90.4	2.61	23890	5972
184a	0.76	2	30	0	0	42.1	0.66	17411	8705
186a	0.74	6	30	1	0	41.9	6.76	26002	4334
186b	0.45	6	35	0	1	60.0	6.67	21067	3511
186c	2.50	6	35	0	1	70.8	4.80	23273	3879
186d	0.98	6	40	0	0	5.1	3.06	29645	4941
186e	0.43	6	40	1	0	25.6	2.33	43555	7259
186f	0.53	6	40	0	0	39.6	3.77	41736	6956
186g	1.27	4	40	0	0	57.5	1.97	39549	9887
190a	1.77	4	50	0	0	4.0	1.69	31255	7814
195a	2.56	2	35	1	0	90.6	1.76	16404	8202
209a	0.86	4	40	0	1	50.0	1.74	39188	9797
209b	0.93	4	50	0	1	16.1	1.61	36715	9179
209c	0.71	6	40	0	1	42.3	5.63	40332	6722
209d	0.99	4	40	0	1	48.5	2.02	33065	8266
209e	1.56	4	45	0	1	43.6	2.56	25399	6350
209g	1.05	2	45	0	1	32.4	0.48	22133	11067

Table B.1 Continued

ID	Length	No. Lanes	Speed	N/S	E/W	Access Density	Sig/ Mile	AADT	AADT/ lane
209h	1.24	2	45	0	0	10.5	0.40	3415	1708
266a	0.50	4	40	0	1	62.0	2.00	39128	9782
266b	1.86	4	55	0	0	4.8	1.61	25663	6416
266c	0.90	4	40	0	1	17.8	5.56	31349	7837
266d	1.20	6	40	0	1	78.3	2.50	31885	5314
266e	1.27	2	40	0	1	74.0	2.36	20912	10456
266f	2.02	2	40	0	1	83.2	1.73	12883	6441
269a	0.90	5	35	0	1	68.9	6.11	39896	7979
269b	0.90	4	35	0	1	56.7	6.67	39598	9900
270a	0.60	6	-	1	0	10.0	6.67	27202	4534
48a	1.98	4	40	0	1	48.5	2.53	27103	6776
48b	0.49	4	35	0	1	57.1	2.04	29068	7267
48c	0.57	5	45	0	1	64.9	4.39	33833	6767
68a	5.03	2	-	1	0	8.3	0.99	13202	6601
68b	1.74	4	45	1	0	72.4	1.15	16844	4211
68c	3.80	6	45	1	0	73.4	1.05	31271	5212
68d	4.66	6	40	1	0	65.5	2.79	48712	8119
68e	0.23	4	40	1	0	30.4	6.52	44415	11104
68h	1.57	4	45	1	0	54.8	2.55	20421	5105
68j	1.36	4	40	1	0	82.4	1.84	22018	5504
71b	2.92	4	40	0	1	8.6	1.37	24873	6218
71c	2.20	3	40/45	1	0	38.2	1.36	25848	8616
71d	0.63	4	40	1	0	36.5	1.59	27478	6870
71e	2.67	4	40	1	0	66.3	2.06	23037	5759
71f	0.98	4	40	1	0	54.1	3.06	27680	6920
71g	3.01	4	45	1	0	60.1	1.99	34985	8746
71h	1.76	8	45	1	0	85.8	1.14	40293	5037
114a	0.45	4	35	0	1	88.9	3.33	34685	8671
114b	3.44	2	45	1	0	43.3	0.58	10587	5293
114c	0.32	4	45	0	0	31.3	1.56	12772	3193
114d	0.55	2	45	0	0	40.0	0.00	12772	6386
114e	1.25	2	45	1	0	29.6	0.80	11978	5989
114f	1.51	2	50	1	0	13.9	0.33	11092	5546
114g	2.02	4	50	1	0	30.7	0.99	15747	3937
114h	0.25	4	40	0	0	80.0	4.00	15747	3937
156a	1.38	4	30	1	0	56.5	5.07	25126	6281
180a	1.04	4	45	1	0	35.6	1.92	18943	4736
189a	1.30	6	40/45	1	0	40.0	2.69	28994	4832
189b	1.98	4	35/40	1	0	56.6	5.81	40830	10208
189c	2.30	4	45	1	0	12.6	1.96	35612	8903
189d	1.69	4	50	1	0	16.0	1.48	17412	4353
198a	0.74	2	40	1	0	56.8	0.68	12168	6084
198b	0.42	2	30	0	0	104.8	2.38	11301	5650
198c	0.72	2	40/45	0	1	58.3	0.00	9405	4703
198d	1.19	2	40	0	0	51.3	0.00	10387	5193
52a	0.46	2	45	0	1	19.6	3.26	10192	5096
52b	1.59	4	45	0	1	24.5	2.83	28843	7211

Table B.1 Continued

ID	Length	No. Lanes	Speed	N/S	E/W	Access Density	Sig/ Mile	AADT	AADT/ lane
52c	1.01	4	40/45	0	1	69.3	1.98	31280	7820
52d	1.42	4	45	0	1	23.9	1.06	14793	3698
73a	1.08	2	30	0	1	70.4	1.39	24103	12052
73b	0.36	4	30	0	1	36.1	4.17	24103	6026
73c	0.41	4	35	0	1	43.9	3.66	10022	2505
18a	1.16	4	45	1	0	33.6	2.16	25953	6488
18b	0.53	4	35/40	1	0	18.9	1.89	39959	9990
18c	1.19	4	35	1	0	40.3	2.94	43461	10865
212a	0.54	2	35	0	1	74.1	0.93	17016	8508
34a	0.57	4	30	0	1	71.9	4.39	20725	5181
34b	1.17	4	30	0	1	88.0	2.99	33382	8345
104a	0.58	4	40	0	1	65.5	1.72	11137	2784
104b	1.27	4	50/55	0	1	3.9	1.97	16279	4070
108g	1.50	2	45	1	0	75.3	1.33	13309	6654
108h	2.89	2	50	0	0	34.3	0.69	14142	7071
126f	0.49	4	45	1	0	108.2	4.08	26674	6669
126g	0.39	4	45	1	0	79.5	5.13	38141	9535
126h	0.60	4	45	1	0	108.3	1.67	25170	6293
126i	0.50	4	45	1	0	56.0	2.00	25170	6293
126j	0.99	4	45/50	1	0	33.3	2.02	21013	5253
126k	1.60	4	55	1	0	51.9	1.25	20320	5080
203a	0.46	4	40	1	0	54.3	2.17	33560	8390
203b	0.13	5	40	1	0	38.5	7.69	47487	9497
203c	0.65	5	40	1	0	27.7	3.08	47487	9497
203d	0.56	4	40	1	0	76.8	1.79	50934	12733
203e	0.57	4	40	1	0	87.7	3.51	43688	10922
203f	1.02	4	40	1	0	112.7	3.43	31886	7971
203g	0.14	4	40	1	0	64.3	3.57	25990	6498
204a	0.92	4	40	1	0	58.7	1.63	26216	6554
204b	0.43	6	40	1	0	65.1	8.14	28143	4690
204c	2.21	4	40	1	0	62.4	2.26	25705	6426
235a	3.07	4	50	1	0	64.2	0.65	24428	6107
26a	0.67	4	45	0	0	28.4	1.49	28691	7173
26b	0.83	4	45	0	0	25.3	4.82	37230	9308
26c	1.03	4	45	0	0	35.9	1.46	47752	11938
26d	0.53	4	35	0	0	45.3	2.83	47752	11938
26e	0.68	4	35	0	0	79.4	4.41	18890	4723
39a	1.88	4	50	0	1	46.3	0.80	25724	6431
39b	0.57	4	40	0	1	70.2	2.63	26440	6610
39c	1.17	4	45	0	1	83.8	1.28	21723	5431
53a	0.45	2	40	0	1	100.0	0.00	17415	8708
53b	0.28	4	30	0	1	39.3	7.14	13187	3297
97a	0.60	2	40	0	1	58.3	0.00	7515	3758
97b	0.45	2	40	0	0	26.7	1.11	7515	3758
97c	1.77	2	35	0	1	57.1	0.85	14994	7497
97d	0.47	4	35	0	1	72.3	7.45	23752	5938

Note: A “1” in the “N/S” column denotes North/South orientation, etc.

