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Examining corridor-level crash rates in consideration of access point density and spacing

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**Examining corridor-level crash rates in consideration of
access point density and spacing**

by

Iftin Thompson

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Transportation Engineering)

Program of Study Committee:
Peter Savolainen, Major Professor
Jing Dong
Kristen Cetin

Iowa State University

Ames, Iowa

2017

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DEDICATION

I would like to dedicate this thesis to my wonderful mother, Kaha Fatah. It is because of her support and encouragement that I have come this far in pursuing my goals. Without her continuous unconditional love and support throughout this journey, this work would have not been possible.

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NOMENCLATURE

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
DIC	Deviance Information Criterion
DOT	Department of Transportation
GEE	Generalized Estimating Equation
GIMS	Geographic Information Management System
GIS	Geographic Information Systems
GLM	Generalized Linear Models
HSM	Highway Safety Manual
IID	Independently and Identically Distributed
InTrans	Institute for Transportation
QA/QC	Quality Assurance/Quality Control
SPF	Safety Performance Function

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DISCLAIMER

The findings and conclusion of this study are those of the author and do not necessarily represent the views of the Iowa Department of Transportation or Iowa State University.

ABSTRACT

Given the degree of traffic conflict inherent in their operations, intersections and driveways continue to experience a disproportionate number of traffic crashes, injuries, and fatalities. Access management strategies, such as the introduction of minimum access point spacing criteria and turning movement restrictions, are important elements to optimizing the operational and safety performance of roadway corridors. The relationship between safety and these types of access policies is a complex issue and the impacts of such features on traffic crashes is in need of further research. The purpose of this study was to identify how driveway density, type, and spacing are related to the rate of crashes among various roadways in Iowa. Data were collected for two types of facilities: (1) priority, or high-growth urban/suburban corridors; and (2) crossroad corridors, beginning at the crossroad terminal of service interchanges.

Detailed driveway information was manually collected along each corridor and integrated with traffic volume, roadway geometry, and traffic control information from the Iowa DOT. Police-reported crash data from 2010 to 2014 were also obtained from an Iowa DOT database. A series of safety performance functions (SPFs) were estimated to ascertain how crash rates change in relation to the frequency of access points observed on these corridors. The results of the study show that crash rates are strongly associated with access point density. Crash rates were higher on corridors with denser traffic signal spacing, as well as on corridors with dense commercial development. Other factors were also found to be associated with changes in crash rates, including divided roads and the posted speed limit.

CHAPTER 1: INTRODUCTION

1.1 Background

The spacing of driveways and intersections is an important element in the planning, design, and operation of roadways. Access points have important impacts on both traffic crashes and congestion as entering and exiting traffic can directly affect the safety and functional integrity of streets and highways. For example, too many closely spaced intersections and driveways increase the potential for crashes, introduce delays, and preclude effective traffic signal coordination. However, a sufficient number of driveways and intersections are necessary so as not to inhibit access and over-concentrate traffic (Levinson & Gluck, 1997).

There has been a significant amount of research conducted over the years that has shown crash rates to increase as the frequency of driveways and intersections increase. Roadways with numerous driveways and signals often have double or triple the crash rates of roadways with wide spacing between access points or of roadways where access is fully controlled (Gluck & Lorenz, NCHRP Report 404: State of the Practice in Highway Access Management, 2010). It was estimated by Gluck et al.. (1999) that for every access point added per mile, the associated crash rate would increase by 4 percent. Other research indicates that an increase from 10 access points to 20 access points per mile increases crash rates by roughly 30 percent (Marek, 2011).

Access points introduce a host of additional concerns, as well. For example, traffic signals cause delay and irregularly spaced signals can reduce travel speeds (Sarasua, et al. 2015). Intersections experience 23 percent of all fatal crashes, with 6 percent of fatal crashes occurring at signalized intersections (Antoucci, et al. 2004). Wang et al.. (2006) found that the

total crash rate increases as signalized intersection density increases. Research conducted by Mouskos et al.. (1999) determined that 30 percent of crashes along various highways in New Jersey were expected to occur between signalized intersections.

Safety performance functions (SPFs), also known as crash prediction models, have been used in various studies to best estimate the safety impacts of various access management features on crash rates. For example, Avelar et al.. (2013) developed SPFs to analyze the safety impacts of driveways on both urban and rural highways. The results indicated that areas where a large amount of driveways are present is associated with more crashes. The use of SPFs is recommended as an appropriate analysis method in the Highway Safety Manual (HSM) (American Association of State Highway and Transportation Officials, 2010).

Continued research on the safety impacts of access features is needed and helps to establish guidance as to appropriate access management strategies. Many states have developed their own state-specific access management policies and procedures to reduce delays, congestion, and crashes, as well as to provide improved accessibility and mobility on their roadways. Effective access management techniques can reduce crashes by 50 percent, increase roadway capacity by 23 to 45 percent, and reduce travel time and delay by 40 to 60 percent. Ultimately, effective access management is essential to the transportation network.

1.2 Research Objectives

The primary objective of this research was to determine how the density, type, and spacing of intersections and driveways affect the rate of crashes among roadways in Iowa. The

research investigates the relationship between crashes and access management strategies among two datasets of interest:

1. A series of priority, high-growth corridors throughout the state of Iowa (referred to as priority corridors); and
2. The corridors in the immediate vicinity of each of Iowa's service interchanges (referred to as crossroad corridors).

Given that crashes are rare and random, there are many factors that can influence crashes, including the density of access points. Data for several additional roadway characteristics of interest were collected, and controlled for, as a part of several analyses to discern the relationship between access spacing and crashes. Roadway characteristics considered included intersection density and type, number of lanes, speed, median width, lane width, and other variables. Using these data, a series of safety performance functions were estimated to better understand the relationship between crashes and the number/density of access points while controlling for various roadway characteristics. The results of this study will help to inform subsequent access management policy decisions in Iowa and other Midwestern states.

1.3 Thesis Structure

This thesis is organized into five chapters, with this chapter providing background to the study and introducing the research questions of interest. A brief description of the subsequent chapters follows:

- Chapter 2 summarizes the extant literature regarding access management. First, a brief overview of access management is provided, followed by a review of previous studies evaluating the safety impacts of intersections and driveways.
- Chapter 3 provides a detailed description of the priority and crossroad corridor datasets. It provides a detailed description of the existing datasets that were integrated to develop each dataset, as well as the methods used for supplementing both datasets through an extensive manual review. This includes building the access point database for the priority corridors, as well as collecting additional detailed information for each crossroad corridor at service interchanges.
- Chapter 4 provides a brief overview of the statistical methods used for the purpose of this study. This is followed by a detailed presentation of the results of a series of statistical analyses conducted during the course of this study. The results focus on the relationships between access density, spacing, and crashes on both the priority and crossroad corridors.
- Chapter 5 provides a concise summary of key findings, highlights important conclusions of the research, and discusses opportunity areas for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 General Overview of Access Management

A fundamental concept in transportation is the strong relationship between transportation and land use. Land use is affected by changes in transportation and transportation is strongly affected by changes in land use. Land development helps to encourage travel and generate the need for new transportation facilities while transportation helps to shape land use by improving mobility and providing access to developments. By providing access to land, transportation will create changes in land patterns and allow opportunities for increased development (Center for Urban Transportation Studies, 1999). However, in order to provide access to land development, proper management within transportation needs to be performed to aid in improved accessibility and mobility.

Access management is defined as the systematic process aimed to ensure that major arterials, intersections, and freeway systems provide safe and efficient access to land development, while simultaneously preserving the flow of traffic (U.S Department of Transportation Federal Highway Administration, 2004). This process is best achieved by managing the design and location of driveways, median openings, and intersections to local roads (Center for Urban Transportation Studies, 1999). Appropriate use of access management techniques can increase roadway capacity and safety, manage congestion, and reduce crashes. Areas characterized by poor access management tend to experience a reduction in overall safety and quality of traffic flow, greater number of conflicts between vehicles and pedestrians, increased congestion, and an overall poor image for the corridor (U.S Department of Transportation Federal Highway Administration, 2004).