Appendix C. Median and Land Use Characteristics of Roadway Segments

Table C.1 Median and Land Use Characteristics of Roadway Segments

ID	Raised Median	TWLTL	Undivided	Commercial	Residential	Industrial	Agricultural
101a	0	0	1	1	1	0	0
218a	0	0	1	0	1	0	0
237a	0	0	1	1	0	0	0
237b	0	1	0	1	0	0	0
238a	0	0	1	0	1	0	0
239a	0	1	0	1	0	0	0
288a	0	0	1	1	0	0	0
288b	0	0	1	1	0	0	0
105a	1	0	0	1	0	0	0
105b	0	1	0	1	0	0	0
106a	0	0	1	0	1	0	0
106b	0	1	0	1	1	0	0
106c	0	1	1	0	1	0	0
106d	0	0	1	0	1	0	0
106e	0	1	1	1	0	0	0
108a	0	1	0	1	0	0	0
108b	0	1	0	0	0	1	1
108c	0	0	1	0	1	0	0
108d	0	1	0	0	1	0	0
108e	0	0	1	0	1	0	1
108f	0	0	1	1	1	1	1
109a	0	1	0	1	0	0	0
109b	0	1	0	0	1	0	0
109c	0	1	0	1	1	0	0
109d	0	0	1	0	1	0	1
126a	0	1	0	1	0	0	0
126b	0	1	0	1	1	0	0
126c	0	1	0	1	1	1	0
126d	0	1	0	1	0	0	0
126e	0	1	0	1	1	0	1
193a	0	1	0	1	1	0	0
193b	0	1	0	1	1	0	1
227a	0	1	0	1	1	0	0
227b	0	1	0	0	1	0	0
232a	0	1	0	1	0	0	0

Table C.1 Continued

ID	Raised Median	TWLTL	Undivided	Commercial	Residential	Industrial	Agricultural
232b	0	1	0	1	1	0	0
273a	0	1	0	1	1	0	0
273b	0	1	0	1	0	0	0
273c	0	1	0	1	0	0	0
37a	0	0	1	0	1	0	0
37b	0	1	0	0	1	0	1
37c	0	1	0	0	1	0	1
151a	0	0	1	0	1	0	0
171a	0	1	0	1	1	0	0
171b	0	1	0	1	1	0	0
171c	0	1	0	1	1	1	0
171d	0	1	0	1	0	0	0
171e	0	1	0	1	0	1	0
171f	1	0	0	1	0	1	0
171g	1	1	0	1	0	1	0
171h	0	1	0	1	0	0	0
171i	0	1	0	1	1	0	0
171j	0	0	1	0	1	0	0
171k	1	0	0	1	0	0	0
173a	0	1	0	0	1	0	0
173b	0	1	0	1	0	0	0
173c	1	1	0	1	0	0	0
173d	1	0	0	1	0	0	0
181a	0	1	0	0	1	0	0
181b	0	1	0	1	1	0	0
181c	1	0	0	0	1	0	0
181d	1	0	0	1	0	0	0
181e	0	1	0	1	0	0	0
181f	0	0	1	0	1	0	0
181g	0	0	1	0	1	0	0
184a	0	0	1	1	1	0	0
186a	1	0	0	1	0	0	0
186b	1	0	0	1	0	0	0
186c	1	0	0	1	1	0	0
186d	1	0	0	1	0	0	0
186e	1	0	0	0	1	0	0
186f	0	1	0	1	0	0	0
186g	0	1	0	0	1	0	0
190a	0	1	0	0	0	1	0
195a	0	1	0	0	1	0	0
209a	0	1	0	1	0	0	0
209b	0	1	0	0	0	0	0
209c	1	0	0	1	0	0	0
209d	0	1	0	0	0	0	0
209e	0	1	0	1	1	0	0
209g	0	0	1	0	1	0	0

Table C.1 Continued

ID	Raised Median	TWLTL	Undivided	Commercial	Residential	Industrial	Agricultural
209h	0	0	1	0	1	0	0
266a	0	1	0	1	0	0	0
266b	1	0	0	0	1	0	0
266c	1	0	0	1	0	1	0
266d	1	1	0	1	1	0	0
266e	0	1	0	1	1	0	0
266f	0	1	1	0	1	0	0
269a	0	0	0	1	0	0	0
269b	0	0	0	1	0	0	0
270a	0	1	0	1	0	0	0
48a	0	1	0	1	0	0	0
48b	0	1	0	1	0	0	0
48c	1	1	0	1	0	0	0
68a	0	0	1	0	1	0	0
68b	0	1	0	1	1	0	0
68c	0	1	0	1	1	0	0
68d	0	1	0	1	0	0	0
68e	0	0	1	0	0	1	0
68h	0	1	0	1	0	1	0
68j	0	1	0	1	1	0	0
71b	1	1	0	1	1	0	0
71c	0	1	0	0	1	0	0
71d	0	1	0	0	1	0	0
71e	0	1	0	1	0	0	0
71f	0	1	0	1	0	0	0
71g	0	1	0	1	1	0	0
71h	0	1	0	1	1	0	0
114a	0	1	0	1	1	0	0
114b	0	0	1	0	1	0	1
114c	0	1	0	1	0	1	0
114d	0	0	1	0	1	0	1
114e	0	1	1	0	0	1	0
114f	0	1	0	0	0	1	0
114g	0	1	0	0	0	1	0
114h	0	1	0	0	1	0	0
156a	0	1	0	1	0	0	0
180a	0	1	0	1	0	0	0
189a	0	1	0	1	0	0	0
189b	0	1	0	1	0	0	0
189c	0	1	0	1	0	0	0
189d	0	1	0	0	0	0	0
198a	0	1	0	1	1	0	0
198b	0	1	0	1	0	0	0
198c	0	1	0	1	0	0	0
198d	0	1	0	1	1	0	0
52a	0	1	0	0	0	1	0
52b	0	1	0	1	0	0	0

Table C.1 Continued

ID	Raised Median	TWLTL	Undivided	Commercial	Residential	Industrial	Agricultural
52c	0	1	0	0	1	0	0
52d	0	1	0	0	1	0	0
73a	0	0	1	1	0	0	0
73b	0	1	0	1	0	0	0
73c	0	1	0	0	0	1	0
18a	0	1	0	1	0	0	0
18b	0	1	0	1	0	0	0
18c	0	1	0	1	0	0	0
212a	0	1	0	1	1	0	0
34a	0	1	0	1	0	0	0
34b	0	1	0	1	0	0	0
104a	0	1	0	0	1	0	0
104b	0	1	0	0	0	0	0
108g	0	0	1	0	1	0	1
108h	0	0	1	0	1	0	1
126f	0	1	0	1	1	0	0
126g	0	1	0	1	0	0	0
126h	0	1	0	1	1	0	0
126i	0	1	0	1	1	0	0
126j	0	1	0	1	1	0	0
126k	0	1	0	0	0	1	1
203a	0	1	0	1	0	0	0
203b	0	1	0	1	0	0	0
203c	0	1	0	1	0	0	0
203d	0	1	0	1	0	0	0
203e	0	1	0	1	1	0	0
203f	0	1	0	0	1	0	0
203g	0	1	0	1	0	0	0
204a	0	1	0	1	0	0	0
204b	0	1	0	1	0	0	0
204c	0	1	0	0	0	1	0
235a	0	1	0	1	1	1	1
26a	0	1	0	1	0	0	0
26b	0	1	0	1	0	0	0
26c	0	1	0	1	0	0	0
26d	0	1	0	1	0	0	0
26e	0	1	0	1	0	0	0
39a	0	1	0	1	1	0	0
39b	0	1	0	1	0	0	0
39c	0	1	0	0	1	0	0
53a	0	1	0	1	1	0	0
53b	0	1	0	1	0	0	0
97a	0	0	1	0	1	0	0
97b	0	1	0	1	1	0	0
97c	0	1	0	0	1	0	0
97d	0	1	0	1	0	0	0

Note: A “1” in each cell denotes that the given condition is present for the road segment (e.g., a “1” under “Raised Median” for “105a” indicates a raised median is present on this road segment).

Appendix D. Crash Rate and Severity Scores of Segments

Table D.1 Crash Rate and Severity Scores of Road Segments

ID	Crash Severity Frequency					Crash Rate per MVMT	Crash Severity Score				
	Non-Injury	Possible Injury	Minor Injury	Major Injury	Fatal		Method 1	Method 2	Method 3	Method 4	Method 5
101a	23	3	2	2	0	2.30	122	104	21	25	227
218a	2	0	0	0	0	1.12	5	0	6	5	5
237a	42	8	3	1	0	10.86	686	374	177	189	1,005
237b	19	5	0	1	0	5.33	316	218	60	69	549
238a	5	1	0	0	0	2.21	31	3	14	13	32
239a	110	39	20	5	0	8.52	1,235	721	245	268	1,827
288a	9	3	1	0	0	16.87	114	28	34	33	120
288b	5	0	1	0	0	8.06	47	21	19	18	51
105a	70	24	15	3	0	15.99	2,384	1,374	484	526	3,457
105b	13	6	3	0	0	3.23	366	110	92	91	391
106a	16	8	0	1	0	0.98	105	64	18	20	172
106b	17	7	1	0	0	3.40	204	37	57	56	214
106c	25	5	4	4	0	2.98	558	503	75	97	1,073
106d	24	5	3	1	0	4.00	285	183	62	68	445
106e	21	11	2	2	0	8.52	868	598	129	154	1,464
108a	109	52	16	12	0	12.98	4,648	3,388	680	821	7,974
108b	185	90	32	19	1	4.94	1,999	1,447	219	262	2,489
108c	65	32	10	3	0	4.13	816	439	153	167	1,185
108d	12	5	3	4	0	4.16	879	823	93	130	1,740
108e	45	29	16	4	0	2.97	325	201	54	60	492
108f	32	17	6	3	0	7.06	562	376	88	102	913
109a	42	17	2	2	0	7.24	948	548	176	198	1,482
109b	19	2	3	4	0	5.68	1,388	1,356	167	228	2,809
109c	24	5	5	0	0	5.14	377	133	115	114	405
109d	23	3	2	1	0	2.35	110	78	25	28	183
126a	225	80	28	26	0	4.76	1,179	929	171	211	2,114
126b	103	41	17	11	1	6.42	2,476	1,872	222	268	2,623
126c	118	54	14	12	2	6.65	3,819	2,862	290	309	3,141
126d	123	65	9	7	0	15.85	3,050	1,735	519	588	4,706
126e	64	30	12	5	2	2.01	1,777	1,309	92	104	987
193a	73	34	18	4	0	6.27	1,536	888	285	313	2,247
193b	207	90	39	25	0	3.57	799	604	117	141	1,386
227a	4	2	0	0	0	1.77	47	5	13	12	49
227b	3	0	1	0	0	2.76	100	49	34	33	110
232a	207	88	14	10	0	28.54	8,088	4,625	1,486	1,670	12470

Table D.1 Continued

ID	Crash Severity Frequency: Non-Injury	Possible Injury	Minor Injury	Major Injury	Fatal	Crash Rate per MVMT	Crash Severity Score: Method 1	Method 2	Method 3	Method 4	Method 5
232b	179	53	30	17	0	5.81	1,369	1,041	221	262	2,366
273a	78	27	16	6	0	4.02	601	414	105	119	973
273b	63	32	11	0	0	10.60	1,015	265	249	248	1,077
273c	55	11	11	1	0	11.82	1,145	581	296	308	1,500
37a	21	14	9	1	0	3.95	409	208	78	82	546
37b	24	10	8	2	0	3.28	308	204	54	60	478
37c	1	0	0	0	0	1.25	3	0	4	3	3
151a	71	35	4	2	0	1.82	326	140	67	71	448
171a	81	45	18	7	2	6.78	2,702	1,955	177	192	1,794
171b	102	48	23	20	0	4.24	1,348	1,127	169	218	2,484
171c	514	314	121	56	2	8.47	3,781	2,622	459	541	5,050
171d	71	56	17	6	0	6.08	3,279	1,893	512	580	4,934
171e	92	49	11	20	0	4.16	2,118	1,822	240	324	4,035
171f	74	33	13	6	0	6.99	1,890	1,263	311	359	3,056
171g	192	89	25	11	1	13.60	6,171	4,030	758	821	6,528
171h	378	120	53	22	1	9.75	2,889	1,964	417	475	3,656
171i	115	32	10	8	0	6.02	947	684	165	193	1,620
171j	53	19	5	7	0	8.00	1,883	1,549	255	324	3,486
171k	76	24	6	4	0	5.40	1,022	655	193	219	1,648
173a	156	70	36	22	1	5.62	3,295	2,549	341	420	4,319
173b	647	239	67	34	1	8.35	2,951	1,879	465	526	3,978
173c	190	58	29	13	0	5.15	1,403	969	250	287	2,297
173d	168	57	20	8	0	7.08	1,521	918	296	329	2,340
181a	180	79	26	14	0	5.43	939	625	155	179	1,527
181b	33	26	15	3	0	5.30	1,296	761	214	237	1,894
181c	5	11	10	2	0	1.15	686	458	98	112	1,051
181d	23	53	24	5	0	4.03	2,865	1,623	403	453	4,149
181e	8	38	9	5	0	3.44	1,741	1,123	192	236	2,800
181f	7	26	5	3	1	2.63	3,352	2,415	176	163	2,047
181g	8	33	18	5	1	2.16	2,077	1,490	127	150	1,650
184a	14	12	5	1	0	2.21	404	215	68	74	571
186a	11	30	24	7	0	3.42	1,820	1,312	233	280	2,961
186b	30	34	20	3	0	8.38	2,179	1,193	354	387	3,044
186c	90	95	41	16	3	3.85	2,819	2,046	187	216	2,264
186d	13	32	10	5	0	1.89	959	646	113	138	1,564
186e	14	27	3	1	0	2.19	966	368	136	147	1,265
186f	8	27	8	0	0	1.78	776	203	127	126	826
186g	17	38	11	4	0	1.27	734	433	95	109	1,116
190a	53	26	8	4	0	1.50	451	289	75	85	719
195a	166	52	10	5	0	5.07	502	261	112	120	737
209a	166	72	17	9	0	7.15	2,273	1,347	409	460	3,519
209b	142	84	14	9	1	6.69	3,540	2,299	364	411	3,508
209c	300	159	19	10	0	15.56	4,294	1,942	825	894	6,014
209d	129	105	17	8	0	7.23	2,169	1,099	346	386	3,151
209e	97	56	6	6	1	3.83	1,648	1,106	137	158	1,396
209f	17	10	2	7	0	1.41	729	697	68	100	1,483
209g	6	2	2	2	0	1.87	439	412	49	67	863