State and local governments have continued to see the need for methods of coordinating transportation and land use and have incorporated access management into their planning and design practices (Gluck & Lorenz, 2010). Planning provides the foundation for effective access management and achieving a useful roadway functional hierarchy. Roadways are classified by function based on the priority given to land access or through movements as shown in Figure 1. Expressways, freeways, and other principal arterials require higher levels of access control to allow traffic to operate safely and more efficiently over long distances at posted speeds. Local streets, cul-de-sacs, and other minor roads provide drivers, bicyclists, and pedestrians with frequent access to properties (Williams, et al. 2014).

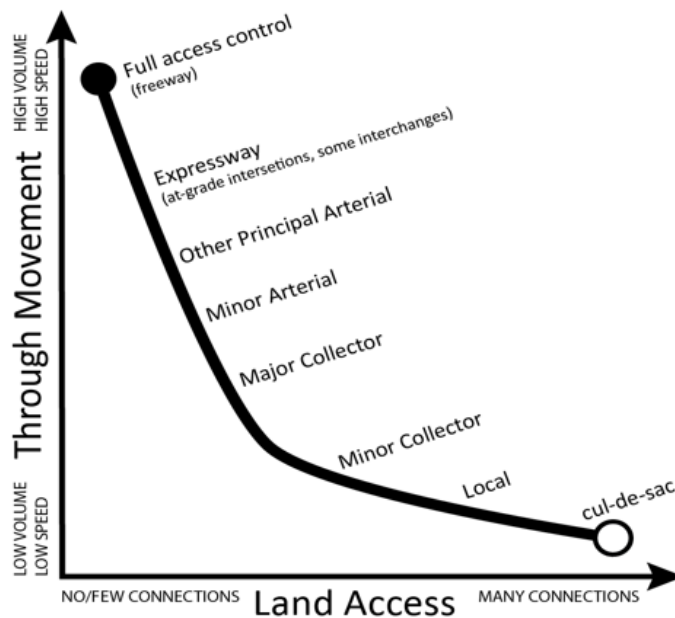


Figure 1: Conceptual Roadway Functional Hierarchy (Williams, et al. 2014)

An effective access management program can reduce crashes by 50 percent, increase roadway capacity by 23 percent to 45 percent, reduce travel time, and delay by 40 percent to 60 percent. Access management is no longer optional, but instead essential to the transportation network. Replacing, widening, or reconstructing transportation systems in the future is not practical. The function of roadways can deteriorate rapidly and begin a cycle of events that will create the need for improvements to access developed land. Access management is not only beneficial to motorists, but supports safe and efficient operations to cyclists, pedestrians, the transit rider and agency, the business owner or operator, the freight industry, government agencies, and the communities (Williams, et al. 2014).

2.2 Access Management at Intersections

Agencies determine which access features will be managed and how they will be managed. Features to control under access management include traffic signals at intersections, driveways to street connections, median and median openings, and interchanges (Gluck & Lorenz, NCHRP Report 404: State of the Practice in Highway Access Management, 2010). For intersections, developing traffic signals, such as spacing and density, is one of the most important techniques in access management. Spacing and density of traffic signals determine the performance of urban and suburban roadways. Traffic signals account for most of the delays that motorists experience and irregularly spaced signals can reduce travel speeds (Sarasua, et al. 2015). Intersections experience 23 percent of all fatal crashes, with 6 percent of fatal crashes occurring at signalized intersections. Signalized intersections also constitute 85 percent of the fatal crashes that occur in urban areas (Antoucci, et. al 2004). Access

management techniques have been implemented to specifically control for access at intersections (Sarasua, et al. 2015).

Adequate space between intersections and minimizing signals improves travel times. For every traffic signal added per mile to a roadway, travel times are reduced by two to three mile per hour. Travel time on a segment with four signals per mile is about 16 percent greater than on a segment with two signals per mile (Marek, 2011). Closer intersection spacing can increase friction among vehicles resulting higher crash rates. Figure 2 is an example of the increase in crashes as the number of intersections increase on urban two-lane roadways in Michigan (Levinson & Gluck, 1997).

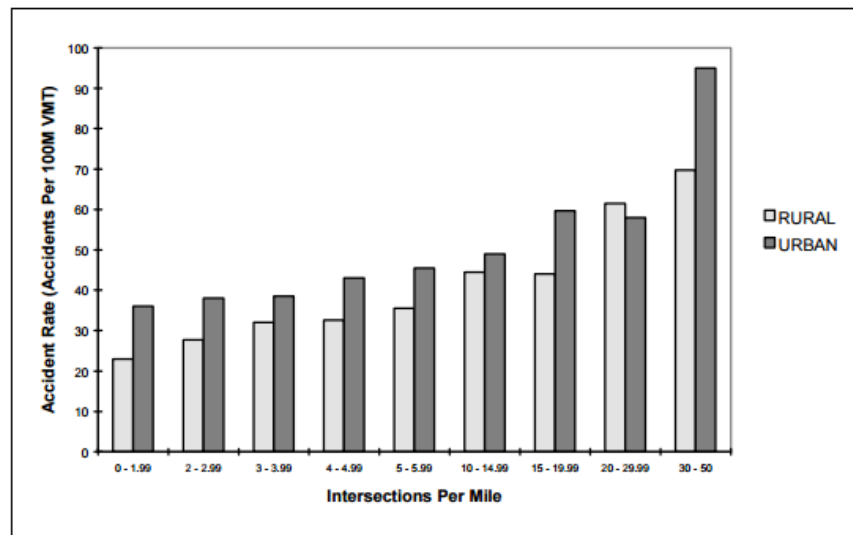


Figure 2: Access related Crashes for two-lane undivided roadways in Michigan (Levinson & Gluck, 1997)

In the Denver metropolitan area, access management plans were implemented for 4.35 miles of Arapahoe Road and 5.16 miles of Parker Road, which resulted in half the crash rates compared to roads without access controls. The plan included physical medians along both roads to separate opposing directions of travel, and confined full movements to signalized

intersections spaced at $\frac{1}{2}$ mile intervals; provided right-turn only access at $\frac{1}{4}$ mile intervals. The wide access spacing allowed drivers to better respond to changing conditions (Levinson & Gluck, 1997).

Similarly, an analysis conducted among urban/suburban areas of five states showed that crashes are affected by increases in the density of traffic signals. The rate for corridors with densities of more than six signals per mile was 2.5 times higher than corridors with two or fewer signals per mile. The results showed that crash frequency also increased when the density of unsignalized intersections increased (Papayannoulis, et al. 2000).

One access management consideration at intersections is corner clearance. Corner clearance is defined as the minimum length between a signalized intersection and the first driveway along the connecting street. Corner clearance is important to separate conflict points effectively and provide drivers with enough time to make safe maneuvers. A few studies have been done exploring the impact of corner clearance on intersections. A study conducted by Xu et al.. (2011) evaluated the impact of access management techniques on crash counts at signalized intersections using random-effect negative binomial models. It was determined that the coefficient for average length of corner clearance was negative. This implied that the longer driveways were from the corner, fewer crashes were expected to happen at intersections. The shorter the corner clearance, the higher the chances of conflicts occurring between turning and through traffic. A longer corner clearance allows drivers to perceive and respond more quickly. The type of land use also affected the impact of corner clearance. When the land use at corners were commercial, more crashes occurred. This was mainly because commercial land use tends to have shorter corner clearance. Overall, the average length of corner clearance had a negative impact on crash occurrence; other factors such as traffic flow, land use type, number of lanes,

and posted speed limit were positively related to crashes at signalized intersections (Xu, et al. 2011).