Table D.1 Continued

ID	Crash Severity Frequency					Crash Rate per MVMT	Crash Severity Score				
	Non-Injury	Possible Injury	Minor Injury	Major Injury	Fatal		Method 1	Method 2	Method 3	Method 4	Method 5
209h	3	3	3	2	0	2.37	211	188	24	31	398
266a	95	36	10	6	0	6.86	2,297	1,491	403	462	3,710
266b	124	50	25	17	1	4.15	2,070	1,620	196	244	2,540
266c	255	95	25	21	1	12.85	5,294	3,856	630	744	6,783
266d	237	83	35	10	1	8.74	3,203	2,047	432	475	3,306
266e	108	39	4	7	1	5.47	1,945	1,409	162	191	1,715
266f	62	27	6	4	1	3.51	1,030	739	69	81	719
269a	37	49	12	9	0	2.72	1,684	1,192	200	249	2,852
269b	35	45	15	8	0	2.64	1,601	1,109	201	244	2,650
270a	9	20	1	3	1	1.90	2,972	2,218	126	122	1,715
48a	340	140	39	23	0	9.22	2,227	1,446	380	437	3,596
48b	71	24	11	6	0	7.18	2,097	1,512	346	406	3,533
48c	167	72	16	4	0	12.26	2,628	1,138	568	602	3,521
68a	236	79	33	12	0	4.95	526	325	102	113	812
68b	144	52	16	7	0	6.82	889	532	171	190	1,370
68c	480	176	51	18	2	5.59	1,914	1,193	253	279	1,911
68d	611	287	96	48	1	4.20	2,279	1,525	328	380	3,262
68e	18	22	2	3	0	4.02	2,301	1,495	275	339	3,817
68h	36	31	10	15	1	2.65	1,996	1,678	120	170	2,386
68j	35	35	19	4	0	2.84	783	462	123	137	1,151
71b	232	61	20	9	0	4.05	675	406	144	159	1,042
71c	114	49	25	13	2	3.26	2,172	1,641	157	188	1,865
71d	69	44	13	4	0	6.86	1,710	922	295	325	2,490
71e	272	170	46	23	1	7.60	2,268	1,482	280	324	2,881
71f	143	55	18	18	1	7.91	3,958	3,112	378	469	4,952
71g	276	120	50	30	3	4.15	2,946	2,209	258	308	3,015
71h	130	47	25	11	1	2.76	1,875	1,369	192	226	1,989
114a	66	32	18	8	1	7.31	6,003	4,486	633	578	5,658
114b	63	29	14	5	0	2.78	300	196	51	58	475
114c	8	4	2	2	0	3.58	808	703	95	125	1,525
114d	6	3	4	2	0	1.95	514	443	65	82	938
114e	23	12	4	3	0	2.56	379	283	54	65	658
114f	23	12	8	2	1	2.51	1,164	857	56	64	598
114g	60	16	9	9	0	2.70	578	501	79	100	1,089
114h	5	5	1	2	0	3.02	988	862	97	136	1,900
156a	156	69	16	14	0	6.72	1,694	1,192	261	311	2,874
180a	79	37	13	7	0	6.30	1,235	841	196	229	2,028
189a	107	35	14	8	1	4.00	2,076	1,527	189	222	1,952
189b	492	203	68	41	2	9.10	4,986	3,552	602	706	6,304
189c	165	60	32	26	2	3.18	2,698	2,172	217	275	3,046
189d	55	16	13	12	0	2.98	887	800	109	144	1,701
198a	32	6	4	3	0	4.56	575	472	94	114	1,043
198b	32	11	4	1	0	9.24	709	367	153	164	1,005
198c	22	6	6	3	1	5.12	2,433	1,900	118	128	1,392
198d	21	4	4	0	0	2.14	110	39	35	34	118
52a	14	8	3	0	0	4.87	315	86	75	74	335
52b	164	59	23	11	0	5.12	1,329	884	234	267	2,147

Table D.1 Continued

ID	Crash Severity Frequency					Crash Rate per MVMT	Crash Severity Score				
	Non-Injury	Poss. Injury	Minor Injury	Major Injury	Fatal		Method 1	Method 2	Method 3	Method 4	Method 5
52c	56	43	12	4	0	3.32	1,027	563	166	185	1,511
52d	27	21	8	2	1	2.56	1,302	918	68	77	702
73a	107	63	11	2	0	6.42	1,005	355	208	217	1,256
73b	70	27	7	3	0	11.26	1,998	1,122	390	431	3,000
73c	31	13	2	0	0	10.22	468	88	128	127	490
18a	103	35	9	9	0	4.73	1,201	893	190	228	2,097
18b	25	10	6	1	0	1.81	598	325	122	130	840
18c	297	113	24	12	0	7.88	2,412	1,330	477	526	3,619
212a	24	14	2	1	0	4.07	523	253	95	104	748
34a	92	34	10	4	0	10.82	1,667	953	327	361	2,512
34b	292	92	25	3	1	9.66	2,726	1,428	434	448	2,147
104a	9	4	3	0	0	2.26	175	60	44	43	188
104b	37	16	8	2	0	2.78	402	236	76	83	596
108g	48	17	9	10	0	3.84	835	741	102	134	1,599
108h	74	10	15	6	0	2.35	335	266	61	71	579
126f	92	24	14	7	0	9.57	2,429	1,782	423	494	4,106
126g	156	49	15	10	0	14.12	4,555	3,114	809	936	7,554
126h	69	20	7	2	0	5.93	938	495	213	228	1,348
126i	36	23	10	3	1	5.30	4,002	2,853	328	278	2,532
126j	26	19	7	4	0	2.46	693	497	95	114	1,168
126k	61	13	9	13	1	2.72	1,745	1,506	114	156	1,982
203a	122	48	15	3	0	11.12	2,428	1,109	534	565	3,265
203b	61	40	9	2	0	16.57	6,023	2,585	1,132	1,208	8,008
203c	86	27	3	9	0	3.70	1,833	1,486	263	331	3,409
203d	52	43	8	5	0	3.46	1,873	1,122	272	316	2,932
203e	57	34	10	4	0	3.85	1,606	947	266	300	2,451
203f	89	53	19	10	0	4.80	1,784	1,227	264	312	2,940
203g	12	10	1	4	0	6.78	3,414	3,009	330	471	6,657
204a	70	25	13	4	1	4.28	2,387	1,698	194	214	1,717
204b	49	31	3	6	0	6.72	2,160	1,549	285	353	3,765
204c	112	59	20	11	2	3.28	2,084	1,525	146	172	1,675
235a	83	39	15	16	2	1.89	1,542	1,237	90	118	1,424
26a	81	41	13	7	0	6.75	1,977	1,312	313	364	3,210
26b	277	132	36	21	0	13.77	4,868	3,156	794	919	7,852
26c	135	58	15	12	0	4.08	1,959	1,380	305	362	3,316
26d	122	52	11	10	0	7.04	3,206	2,215	507	600	5,400
26e	57	27	12	6	1	7.32	3,471	2,578	268	297	2,893
39a	117	37	13	8	0	3.30	750	521	132	152	1,248
39b	75	36	17	12	0	8.48	3,127	2,480	420	525	5,570
39c	34	12	9	4	1	2.16	1,678	1,287	94	113	1,140
53a	13	6	2	4	0	2.91	1,019	950	105	149	2,029
53b	30	10	3	2	0	11.13	1,271	868	222	257	2,107
97a	13	6	2	1	0	4.46	324	212	54	62	522
97b	12	10	3	3	0	7.56	947	758	110	142	1,716
97c	90	37	15	6	0	5.09	702	450	124	140	1,107
97d	144	45	14	4	0	16.93	2,511	1,275	565	606	3,562

Appendix E. Collision Types on Road Segments

Table E.1 Collision Types on Road Segments

ID	Collision Type Frequency							Collision Type Rate (Crashes/MVMT)					
	Right Angle	Rear End	Side Swipe	Head On	S S Opp.	Other	Single Veh.	Right Angle	Rear End	Side Swipe	Opp.	Other	Single Veh.
101a	10	5	0	0	0	3	7	0.77	0.38	0.00	0.00	0.23	0.54
218a	0	1	0	0	0	1	0	0.00	0.56	0.00	0.00	0.56	0.00
237a	16	17	6	0	0	6	4	3.22	3.42	1.21	0.00	1.21	0.80
237b	17	2	1	0	0	0	2	3.62	0.43	0.21	0.00	0.00	0.43
238a	2	2	0	0	0	1	1	0.74	0.74	0.00	0.00	0.37	0.37
239a	85	69	8	0	0	7	5	4.16	3.38	0.39	0.00	0.34	0.24
288a	4	8	1	0	0	0	0	5.19	10.38	1.30	0.00	0.00	0.00
288b	1	1	0	0	0	2	0	1.34	1.34	0.00	0.00	2.69	0.00
105a	51	36	9	0	1	10	4	7.28	5.14	1.28	0.14	1.43	0.57
105b	11	8	1	0	0	1	1	1.62	1.18	0.15	0.00	0.15	0.15
106a	1	11	0	0	0	3	9	0.04	0.43	0.00	0.00	0.12	0.35
106b	9	5	0	1	0	6	1	1.22	0.68	0.00	0.14	0.82	0.14
106c	19	10	2	0	1	1	5	1.49	0.78	0.16	0.08	0.08	0.39
106d	13	12	1	0	0	1	5	1.58	1.45	0.12	0.00	0.12	0.61
106e	22	10	0	0	0	3	2	5.21	2.37	0.00	0.00	0.71	0.47
108a	82	94	5	0	0	3	5	5.63	6.46	0.34	0.00	0.21	0.34
108b	145	141	10	2	3	9	17	2.19	2.13	0.15	0.08	0.14	0.26
108c	28	69	0	0	1	5	6	1.05	2.59	0.00	0.04	0.19	0.23
108d	6	12	1	0	0	1	4	1.04	2.08	0.17	0.00	0.17	0.69
108e	47	23	0	2	2	5	14	1.49	0.73	0.00	0.13	0.16	0.44
108f	25	30	0	0	0	1	0	3.04	3.65	0.00	0.00	0.12	0.00
109a	8	48	1	0	0	0	6	0.92	5.52	0.11	0.00	0.00	0.69
109b	9	11	0	1	1	1	5	1.83	2.23	0.00	0.41	0.20	1.02
109c	20	5	2	0	0	2	3	3.02	0.76	0.30	0.00	0.30	0.45
109d	3	7	0	0	0	5	13	0.24	0.57	0.00	0.00	0.41	1.05
126a	159	126	18	2	7	16	25	2.11	1.67	0.24	0.12	0.21	0.33
126b	83	58	7	3	0	5	13	3.08	2.15	0.26	0.11	0.19	0.48
126c	75	81	7	4	3	9	17	2.49	2.69	0.23	0.23	0.30	0.56
126d	113	71	7	0	0	6	6	8.78	5.52	0.54	0.00	0.47	0.47
126e	56	42	3	1	2	1	6	0.99	0.75	0.05	0.05	0.02	0.11
193a	56	55	3	0	1	3	10	2.72	2.68	0.15	0.05	0.15	0.49
193b	108	172	15	2	5	12	46	1.07	1.70	0.15	0.07	0.12	0.45
227a	2	2	0	0	0	0	2	0.59	0.59	0.00	0.00	0.00	0.59
227b	0	2	0	0	0	0	2	0.00	1.38	0.00	0.00	0.00	1.38
232a	141	157	10	1	2	4	2	12.62	14.05	0.89	0.27	0.36	0.18