In Utah, 144 signalized intersections were examined to determine the impact of access on crashes within the functional area of intersections. Data included as a part of this analysis included access classification, proximity to freeway interchange, upstream corner clearance, total access points within the functional area, access density, conflict density, and access land use. The results showed that access density, access location, and access type have a significant impact on safety within the intersection functional area. Access points within functional areas of the intersections showed a relationship with increased crashes and increased severity costs. An increase in commercial access density was associated with an increase in total crashes, crash rates, and rear-end crashes within intersection functional areas. Intersections that adhered to Utah DOT corner clearance standards exhibited fewer crashes and lower crash severity costs (Schultz, et al. 2010).

The New Jersey DOT conducted a statistical analysis to determine the effect of various traffic, geometric, and environmental factors on accident rates on New Jersey State highways. The main concern was the effect of midblock access points on accident rates, but a comparison study was also conducted to investigate the effect of various factors on both section crashes and signalized intersection crashes. Around 30 percent of crashes along the highways of observation were expected to occur between signalized intersections. Seven percent of crashes are directly attributed to maneuvering to and from access points. Other factors such as access density, median, shoulder, and speed limit were also related to crashes (Mouskos, et al. 1999).

Guo et al.. (2009) developed several Bayesian models for crash data from 170 four-legged signalized intersections along arterials in the state of Florida. Safety impacts of risk

factors such as geometric design features, traffic control, and traffic flow characteristics were evaluated. Geometric design features included number of through lanes, number of left-turn lanes, exclusive left turn lanes, presence of median, presence of exclusive right-turn lanes, types of left-turn lane offset, direction of each intersection roadway, and angle of intersecting roadways. A mixed effect model and a conditional autoregressive model were utilized to capture spatial correlation among intersections (Guo, et al. 2009).

Another study conducted in Florida used generalized estimating equations (GEEs) with a negative binomial link function to model rear-end crash frequencies at signalized intersections. The purpose was to further investigate the safety effect of intersection-related variables on rear-end crash occurrence. A temporal and spatial correlation were used to investigate rear end crash frequencies on signalized intersections. For the temporal analysis, 208 four-legged signalized intersections were selected in suburban areas of two counties in Florida. For the spatial analysis, 476 signalized intersections were selected along 41 principal and minor arterials within three different counties of Florida. The results of the study were that the number and types of right-turn lanes on minor roadways, the number of right-turn lanes on major roadways, the number of left-turn lane on major roadways, medians on minor roadways, and 3 or 4 leg intersection configuration are all significant to affect rear-end crash occurrence. Three-legged intersections appear to experience lower rear-end crashes than four-legged intersections. Higher numbers of turning lanes on a major roadway are found to increase rear-end crashes. The presence of medians on the minor roadway are associated with reducing rear-end crashes. Left-turn protection on the major roadway is associated with lower risks of rear-end crashes, but left-turn protected movements on minor roadways increase rear-end crashes. The number of approaches with protected left turn lanes is directly related to the number of

phases per cycle, therefore increasing the number of phases increases rear-end crashes at intersections. High speed limit on a major roadway is related to more rear-end crashes. For the temporal analysis, intersections located in high population areas are associated with high rear-end crash frequency. The spatial analysis study, found that there is a high correlation between the closest intersections along a corridor, and as the space between intersections increased, the correlation decreased. The average distance to the neighboring signals along the corridors is identified to be significant to affect rear-end crashes. This indicated that intersections along corridors affect each other and should not be considered in isolation. For safety purposes, it was recommended that intersections along corridors should have well-coordinated signals and spacing in order to reduce rear-end crashes (Wang & Abdelaty, Temporal and Spatial Analyses of Rear-End Crashes at Signalized Intersections., 2006).

Similar studies from other parts of the world have also been conducted to determine factors that influence crashes at intersections, particularly in urban and suburban areas. Currently, China does not have much guidance for signal spacing access features or other access management criteria. In suburban areas, there is rarely careful consideration regarding safety during transportation planning and roadway design. Signal spacing is inconsistent which interrupts traffic flow and prevents proper safety. Researchers in China examined 161 road segments that were each between two adjacent signalized intersections of eight suburban arterials within Shanghai. The goal was to determine the effect of signal spacing, geometric design, access features, and traffic characteristics on total crash occurrence. Hierarchical negative binomial Bayesian models were developed for the total crashes and bivariate hierarchical negative binomial models were developed for minor and severe injuries to account for the correlation in crash counts among different severity levels. Two variables were created

from the data for analysis purposes. The variables were arterial-level and segment-level. Arterial-level was focused on the density of signals along arterials (DOSP), and the standard deviation of signal spacing (SDSP). Segment-level analysis focused on geometric design, access features, traffic characteristics, and area type. The results for the arterial-level variables found that signalized intersection density is positively correlated with crash occurrence on suburban arterials. The total crash rate increases as signalized intersection density increases. Irregularity of signal spacing was significant in a model of minor injury crashes showing that it has a negative impact on safety. The results for the segment-level analysis determined access density has an increasing effect on minor crashes, severe crashes, and total crashes. Higher percentages of heavy vehicles were also found to be correlated with more crashes (Wang, et al. 2013).

2.3 Access Management at Driveways

Driveways are another feature to control under access management policies and guidelines. Driveways are commonly referred to as access points and introduce several conflicts to the traffic flow on roadways (Gluck, et al. 1999). Driveway-related crashes are typically the result of conflicts between vehicles such as turning movements at the access point or speed differentials and queued vehicles upstream of the access point (Avelar, et al. 2013). As the number of driveways along a road increases, the crash rate also begins to increase. Figure 3 shows the composite crash rate indices derived from the analysis of 37,500 crashes. The indices were developed by correlating crash rates with access point density. The crash rate for 10 access points per mile was used as the base and the crash rates were averaged for each

access density value. These indices suggest that an increase from 10 access points to 20 access points per mile would increase crash rates by roughly 30 percent (Marek, 2011).

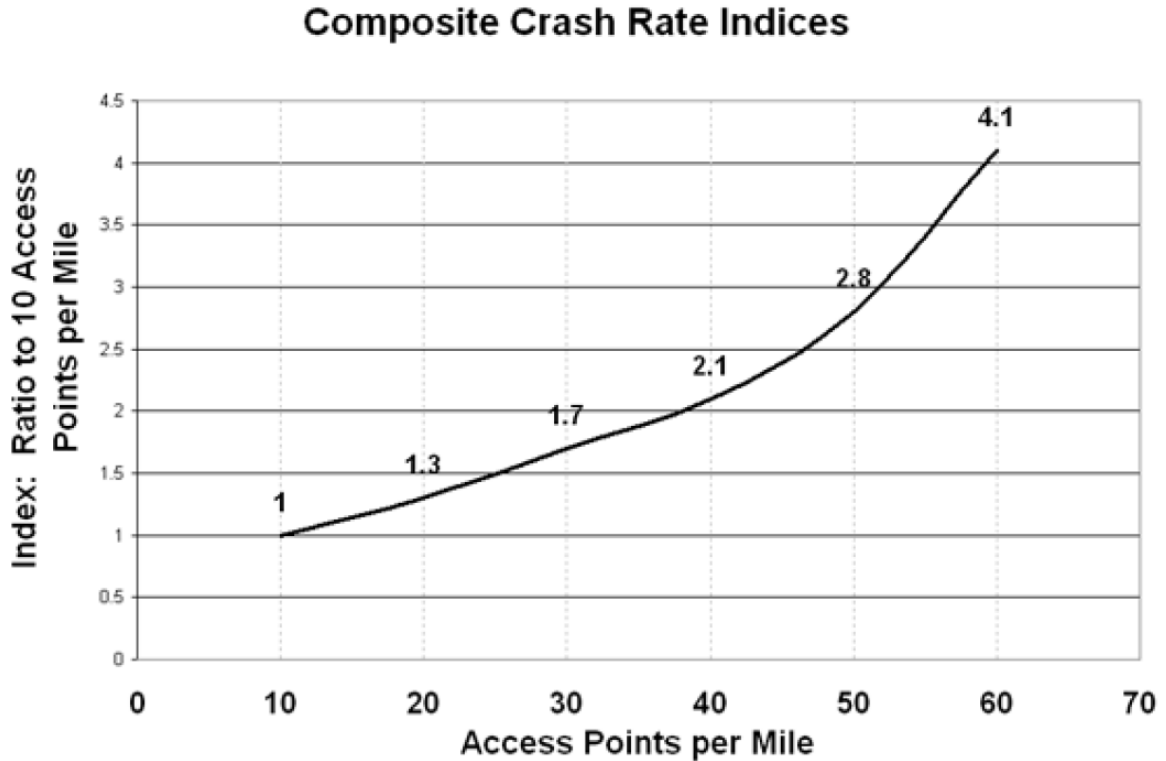


Figure 3: Crash Rate Indices for Access Points (Marek, 2011)

According to AASHTO's *A Policy on Geometric Design of Highways and Streets*, "Driveways are, in effect, at-grade intersections. The number of accidents is disproportionately higher at driveways than at other intersections; thus their design and location merit special consideration." The main goal of driveway regulation is to provide desirable spacing between driveways and to ensure safety along roadways. The spacing of driveways should reflect the impact length (the distance back from a driveway that cars begin to be affected) and influence areas associated with motorists entering or leaving a driveway (American Association of State Highway and Transportation Officials, 2001). Separation or spacing of driveways provides motorists with adequate perception and reaction time. Driver safety will begin to improve if

motorists are provided with enough time to address potential conflicts. Figure 4 is an example of conflicts that are introduced to motorists when improved access spacing is not put in place. Figure 5 is an example of the same roadway shown in Figure 4, but with improved access spacing and medians (Williams, et al. 2014).

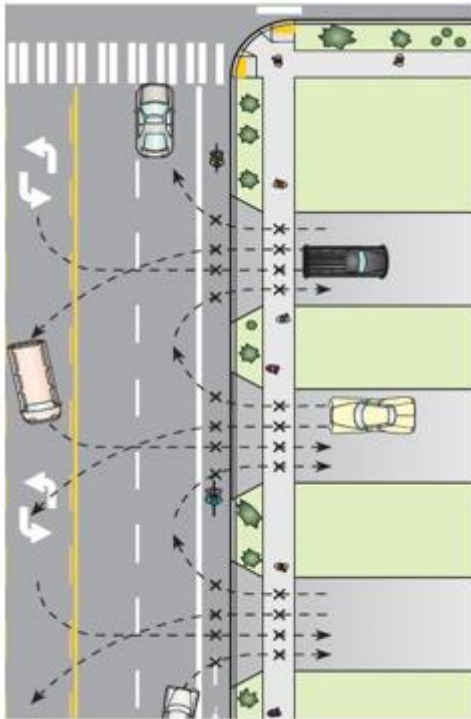


Figure 4: Conflicts between motorists and driveways (Williams, et al. 2014)

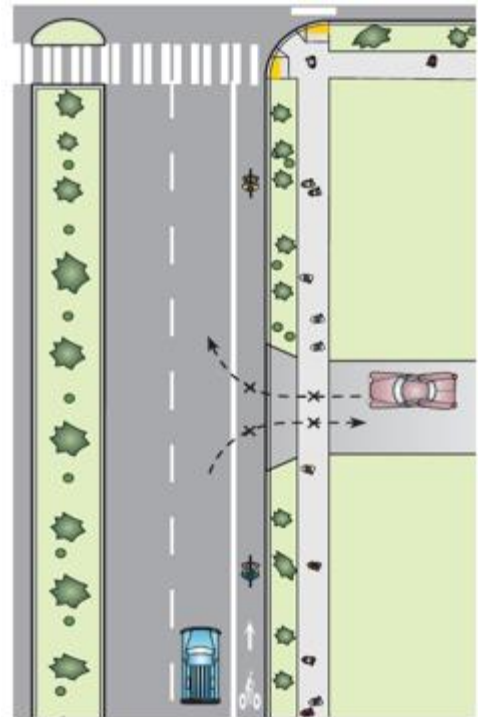


Figure 5: Improved Access Spacing and Medians (Williams, et al. 2014)

Limiting turning movements or adding turning lanes are also effective strategies in improving safety along roadways with driveway access. Managing conflicting maneuvers at driveways helps to reduce the number of crashes that may occur due to turning vehicles. Left turns in particular are the cause for most driveway-related crashes (Dixon, et al. 2015). Figure 6 displays the percentage of driveway crashes by turning movements.

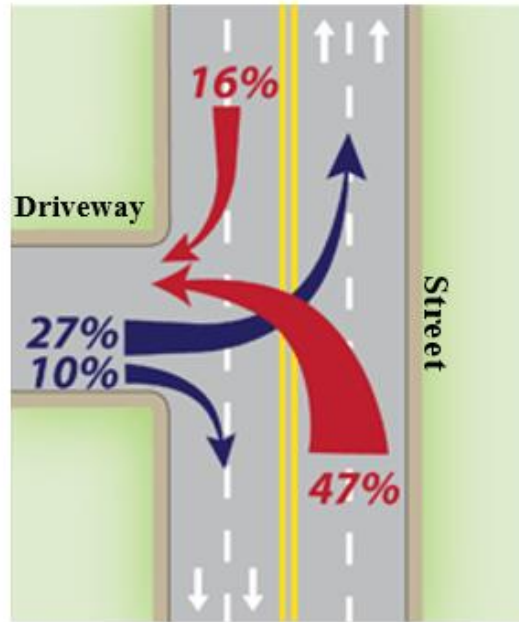


Figure 6: Percentage of Driveway Crashes by Turning Movements (Williams, et al. 2014)

In the state of Illinois, a study was conducted to develop a method to quantify the impact of driveway types and density on crash frequencies, types, and severities. The different types of driveways along with crashes from 2005 to 2009 occurring in the impact area of each driveway were collected. Driveways were grouped into four categories: commercial, commercial drive-thru, industrial-institutional and residential. Sixty driveways were selected for each category and its associated crashes. The results showed that commercial driveways with a drive-thru exhibited the highest crash rate while residential driveways experienced the lowest crash rate. (Williamson & Zhou, 2014).

Rural and urban highways in Oregon were analyzed to evaluate the safety impacts of various driveway configurations. The data collected for the study included forty segments restricted to lengths of 2 miles or less from urban and rural roadways and crash data from 2004 to 2008. The rural segments were further divided into 82 shorter segments because of

noticeable clustering of driveways throughout the corridors. Clustering of driveways is defined as the set of driveways on the same side of the road that are located so that a car driving at the speed limit can travel past two consecutive driveways in 1.5 seconds or less. A statistical approach, developing safety performance functions (SPFs), was performed to analyze the driveway data for both urban and rural highways. The results indicate that for the urban models higher percentages of intensive land use are associated with more crashes, mainly because large amount of driveways are more likely to be present. Industrial and commercial driveways are associated with a stronger crash occurrence than other types of driveways in urban environments. For the rural data, the total number of driveway clusters is associated with more crashes, but larger clusters are associated with fewer crashes. Highly clustered driveways are expected to have fewer crashes than isolated driveways. Crashes are also more expected at locations with larger percentages of industrial driveways. Overall, the research found that the safety effect of driveways depends on two components: the total number of driveways and how these driveways are clustered along the segment (Avelar, et al. 2013).