Table E.1 Continued

ID	Collision Type Frequency							Collision Type Rate (Crashes/MVMT)					
	Right Angle	Rear End	Side Swipe	Head On	S S Opp.	Other	Single Veh.	Right Angle	Rear End	Side Swipe	Opp.	Other	Single Veh.
232b	128	96	12	1	2	16	16	2.67	2.00	0.25	0.06	0.33	0.33
273a	67	29	5	0	1	11	9	2.12	0.92	0.16	0.03	0.35	0.28
273b	22	60	6	0	2	5	7	2.20	6.00	0.60	0.20	0.50	0.70
273c	40	19	2	0	0	7	8	6.06	2.88	0.30	0.00	1.06	1.21
37a	25	12	0	0	0	1	3	2.19	1.05	0.00	0.00	0.09	0.26
37b	19	14	0	0	1	2	8	1.41	1.04	0.00	0.07	0.15	0.60
37c	1	0	0	0	0	0	0	1.25	0.00	0.00	0.00	0.00	0.00
151a	36	64	1	0	1	2	8	0.58	1.04	0.02	0.02	0.03	0.13
171a	69	45	3	3	3	8	16	3.06	1.99	0.13	0.27	0.35	0.71
171b	89	57	4	0	5	7	31	1.95	1.25	0.09	0.11	0.15	0.68
171c	447	407	45	2	5	31	66	3.76	3.42	0.38	0.06	0.26	0.55
171d	46	60	17	0	1	10	7	1.86	2.43	0.69	0.04	0.41	0.28
171e	68	62	12	3	2	8	16	1.64	1.50	0.29	0.12	0.19	0.39
171f	61	43	6	0	0	7	7	3.38	2.38	0.33	0.00	0.39	0.39
171g	107	157	15	0	0	12	26	4.57	6.71	0.64	0.00	0.51	1.11
171h	232	213	44	2	0	30	50	3.94	3.62	0.75	0.03	0.51	0.85
171i	93	36	11	1	0	11	13	3.39	1.31	0.40	0.04	0.40	0.47
171j	36	36	1	1	0	4	6	3.43	3.43	0.10	0.10	0.38	0.57
171k	54	28	8	0	0	13	6	2.65	1.37	0.39	0.00	0.64	0.29
173a	133	83	16	1	4	14	30	2.62	1.64	0.32	0.10	0.28	0.59
173b	430	395	61	5	3	44	41	3.63	3.34	0.52	0.07	0.37	0.35
173c	103	140	10	1	0	10	21	1.83	2.49	0.18	0.02	0.18	0.37
173d	87	120	19	1	0	8	16	2.43	3.36	0.53	0.03	0.22	0.45
181a	95	125	13	3	1	16	32	1.73	2.27	0.24	0.07	0.29	0.58
181b	47	21	2	0	0	0	7	3.24	1.45	0.14	0.00	0.00	0.48
181c	14	9	0	0	0	0	4	0.58	0.37	0.00	0.00	0.00	0.16
181d	39	50	3	0	0	1	11	1.50	1.92	0.12	0.00	0.04	0.42
181e	4	46	3	0	1	0	5	0.23	2.64	0.17	0.06	0.00	0.29
181f	6	25	0	0	1	0	3	0.38	1.56	0.00	0.06	0.00	0.19
181g	19	31	3	0	1	0	11	0.63	1.03	0.10	0.03	0.00	0.37
184a	10	14	0	0	0	1	5	0.69	0.97	0.00	0.00	0.07	0.35
186a	43	13	0	0	0	4	12	2.04	0.62	0.00	0.00	0.19	0.57
186b	38	20	3	0	0	7	15	3.66	1.93	0.29	0.00	0.67	1.45
186c	47	95	10	0	0	15	71	0.74	1.49	0.16	0.00	0.24	1.11
186d	20	24	3	0	0	7	6	0.63	0.75	0.09	0.00	0.22	0.19
186e	6	27	2	1	1	1	7	0.29	1.32	0.10	0.10	0.05	0.34
186f	11	22	1	0	1	3	4	0.45	0.91	0.04	0.04	0.12	0.17
186g	13	32	2	2	0	0	9	0.24	0.58	0.04	0.04	0.00	0.16
190a	19	32	0	0	0	10	30	0.31	0.53	0.00	0.00	0.17	0.50
195a	74	101	9	2	2	13	23	1.61	2.20	0.20	0.09	0.28	0.50
209a	92	129	13	2	2	16	8	2.49	3.50	0.35	0.11	0.43	0.22
209b	57	152	13	1	0	9	17	1.52	4.07	0.35	0.03	0.24	0.45
209c	174	228	45	1	2	19	17	5.55	7.27	1.44	0.10	0.61	0.54
209d	80	140	12	0	1	11	14	2.23	3.91	0.33	0.03	0.31	0.39
209e	70	61	11	0	0	14	7	1.61	1.41	0.25	0.00	0.32	0.16
209f	14	9	1	0	2	4	6	0.55	0.35	0.04	0.08	0.16	0.24
209g	8	0	0	0	0	0	3	1.25	0.00	0.00	0.00	0.00	0.47

Table E.1 Continued

ID	Collision Type Frequency							Collision Type Rate (Crashes/MVMT)					
	Right Angle	Rear End	Side Swipe	Head On	S S Opp.	Other	Single Veh.	Right Angle	Rear End	Side Swipe	Opp.	Other	Single Veh.
209h	7	2	0	0	0	0	2	1.51	0.43	0.00	0.00	0.00	0.43
266a	57	66	6	0	0	11	5	2.66	3.08	0.28	0.00	0.51	0.23
266b	123	54	6	0	0	12	17	2.35	1.03	0.11	0.00	0.23	0.33
266c	106	231	28	0	2	19	10	3.43	7.48	0.91	0.06	0.61	0.32
266d	167	128	21	1	1	24	21	3.99	3.06	0.50	0.05	0.57	0.50
266e	40	95	5	1	0	11	5	1.38	3.27	0.17	0.03	0.38	0.17
266f	36	35	3	1	1	9	10	1.26	1.23	0.11	0.07	0.32	0.35
269a	21	42	13	0	0	16	11	0.53	1.07	0.33	0.00	0.41	0.28
269b	35	38	10	0	0	14	3	0.90	0.97	0.26	0.00	0.36	0.08
270a	22	6	1	0	0	3	1	1.23	0.34	0.06	0.00	0.17	0.06
48a	133	328	16	2	5	22	33	2.26	5.58	0.27	0.12	0.37	0.56
48b	46	45	7	0	1	5	8	2.95	2.89	0.45	0.06	0.32	0.51
48c	70	159	12	0	0	8	8	3.31	7.53	0.57	0.00	0.38	0.38
68a	111	171	10	2	2	20	38	1.53	2.35	0.14	0.06	0.28	0.52
68b	75	85	14	0	2	12	24	2.34	2.65	0.44	0.06	0.37	0.75
68c	258	288	71	4	3	42	58	1.98	2.21	0.55	0.05	0.32	0.45
68d	391	430	73	3	3	60	75	1.57	1.73	0.29	0.02	0.24	0.30
68e	14	19	1	0	1	4	6	1.25	1.70	0.09	0.09	0.36	0.54
68h	41	27	4	2	1	1	15	1.17	0.77	0.11	0.09	0.03	0.43
68j	42	16	2	0	2	1	23	1.28	0.49	0.06	0.06	0.03	0.70
71b	90	151	10	3	4	28	35	1.13	1.90	0.13	0.09	0.35	0.44
71c	96	56	11	1	3	10	26	1.54	0.90	0.18	0.06	0.16	0.42
71d	51	64	3	1	0	3	8	2.69	3.38	0.16	0.05	0.16	0.42
71e	222	196	20	1	1	26	42	3.30	2.91	0.30	0.03	0.39	0.62
71f	110	78	9	2	0	20	19	3.70	2.63	0.30	0.07	0.67	0.64
71g	196	191	29	3	2	23	33	1.70	1.66	0.25	0.04	0.20	0.29
71h	80	71	22	0	0	16	23	1.03	0.91	0.28	0.00	0.21	0.30
114a	53	38	10	0	0	13	10	3.10	2.22	0.59	0.00	0.76	0.59
114b	22	51	1	1	1	12	20	0.55	1.28	0.03	0.05	0.30	0.50
114c	2	6	1	0	0	4	2	0.45	1.34	0.22	0.00	0.89	0.45
114d	1	6	0	0	0	4	3	0.13	0.78	0.00	0.00	0.52	0.39
114e	6	21	0	0	0	3	10	0.37	1.28	0.00	0.00	0.18	0.61
114f	16	12	1	2	0	5	7	0.87	0.65	0.05	0.11	0.27	0.38
114g	38	33	5	0	1	6	9	1.09	0.95	0.14	0.03	0.17	0.26
114h	2	7	0	0	1	2	1	0.46	1.62	0.00	0.23	0.46	0.23
156a	93	121	3	0	0	11	21	2.45	3.19	0.08	0.00	0.29	0.55
180a	37	75	6	0	0	8	8	1.72	3.48	0.28	0.00	0.37	0.37
189a	71	67	8	1	0	8	9	1.72	1.62	0.19	0.02	0.19	0.22
189b	268	464	22	1	3	19	35	3.03	5.24	0.25	0.05	0.21	0.40
189c	136	98	7	3	1	7	33	1.52	1.09	0.08	0.04	0.08	0.37
189d	21	40	4	2	0	7	21	0.65	1.24	0.12	0.06	0.22	0.65
198a	22	19	0	0	0	2	3	2.23	1.93	0.00	0.00	0.20	0.30
198b	25	11	2	0	0	5	4	4.81	2.12	0.38	0.00	0.96	0.77
198c	23	5	1	0	0	6	2	3.10	0.67	0.13	0.00	0.81	0.27
198d	2	11	0	0	0	4	4	0.15	0.81	0.00	0.00	0.30	0.30
52a	16	3	0	0	0	3	2	3.12	0.58	0.00	0.00	0.58	0.39
52b	128	88	7	1	0	15	17	2.55	1.75	0.14	0.02	0.30	0.34

Table E.1 Continued

ID	Collision Type Frequency							Collision Type Rate (Crashes/MVMT)					
	Right Angle	Rear End	Side Swipe	Head On	S S Opp.	Other	Single Veh.	Right Angle	Rear End	Side Swipe	Opp.	Other	Single Veh.
52c	55	38	6	1	2	3	9	1.59	1.10	0.17	0.09	0.09	0.26
52d	30	10	3	1	1	4	10	1.30	0.43	0.13	0.09	0.17	0.43
73a	23	134	3	0	0	6	13	0.81	4.70	0.11	0.00	0.21	0.46
73b	60	29	4	0	0	8	5	6.31	3.05	0.42	0.00	0.84	0.53
73c	19	16	2	0	1	2	5	4.22	3.56	0.44	0.22	0.44	1.11
18a	90	40	8	1	1	10	6	2.73	1.21	0.24	0.06	0.30	0.18
18b	26	11	1	0	1	0	3	1.12	0.47	0.04	0.04	0.00	0.13
18c	94	318	15	0	0	11	7	1.66	5.62	0.26	0.00	0.19	0.12
212a	17	18	2	0	0	1	3	1.69	1.79	0.20	0.00	0.10	0.30
34a	43	80	3	0	0	5	7	3.32	6.18	0.23	0.00	0.39	0.54
34b	100	273	12	0	0	15	12	2.34	6.38	0.28	0.00	0.35	0.28
104a	8	1	1	0	0	1	0	1.13	0.14	0.14	0.00	0.14	0.00
104b	28	23	2	1	0	6	3	1.24	1.02	0.09	0.04	0.27	0.13
108g	35	26	2	1	0	5	10	1.60	1.19	0.09	0.05	0.23	0.46
108h	29	47	2	3	4	5	12	0.65	1.05	0.04	0.16	0.11	0.27
126f	87	33	7	0	0	4	5	6.08	2.31	0.49	0.00	0.28	0.35
126g	86	120	10	0	0	8	6	5.28	7.37	0.61	0.00	0.49	0.37
126h	49	29	6	0	0	5	9	2.96	1.75	0.36	0.00	0.30	0.54
126i	33	25	0	0	1	4	9	2.39	1.81	0.00	0.07	0.29	0.65
126j	25	15	4	0	2	2	6	1.10	0.66	0.18	0.09	0.09	0.26
126k	46	26	6	3	1	8	6	1.29	0.73	0.17	0.11	0.22	0.17
203a	62	108	4	2	1	5	5	3.67	6.39	0.24	0.18	0.30	0.30
203b	37	68	5	0	0	1	1	5.47	10.06	0.74	0.00	0.15	0.15
203c	24	80	8	0	0	9	6	0.71	2.37	0.24	0.00	0.27	0.18
203d	29	63	3	0	3	2	7	0.93	2.02	0.10	0.10	0.06	0.22
203e	20	65	5	0	0	4	6	0.73	2.38	0.18	0.00	0.15	0.22
203f	80	62	5	0	1	7	8	2.25	1.74	0.14	0.03	0.20	0.22
203g	21	8	0	0	0	0	0	5.27	2.01	0.00	0.00	0.00	0.00
204a	57	34	3	0	2	6	10	2.16	1.29	0.11	0.08	0.23	0.38
204b	36	39	5	0	2	2	5	2.72	2.94	0.38	0.15	0.15	0.38
204c	76	84	8	1	0	15	15	1.22	1.35	0.13	0.02	0.24	0.24
235a	65	51	6	4	2	10	16	0.79	0.62	0.07	0.07	0.12	0.19
26a	65	56	8	0	1	5	6	3.09	2.66	0.38	0.05	0.24	0.29
26b	176	257	9	0	1	10	13	5.20	7.60	0.27	0.03	0.30	0.38
26c	52	148	7	2	2	6	4	0.97	2.75	0.13	0.07	0.11	0.07
26d	75	96	8	0	2	9	4	2.71	3.46	0.29	0.07	0.32	0.14
26e	43	43	1	0	0	12	5	3.06	3.06	0.07	0.00	0.85	0.36
39a	50	87	13	0	0	14	8	0.94	1.64	0.25	0.00	0.26	0.15
39b	88	30	5	0	0	6	10	5.33	1.82	0.30	0.00	0.36	0.61
39c	24	19	5	1	0	1	10	0.86	0.68	0.18	0.04	0.04	0.36
53a	5	11	0	1	1	1	6	0.58	1.28	0.00	0.23	0.12	0.70
53b	17	23	1	0	0	2	0	4.20	5.69	0.25	0.00	0.49	0.00
97a	8	7	1	0	0	1	2	1.62	1.42	0.20	0.00	0.20	0.41
97b	17	5	0	0	0	1	5	4.59	1.35	0.00	0.00	0.27	1.35
97c	39	97	3	2	0	2	5	1.34	3.34	0.10	0.07	0.07	0.17
97d	83	94	13	0	0	12	4	6.79	7.69	1.06	0.00	0.98	0.33