Researchers in Indiana developed negative binomial regression models to predict the total number of crashes, number of property-damage-only crashes, and number of fatal and injury crashes on urban multi-lane arterial segments. The data collected for the statistical analysis was five years of crash data (from 1991 to 1995), AADT, calculated segment lengths, and access density, which included both signalized and unsignalized access points. The developed models determined that the coefficient for access points was positive, indicating that segments with more frequent access points experience more crashes. The proportion of access points that are channelized and the proportion of access points with right-turn lanes were also tested in the model and both were individually significant with positive coefficients.

This indicated that the presence of high-volume access points is associated with higher frequencies of crashes. Furthermore, ten additional access points are associated with a 32 percent increase in the number of crashes. The crash ratio for urban roadways is over four times higher than for suburban roadways, and the percentage of injury and fatality crashes increases with an increase in access density. Thirty two percent of crashes reported on suburban roadways with full access control involve injury or death, and urban areas with 50 access points with unrestricted movements and some traffic signals experience 31 percent injury/fatal crashes. The models also indicated that the presence of signals is associated with higher crash rates and that an outside shoulder, two-way left-turn lane, or median without openings between signals leads to a reduction in the number of crashes. Figure 8 and Figure 7 display the effects of access density on crash frequency and crash severity (Brown & Tarko, 1999).

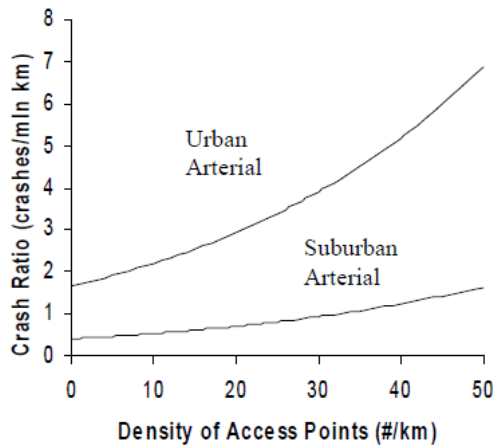


Figure 8: Effects of Access Points on Crash Frequency (Brown & Tarko, 1999)

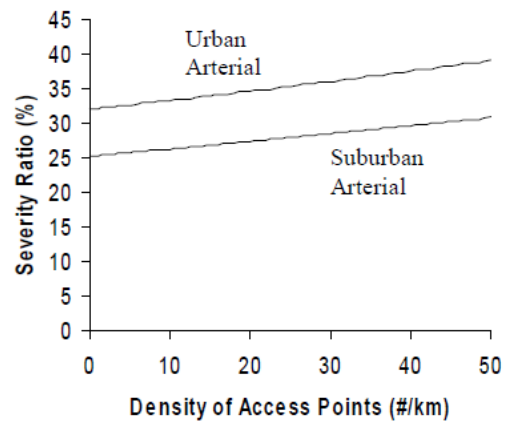


Figure 7: Effects of Access Points on Crash Severity (Brown & Tarko, 1999)

Ten corridors in Texas and one corridor in Oklahoma were investigated to estimate relationships between crash rates and access point densities, as well as the presence of raised medians or two-way left-turn lanes (TWLTLs). Data collected for this study included lane configurations, lane widths, driveway widths, distance between driveways, lengths of

dedicated lanes, traffic volumes and turning movement counts, and the number of signalized intersections and driveways along the corridor. The VISSIM microsimulation tool was used for the analysis because of its ability to analyze many aspects of the corridor. The results determine that a reduction in the number of conflict points, such as driveways, within a corridor will likely reduce the number of crashes within that corridor. Installing a raised median decreases the number of conflict points from 1,220 to 300, a decline of roughly 75 percent. When the number of driveways increases from 18 to 42, the total conflict points for the scenarios with a TWLTL increased from 338 to 650 (five lanes) and 674 (seven lanes) which was an increase of approximately 50 percent. As access point density increases, crash rates begin to increase. This is also true for corridors that have raised medians. However, the relationship between access points and crash rates increases slightly more on roadways without raised medians (Eisele & Frawley, 2005).

The Minnesota Department of Transportation (MnDOT) conducted research analyzing the relationship between access density and crash rates in eleven roadway categories (five rural and six urban). The data collected for the study included the number of access points in each segment, the three-year crash statistics for each segment, and the characteristics of each segment. Access type was classified into five categories: public street, commercial driveway, residential driveway, field entrances, and other access. The total number of crashes and crash severity was obtained for a three-year period from 1994 to 1996. Segment characteristics such as segment length, speed limit, number of through lanes, and median treatment were also gathered. The study showed an increasing crash rate as access density increases (Preston, et al. 1998).

Sites in Michigan were evaluated to determine the safety and operational impacts under various access configurations and provide basic guidelines as to when left turns at driveways should be prohibited. Particularly, one of the objectives of this study was to evaluate the safety-related outcomes of right-turn-only restrictions in Michigan. Nine sites that recently prohibited left turns were selected for evaluation. Each site was supplemented with a selection of similar sites for comparison. The crash history before and after turning restrictions were implemented was gathered and compared as shown in Figure 9. For one of the sites, located on Saginaw Highway and Creyts Road in Lansing, the right-in/right-out driveway restriction was implemented in 2004. Therefore, crashes four years before and after left turns were restricted was collected for comparison. Crashes for the similar site, located on Pennsylvania Avenue and Michigan Avenue in Lansing, was collected as well. The two comparisons determined that restricting left turn movements has contributed to improving the safety by reducing the number of crashes (Lyles, et al. 2009).

Site	Type of Access	Adjacent Road	Time Span	Total Crashes on the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 1	RIRO	Saginaw Hwy	Before 2004	16	3	18.8
			After 2004	15	0	0
Similar Site	Full Access	Pennsylvania Ave	2000-2007	58	9	15.5

Figure 9: Comparison of Driveway Related Crashes for the Before and After Study and Similar Site (Lyles, et al. 2009)

Similarly, studies in Ohio evaluated the safety and operational impacts of restricting direct left turns from a driveway and providing alternatives to accommodate the left turn deterred traffic. Eight sites that included multilane divided, multilane undivided and two-lane roads were selected for evaluation. Roadway and driveway characteristics such as traffic flow,

volume counts by movement, and turning prohibitions were collected for each of the eight study sites. Crash data for a three-year period was collected, plotted, and categorized by crash type such as rear end, sideswipe, angle, and left-in/left-out, at each driveway. Left-turn crash rates for entering the unsignalized driveway intersection was calculated. The results indicated that left-turning crashes represented a high percentage of the total number of crashes as shown in Figure 10. Conflict points appear to reduce when a restriction is placed on left turning movements. This suggested that reducing or restricting left-turning vehicles at un-signalized driveways could possibly decrease crashes (Chowdhury, et al. 2003).

Type of Site	Multi-lane Undivided				Multi-lane Divided		2-Lane	
Site	Lyons	Alex Bell	SR 725	SR 741	SR 725	West Broad	US 36	US 22
Left Turn Crash Percentage (Left Turn Crashes/Total Crashes)	50%	15%	26%	11%	40%	21%	40%	100%
Left Turn Crash Rate (# Crashes per Million-Entering Vehicles)	49	25	101	16	113	54	125	58

Figure 10: Left-Turn Crash Summary (Chowdhury, et al. 2003)

Jacobson et al.. (1999) conducted a study to develop recommended spacing between an exit ramp and a downstream driveway along a frontage road as well as between frontage-road driveway access and a downstream entrance ramp. The research was conducted in Texas evaluating highways of five study sites and one control site within San Antonio and Austin. A site included an entrance ramp downstream of multiple driveway-access points along the frontage road. The data collection process consisted of video cameras for recording the origin and destination of vehicles entering the frontage road from a driveway and magnetic-imaging traffic recorders for gathering speed data and determining the time of entrance for vehicles originating from the frontage-road driveways. Six to twelve hours of video and traffic recorder data was collected depending on each site, and crash data was analyzed for a four-year period

from 1995 to 1998. Crash diagrams were created to determine the type and frequency of accidents occurring near the entrance-ramp and driveway vicinity. Observations from the crash diagrams indicated that rear-end collisions near entrances to frontage road driveways, angular collisions near exits from driveways, and sideswipe collisions near approaches to freeway entrance ramp appear to be prevalent. An accident rate for the different study sites was then calculated after reviewing and analyzing the crash data. The results (shown in Figure 11) determined that the crash rate increases significantly (roughly two to three times as frequently) for driveways located within 100 feet or less of the downstream entrance ramp. This suggested that there would likely be safety-related benefits in requiring greater distances between driveways and downstream entrance ramps. Jacobson et al.. (1999) recommend that the current guidelines be increased to 200 feet upstream and 100 feet downstream of the entrance ramp (Jacobson, et al. October 1999).