Appendix F. Recommended Segments for Limiting Access Density

Table F.1 Recommended Road Segments for Limiting Access Density

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
101a	Main St	Cache	101	3.74	5.91	400 W to SR 165	7
237a	800E	Cache	237	0	0.38	700 N to 1000 N	5
237b	800E	Cache	237	0.38	0.87	1000 N to 1400 N	5
239a	1400N	Cache	239	0	1.04	SR 91 to SR 237	5
288a	1200E	Cache	288	0	0.49	SR 89 to 1000 N	8
288b	1000N	Cache	288	0.49	0.98	1200 E to 800 E	8
105a	Parrish Lane	Davis	105	0	0.35	RR to 400 W	6
105b	Parrish Lane	Davis	105	0.35	0.69	400 W to Main (SR 106)	6
106b	State/Main	Davis	106	6.9	7.4	200 S to 100 N	6
106e	Sheppard Ln	Davis	106	9.04	9.43	Main St to SR 89	5
108b	Antelope Rd	Davis	108	0.62	2.92	SR 126 to 1000 W	5
108f	2000 West	Davis	108	7.41	8.42	Clinton Rd to 6000 S	5
109a	Gentile St	Davis	109	0	0.44	Main St to Fort Lane	6
109c	Gentile St	Davis	109	0.76	1.19	700 E to Adamswood Rd	5
126c	State St	Davis	126	4.45	5.64	SR 193 to 300 N	5
126d	Main St	Davis	126	5.64	6.14	300 N to 800 N	5
126e	Main St	Davis	126	6.14	8.17	800 N to 6000 S	5
227a	200 West	Davis	227	0	0.49	I-15 to State St	5
227b	State St	Davis	227	0.49	0.7	200 W to Main	6
232b	Hill Field Rd	Davis	232	0.27	2.26	Gordan Ave to SR 193	5
273c	Main St	Davis	273	2.48	2.87	100 W to I-15	5
171a	3500 S	SL	171	0	1.5	SR 111 to 7200 W	5
171e	3500S/3300S	SL	171	8.05	9.24	Redwood Rd. to 900 W	5
171f	3300 S	SL	171	9.24	9.85	900 W to 500 W	5
171g	3300 S	SL	171	10.14	10.75	300 W to State St.	5
171k	3300 S	SL	171	14.61	15.36	2700 E to 3300 E	5
173c	5400 South	SL	173	6.93	8.65	1900 W to 700 W	-
173d	5300 S	SL	173	8.65	9.82	700 West to SR 89	-
181b	13th East	SL	181	2.81	3.44	3300 S to Crandall	5
181c	13th East	SL	181	3.44	4.12	Crandall to 2455 S	5
181d	13th East	SL	181	4.12	4.61	2455 S to 2100 S	3,6
181e	13th East	SL	181	4.61	5.17	2100 S to 1700 S	6
181g	13th East	SL	181	5.74	6.89	1300 S to 500 S	6
186a	300 West	SL	186	4.35	5.09	North Temple to 400 S	6
186b	400 South	SL	186	5.09	5.54	300 W to Main Street	6
186c	400/500 South	SL	186	5.54	8.04	Main St. to Guardsman	6

Table F.1 Continued

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
186d	Foothill	SL	186	8.04	9.02	Guardsman to Sunnyside	3
186e	21st East	SL	186	9.02	9.45	Sunnyside to Foothill	5
190a	Wasatch Blvd	SL	190	0.07	1.84	I-215 to Fort Union	3
209a	9000 S	SL	209	5.35	6.21	Redwood Rd to 1075 W	5
209c	9000 S	SL	209	7.14	7.85	Sandy Pkwy to State St	3,5
266a	4700 S	SL	266	0.27	0.77	2200 W to Redwood Rd.	5
266c	4500 S	SL	266	2.63	3.53	500 W to State	5
266d	4500 S	SL	266	3.53	4.73	State to 900 E	5
266e	4500 S	SL	266	4.73	6	900 E to Highland	5
48c	7200 South	SL	48	12.12	12.69	400 W to SR 89	5
68c	Redwood Rd.	SL	68	46.95	50.75	SR 209 to I-215	5
68h	Redwood Rd.	SL	68	57.31	58.88	1500 S to 400 S	5
71e	700 East	SL	71	9.05	11.72	9950 S to 7800 S	5
71g	900 East	SL	71	12.7	15.71	Fort Union to SR 152	5
71h	700 East	SL	71	16.52	18.28	4500 S to 3300 S	5
114c	Geneva Road	Utah	114	4.87	5.19	University Pk to 1000 S	6
114e	Geneva Road	Utah	114	5.74	6.99	575 S to 400 N	6
114f	Geneva Road	Utah	114	6.99	8.5	400 N to 1600 N	5
114h	Geneva Road	Utah	114	10.52	10.77	700 S to SR 89	5
189c	University Ave	Utah	189	3.5	5.8	University Pk to 4200 N	3
198a	State/100W	Utah	198	4.38	5.12	800 S to 200 S	5
198b	100W/100N	Utah	198	5.12	5.54	200 S to 200 E	8
198c	100N	Utah	198	5.54	6.26	200 E to 1000 E	6
198d	State	Utah	198	7.92	9.11	300 S to 400 N	6
52a	800 North	Utah	52	0	0.46	Geneva Road to I-15	6
73b	Main Street	Utah	73	40.43	40.79	500 E to I-15	5
73c	Main Street	Utah	73	40.79	41.2	I-15 to SR 89	5
18b	Bluff St	Wash.	18	1.45	1.98	400 S to Tabernacle St	5
34a	St George Blvd	Wash.	34	0	0.57	SR 18 to Main St	5
126h	1900 West	Weber	126	9.05	9.65	5300 S to 4800 S	5
126i	1900 West	Weber	126	9.65	10.15	4800 S to 4400 S	5
126j	1900 West	Weber	126	10.15	11.14	4400 S to SR 79	5
203d	Harrison Blvd	Weber	203	3.08	3.64	3600 S to 3200 S	6
204a	Wall Avenue	Weber	204	0	0.92	SR 26 to 32nd	5
26a	Riverdale Rd	Weber	26	0	0.67	SR 126 to 1500 W	5
26c	Riverdale Rd	Weber	26	1.5	2.53	900 W to 500 W	5
26e	Riverdale Rd	Weber	26	3.06	3.74	40th to SR 89	5
39a	1200 South	Weber	39	4.12	6	I-15 NB ramp to SR 204	3
53b	MLK Jr St	Weber	53	1.67	1.95	Lincoln to Washington	6
97b	5600 South	Weber	97	2.63	3.08	3800 W to 3500 W	5
97d	5600 South	Weber	97	4.85	5.32	2100 W to Park Dr	5

Appendix G. Recommended Segments for Raised Medians

Table G.1 Recommended Road Segments for Installing Raised Medians

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
108a	Antelope Rd	Davis	108	0.2	0.62	I-to State (SR 126)	5
193a	700 South	Davis	193	0	0.7	SR 126 to I-15 NB ramp	5
232a	Hill Field Rd	Davis	232	0	0.27	SR 126 to Gordon Ave	5
171c	3500 S	SL	171	3.53	7.03	5600 W to 2700 W	5
171d	3500 S	SL	171	7.61	8.05	2200 W to Redwood Rd	5
171h	3300 S	SL	171	10.75	12.73	State to Highland Dr.	5
173b	5400 South	SL	173	4.07	6.93	4460 W to 1900 W	-
186f	Foothill	SL	186	9.45	9.98	2100 E to 2300 E	5
209d	9000 S	SL	209	7.85	8.84	State Street to SR 71	5
209e	9400 S	SL	209	10.18	11.74	1300 E to Quail Hollow	5
270a	West Temple	SL	270	0.15	0.75	800 S to 400 S	6
48a	7800 S	SL	48	8.13	10.11	Bangerter to Redwood	5
48b	7000S	SL	48	10.11	10.6	Redwood Rd to 1300 W	5
68d	Redwood Rd.	SL	68	51.47	56.13	5400 S to 2320 S	5
68e	Redwood Rd.	SL	68	56.13	56.36	2320 S to SR 201	5
71f	900 East	SL	71	11.72	12.7	7800 S to Fort Union	5
114a	Center Street	Utah	114	0	0.45	500 W to 1000 W	8
156a	Main Street	Utah	156	1.38	0	I-15 ref point 2 to 300 S	8
189a	University Ave.	Utah	189	0.22	1.52	I-15 to 500 S	5
189b	University Ave.	Utah	189	1.52	3.5	500 S to University Pk	6
52b	800 North	Utah	52	0.46	2.05	I-15 to Main St	6
18a	Bluff St	Wash.	18	0.29	1.45	I-15 SB ramp to 400 S	5
18c	Bluff St	Wash.	18	1.98	3.17	Tabernacle to Sunset	5
34b	St George Blvd	Wash.	34	0.57	1.74	Main St to 1000 E	5
126f	1900 West	Weber	126	8.17	8.66	6000 S to 5600 S	5
126g	1900 West	Weber	126	8.66	9.05	5600 S to 5300 S	5
203a	Harrison Blvd	Weber	203	1.84	2.3	4600 S to 4200 S	6
203b	Harrison Blvd	Weber	203	2.3	2.43	4200 S to 4100 S	6
203c	Harrison Blvd	Weber	203	2.43	3.08	4100 S to 3600 S	6
203e	Harrison Blvd	Weber	203	3.64	4.21	3200 S to 2800 S	6
203f	Harrison Blvd	Weber	203	4.21	5.23	2800 S to 2100 S	6
203g	Harrison Blvd	Weber	203	5.23	5.37	2100 S to 2000 S	6
204b	Wall Avenue	Weber	204	0.92	1.35	32nd to 29th	5
204c	Wall Avenue	Weber	204	1.35	3.56	29th to 12th	5
26b	Riverdale Rd	Weber	26	0.67	1.5	1500 W to 900 W	3
26d	Riverdale Rd	Weber	26	2.53	3.06	500 W to 40th	5
39b	1200 South	Weber	39	6	6.57	SR 204 to Adams Ave	5