Location	Crash Rate (per million vehicles) ¹	Number of Access Points ²	Closest Driveway Location (ft) ³
Loop 410 SB. north of New Valley High ⁴	0.38	4	735
Loop 1604 EB. east of Gold Canyon ⁴	0.32	1	635
US 281 NB. north of Nakoma	0.96	4	75
US 281 NB. north of Brook Hollow	0.99	6+	105
US 281 SB. south of Thousand Oaks	0.66	4	50

Figure 11: Crash data for Downstream Entrance Ramp (Jacobson, et al. 1999)

As a result of literature found on previous studies conducted, it is evident that access management is important to the roadway network. Access points have a significant impact on the effect of crashes and continued research is critical in helping to determine the most efficient way to manage access points. This study aims to identify how access point density, type, and spacing affect the rate of crashes among roadways within Iowa. The results of this study will

help to provide Iowa and other Midwestern states with information on how to adequately manage access points.

CHAPTER 3: DATA COLLECTION AND DATA SUMMARY

This study involves an investigation into the relationship between access management and traffic safety. This investigation focuses on how the frequency of police-reported crashes is impacted by the number and type of access points in two settings:

1. A series of priority, high-growth corridors throughout the state of Iowa (referred to as priority corridors); and
2. The corridors in the immediate vicinity of each of Iowa's service interchanges (referred to as crossroad corridors).

This chapter provides an overview of the datasets developed as a part of this study, as well as the data collection sources and processes that were utilized to develop the datasets for each of these two analyses.

3.1 Priority Corridors

The purpose of the first study presented in this thesis was to determine how driveway density, type, and spacing affect the rate of crashes among roadways in areas of high-density development. The areas of interest for this study consist of various corridors within Iowa that were identified as priority, or high-growth, corridors by the Iowa Department of Transportation (DOT). Collectively, these corridors either currently include high-density development or were anticipated to see increasing development in the near future. These priority corridors were among different counties and were divided between urban and suburban areas. A detailed list and explanation of each priority corridor is provided below in Table 1. Refer to Appendix 1 for more detailed information of each corridor.

Table 1: Priority Corridor Descriptions

Location	Annual Average Daily Traffic (veh/day)	Length (mi)	Number of Driveways	Number of Intersections
Adel - US 169 South of US 6	5900	1.01	21	5
Ames - US 69 North of S 16th Street	25056	0.62	19	3
Cedar Rapids - US 30 East of C Street	20263	4.74	4	9
Coralville - IA 695 North of I-80 Interchange	36634	1.94	24	5
Coralville - US 6 south of I-80	21753	4.68	62	17
Davenport - Kimberly Road East of NW Blvd	21754	4.47	59	22
Des Moines - Merle Hay Road (Aurora Ave to Meredith Drive)	27600	0.50	8	3
Des Moines - Merle Hay Road at Hickman Intersection - East to 44th Street	16302	1.14	75	17
Des Moines - Merle Hay Road at Hickman Intersection - North to Urbandale Ave	22400	0.50	32	5
Des Moines - Merle Hay Road at Hickman Intersection - South to University Ave	8887	1.00	106	14
Des Moines - Merle Hay Road at Hickman Intersection - West to 73rd Street	19765	1.08	35	11
Des Moines - Merle Hay Road South of Douglas Avenue	22400	0.50	33	3
Des Moines - US 6 Hickman Road 156th St to 142nd St	27900	1.00	5	5
Des Moines - US 6 Hickman Road Alice's Road Intersection, 156th St	23600	100	7	5
Des Moines - US 6 Hickman Road Alice's Road Intersection, 280th St	4220	0.99	16	1
Des Moines - US 6 Hickman Road Alice's Road Intersection, University Ave	6776	1.01	10	6
Des Moines - US 6 Hickman Road Alice's Road Intersection, Warrior Lane	22000	1.00	3	5
Des Moines-US 6 Euclid Ave west of 2nd Ave	19956	2.04	103	14
Des Moines-I-80/I-35 to 100th Street	31153	1.08	4	8
Des Moines-I-80/I-35 to 128th Street	34400	0.77	9	5
Dyersville - US 20 East of 332nd Ave	8854	2.39	1	4

Table 1 Continued

Dubuque - US 20 Fremont Ave to Mississippi River	30716	1.76	0	5
Dubuque - US 20 Menard Ct to Fremont Ave	31538	2.26	11	10
Granger - IA 141/IA415 Interchange Area	16018	3.15	2	4
Grimes - IA 141 North of I-80/I-35	30246	2.44	5	9
Grimes - IA 44 at IA 141 Interchange, 70th Ave	5546	1.96	16	17
Grimes - IA 44 at IA 141 Interchange, Maplewood Dr.	10904	1.30	32	21
Grimes - IA 44 at IA 141 Interchange, Towner Dr.	19030	2.54	7	5
Indianola-US65/69	19600	1.01	8	2
Marion - IA 100 West of 1st Avenue	25189	2.71	8	8
Marshalltown - IA 14 North of Linwood Ave	6403	1.26	19	4
Marshalltown - US 30 Interchange	11458	3.00	36	27
Mason City/Clear Lake - IA 122 East of I-35 Interchange	16464	7.57	62	37
Mason City/Clear Lake - IA 122 EB One-Way	7099	0.85	39	13
Mason City/Clear Lake - IA 122 WB One-Way	9331	0.78	28	12
Mason City/Clear Lake - IA 122 West of I-35 Interchange	13779	2.69	34	19

For analysis purposes, the priority corridor data were analyzed at two levels of detail:

- Corridor Level- The entire length of each priority corridor was examined by combining available geometric, traffic, and other pertinent characteristics for these 37 corridor locations. However, too few for a rigorous statistical analysis, a series of crash risk plots are developed for each, allowing for a visual examination of the relationship between access density and crash density.
- Individual Segment Level- At a more detailed level of analysis, these corridors were divided into a series of individual segments ranging from 0.5 mi to 2 mi in length.

These segments were subsequently analyzed at a greater level of detail.

Figure 12 shows the corridor data at the finest level of detail. These segments are based upon the Iowa DOT Geographic Information Management System (GIMS), which is described in further detail in Chapter 4.

Figure 13 shows how these individual segments are aggregated into larger segments that span the entire physical limits of each corridor. Ultimately, these corridors were very large, in some cases more than 4 miles in length. For analysis purposes, these larger segments were not able to effectively capture changes that occurred over the extent of the priority corridors.

Consequently, the corridors were ultimately disaggregated into segments of an intermediate length, ranging from 0.5 to 2.0 miles. An example of these intermediate length corridors is provided in Figure 14.



Figure 12: Separated Segments

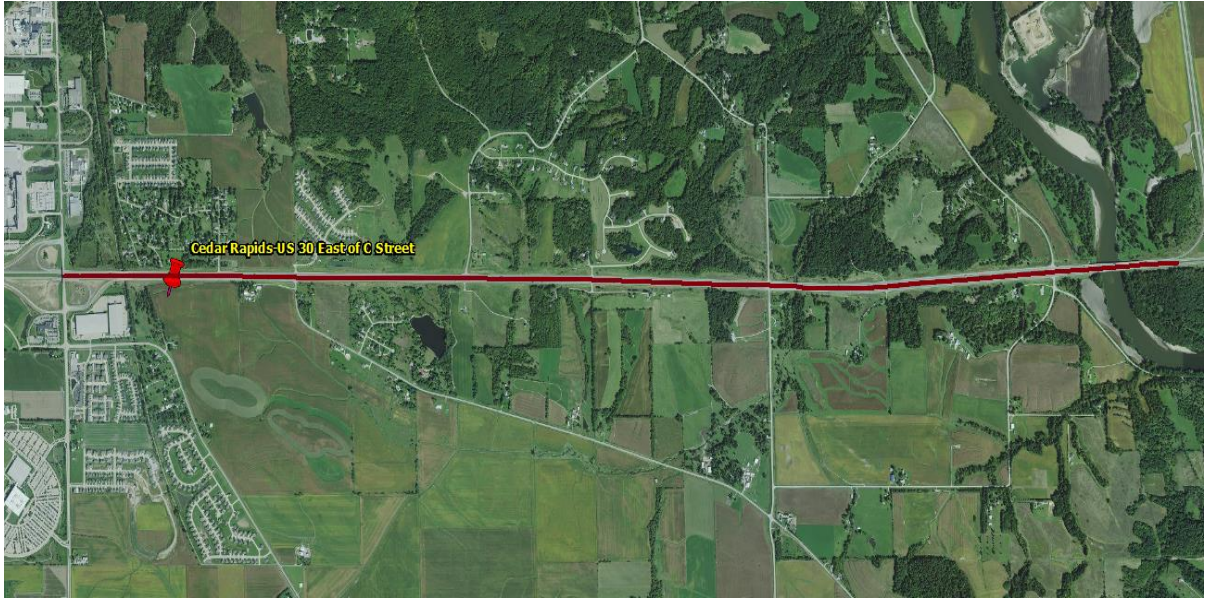


Figure 13: Combined Segments

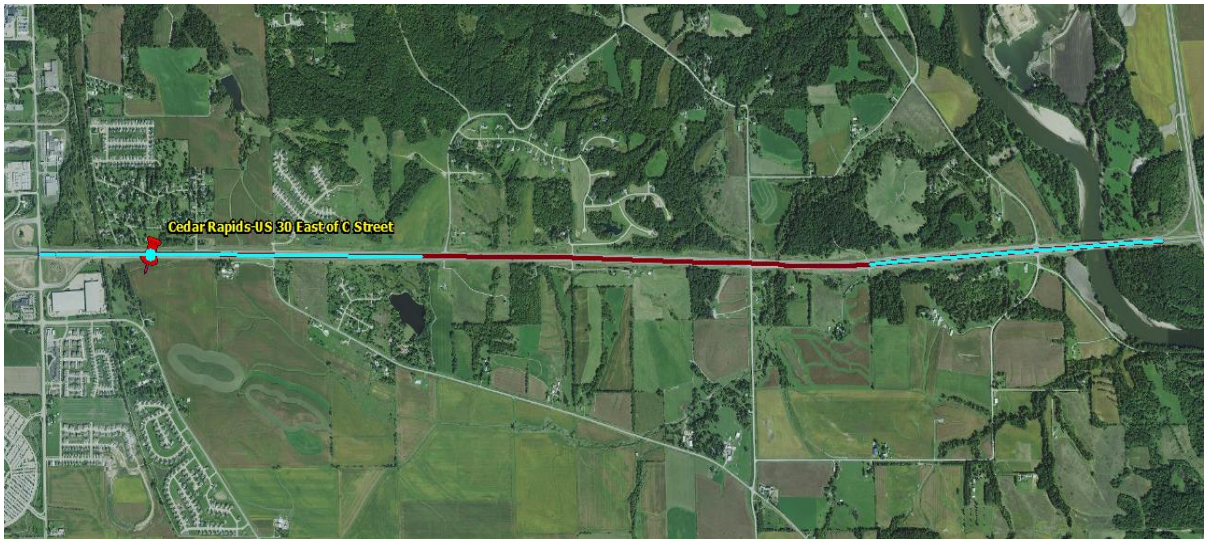


Figure 14: Separated Segment Level Segments

3.2 Crossroad Corridors

A principal concern pertaining to access management is controlling the location of driveways and intersections near the termination point of highway interchange off-ramps. Access point density is often identified as a primary contributor to poor safety performance on any type of corridor. Densely spaced driveways present conflicting movements, which may adversely affect driver behavior; this problem may be exacerbated when drivers are transitioning from an uninterrupted flow roadway (such as a freeway) to a surface street. All segments considered ramps that are connected to interchanges and transitioned to a surface street were collected in the entire state of Iowa using ArcGIS and the GIMS database. An example of the ramps of interest is shown in Figure 15.

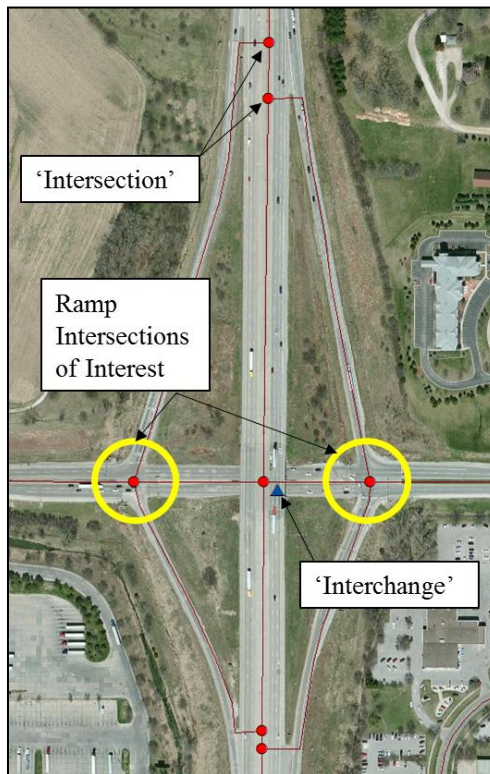


Figure 15: Ramp Intersection Manual Identification (I-35 and Hickman)

The crossroad corridor dataset contains information about the roadway and access points for a distance of approximately half a mile from the ramp bifurcation point. It was used to examine the relationship between crashes and access density from the point of ramp bifurcation.

Interchanges were manually identified using an attribute query of the GIMS database to identify any segment considered to be a “ramp”. This process resulted in the identification of all controlled-access highway to surface street interchange locations, however, also included all system interchanges, including fully directional interchanges. Therefore, a preliminary manual review of all interchanges was conducted to identify such ramp terminal intersections. During the course of the manual review, other important information was collected including interchange type, traffic control on interchange ramps, whether roadways were divided or undivided, and whether or not a relevant spatial analysis could be conducted at each interchange. Ultimately, it was found 406 interchanges in Iowa could be used as study locations for the spatial analysis. The manual review included collecting the following information:

- Distance to first driveway
- Distance to every intersection in study area (up to 1 mile from exit ramp bifurcation point)
- Distance to first field access
- Count of driveways to first and second intersections and total
- Median width at exit ramp bifurcation point, at first driveway, and at first intersection

- Median type at exit ramp bifurcation point, at first driveway, and at first intersection
- Side of the road for first driveway or intersection

3.3 Data Overview

For both the priority corridor and crossroad corridor datasets, detailed information was gathered from a series of databases provided by the Iowa DOT and the Institute for Transportation (InTrans) at Iowa State University. These databases included the Geographic Information Management System (GIMS), the Iowa DOT crash database, and the Iowa DOT intersection database. The following sub-sections provide a brief overview of these data sources, as well as additional information obtained through a detailed manual review of access point data.