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Appendix H. Recommended Segments for Future Planning

Table H.1 Recommended Road Segments for Future Planning

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
101a	Main St	Cache	101	3.74	5.91	400 W to SR 165	7
218a	100N	Cache	218	7.77	8.2	300 W to SR 91	5
238a	300 S	Cache	238	4.21	4.68	Main St to 400 E	7
106a	2nd East	Davis	106	5.18	6.9	1700 S to 200 S	5
106b	State/Main	Davis	106	6.9	7.4	200 S to 100 N	6
106c	Main	Davis	106	7.4	8.29	100 N to SR 225	6
106d	Main	Davis	106	8.29	9.04	SR 225 to Sheppard Lane	5
108b	Antelope Rd	Davis	108	0.62	2.92	State to 1000 W	5
108c	Antelope Rd	Davis	108	2.92	3.92	1000 W to 2000 W	5
108d	2000 West	Davis	108	3.92	4.45	1700 S to 1175 S	5
108e	2000 West	Davis	108	4.45	7.41	1175 S to Clinton Rd	5
108f	2000 West	Davis	108	7.41	8.42	Clinton Rd to 6000 S	5
109b	Gentile St	Davis	109	0.44	0.76	Fort Lane to Chapel St	6
109d	Oak Hills Rd	Davis	109	1.36	2.96	Rosewood Lane to US 89	3
126a	Main St	Davis	126	0	3.21	900 S to Antelope Dr	5
126b	State St	Davis	126	3.21	4.45	Antelope Dr to SR 193	5
126e	Main St	Davis	126	6.14	8.17	800 N to 6000 S	5
193b	SR 193	Davis	193	0.7	5.67	I-15 NB ramp to US 89	3
227a	200 West	Davis	227	0	0.49	I-15 to State St	5
273a	Main St	Davis	273	0	1.92	US-89 to 200 S	5
273b	Main St	Davis	273	1.92	2.48	200 S to 100 W	6
37a	1800N	Davis	37	0	0.99	Main St to 1000 W	5
37b	1800N	Davis	37	0.99	2.42	1000 W to 2430 W	5
37c	1800N	Davis	37	2.42	2.76	2430 W to 2750 W	5
151a	S Jordan Pkwy	SL	151	0	2.01	Bangerter to Redwood	5
171a	3500 S	SL	171	0	1.5	SR 111 to 7200 W	5
171b	3500 S	SL	171	1.5	3.53	7200 W to 5600 W	5
171i	3300 S	SL	171	12.73	14.11	Highland Dr. to 2300 E	5
171j	3300 S	SL	171	14.11	14.61	2300 E to 2700 E	5
173a	5400 South	SL	173	2.64	4.07	5600 W to 4460 W	-
181a	13th East	SL	181	0	2.81	SR-152 to 3300 S	5
181f	13th East	SL	181	5.17	5.74	1700 S to 1300 S	6
184a	State	SL	184	0	0.76	North Temple to Zane	6
186g	Foothill	SL	186	9.98	11.25	2300 E to Stringham	5
195a	2300 E	SL	195	0	2.56	4500 S to I-80	3
209b	9000 S	SL	209	6.21	7.14	1075 W to Sandy Pkwy	3
209f	Lt Cottonwood	SL	209	11.74	12.79	Quail Hollow to 3100 E	5

Table H.1 Continued

ID	Street Name	County	Rt. No.	Beginning Milepost	Ending Milepost	Description	Access Category
209g	Lt Cottonwood	SL	209	12.79	13.33	3100 E to Wasatch Blvd	5
209h	Lt Cottonwood	SL	209	13.33	14.57	Wasatch Blvd to SR 210	5
266b	4700 S	SL	266	0.77	2.63	Redwood Rd to 500 W	3
266f	4500 S	SL	266	6	8.02	Highland to I-215	5
68a	Redwood Rd.	SL	68	40.18	45.21	SR 140 to 104th South	5
68b	Redwood Rd.	SL	68	45.21	46.95	SR 151 to 90th South	5
68c	Redwood Rd.	SL	68	46.95	50.75	SR 209 to I-215	5
68j	Redwood Rd.	SL	68	59.63	60.99	N Temple to 1100 N	5
71b	126th South	SL	71	0	2.92	Bangerter to 1300 W	5
71c	700 East	SL	71	6.02	8.22	123rd S to 106th S	5
71d	700 East	SL	71	8.22	8.85	106th S to Carnation Dr	5
71g	900 East	SL	71	12.7	15.71	Fort Union to SR 152	5
71h	700 East	SL	71	16.52	18.28	4500 S to 3300 S	5
114b	Geneva Road	Utah	114	1.43	4.87	Center to University Pk	6
114d	Geneva Road	Utah	114	5.19	5.74	1000 S to 575 S	6
114g	Geneva Road	Utah	114	8.5	10.52	1600 N to 700 S	5
180a	500 East	Utah	180	0	1.04	I-15 to State	5
189d	University Ave	Utah	189	5.8	7.49	4200 N to SR-52	3
198a	State/100W	Utah	198	4.38	5.12	800 S to 200 S	5
198d	State	Utah	198	7.92	9.11	300 S to 400 N	6
52c	800 North	Utah	52	2.05	3.06	Main St to 800 E	6
52d	800 North	Utah	52	3.06	4.48	800 E to SR 189	6
73a	Main Street	Utah	73	39.35	40.43	780 W to 500 E	6
212a	Telegraph St	Wash.	212	0.74	1.28	300 W to 300 E	5
104a	Wilson Lane	Weber	104	0	0.58	SR 126 to I-15 SB ramp	5
104b	Wilson Lane	Weber	104	0.58	1.85	I-15 SB to Beg Div Hwy	3
108g	3500W	Weber	108	8.42	9.92	6000 S to 4800 S	5
108h	Midland Drive	Weber	108	9.92	12.81	4800 S to 1900 W	5
126h	1900 West	Weber	126	9.05	9.65	5300 S to 4800 S	5
126i	1900 West	Weber	126	9.65	10.15	4800 S to 4400 S	5
126k	1900 West	Weber	126	11.67	13.27	Sr 108 to SR 104	5
235a	Washington	Weber	235	0	3.07	200 S (SR89) to 2550 N	3
39a	1200 South	Weber	39	4.12	6	I-15 NB ramp to SR 204	3
39c	1200 South	Weber	39	6.57	7.74	Adams Ave to SR 203	5
53a	MLK Jr St	Weber	53	0.5	0.95	G Ave to A Ave	5
97a	5500 South	Weber	97	2.03	2.63	4300 W to 3800 W	5
97b	5600 South	Weber	97	2.63	3.08	3800 W to 3500 W	5
97c	5600 South	Weber	97	3.08	4.85	3500 W to 2100 W	5