3.4 Geographic Information Management System (GIMS)

The Geographic Information Management System (GIMS) consists of georeferenced shapefiles containing statewide data that provides details of roadway geometry and traffic operational characteristics. Three of the shapefiles within GIMS used to gather information on roadway characteristics were the Road Info, Traffic, and Direct Lane files. Each shapefile is presented as segments along roadways within Iowa. Figure 16 is an example of the roadway segments within GIMS. The light blue lines represent selected segments whereas the purple lines represent different segments that are separate from those included in the analysis. In the attribute table of the GIMS shapefile, every segment has a unique identifier known as an MSLINK that provides specific characteristics for the entire roadway system. The roadway characteristics provided by MSLINKS vary between the three shapefiles, which will be further

explained below. Roadway information or characteristics can change throughout years however; the GIMS database provides new data annually to reflect up-to-date roadway information. The data from each shapefile were collected for a five-year period from 2010 to 2014.

- Road Info- contains roadway characteristics such as number of lanes, median width and type, level of service, presence of tolls and presence of truck traffic.
- Traffic- contains roadway characteristics such as AADT for cars, motorcycles, pickup trucks, and buses.
- Direct Lane- contains roadway characteristics such as speed limit, length and width of the road segment, surface type, shoulder width and type, and presence of rumble strips.

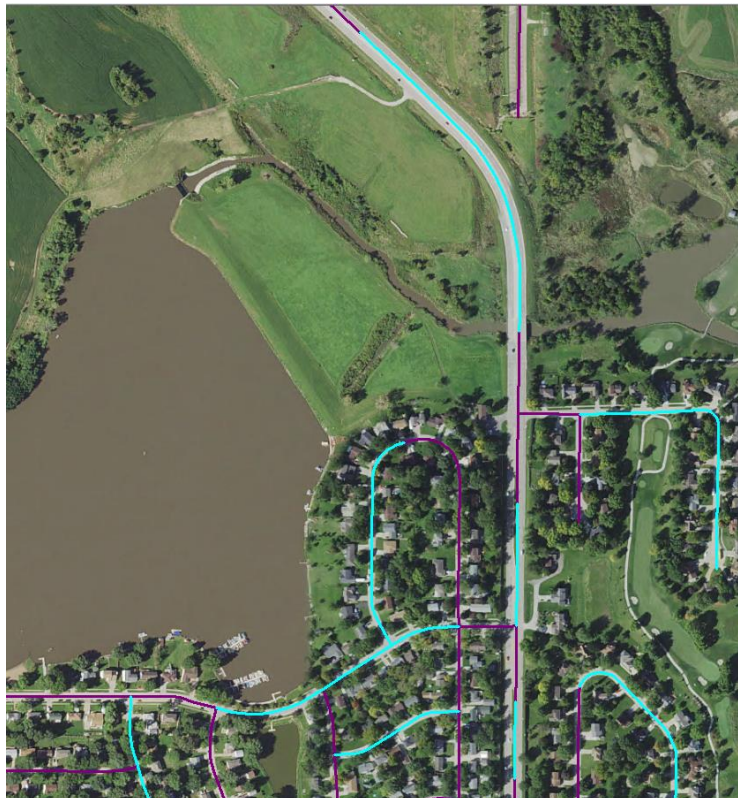


Figure 16: Roadway Segments in GIMS

Both the priority corridor and crossroad corridor datasets required the collection of additional information related to access points. After access points were identified, roadway data for every location was collected using the Iowa DOT GIMS Direct Lane, Traffic, and Road Info shapefiles in GIS.

First, the MSLINKS were identified for each corridor. This field is a unique identifier for individual road segments, which was ultimately used to integrate data across the various shapefiles. Using the Road Info shapefile the MSLINKS were collected and documented in Microsoft Excel. Figure 17 is an example of MSLINKS (highlighted in blue) being collected in GIS. This process was done for all five years (2010 to 2014).

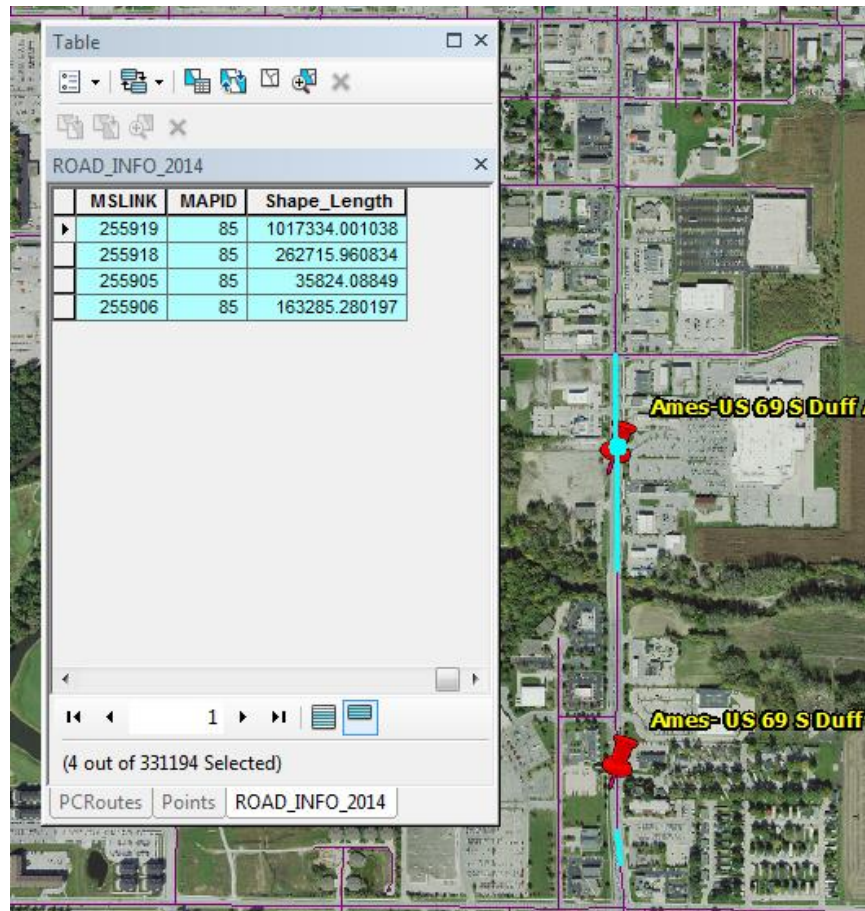


Figure 17: MSLINKS Data Collection

Once the MSLINKS were identified for all five years using the Road Info shapefile, a new field was created in the attribute table that was common for all the MSLINKS along the same corridor. For example, referring to Figure 17 the collected MSLINKS that are highlighted in blue are located in Ames along the US 69/South Duff Avenue corridor. The new spreadsheet containing the MSLINKS and location name was joined to each year of the direct lane file using the join attributes from a table tool in ArcGIS. This allowed the MSLINKS from the road info file to be properly matched to the direct lane file. When the MSLINKS were matched to the direct lane file, the data from the attribute table was exported into a new Excel spreadsheet. This new Excel spreadsheet was used to determine the roads within the corridors that were divided and undivided. The roads that were divided had two MSLINKS in the dataset when only one MSLINK was needed. This required a VLOOKUP function in Excel to identify these divided roads and assign them to only one MSLINK. Figure 18 shows an example of the VLOOKUP process in excel. The field labeled “Divided” shows the letter S if the MSLINK corresponds to a divided highway and #N/A if the segment is undivided.

BX16 : X ✓ fx =VLOOKUP(\$A16, South!\$A:\$B, N\$2, FALSE)

	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX
1	MAPID	UKEY	OBJECTID_1	Location	Shape_Le	Divided	OBJECTID	COUNTYN	JURISDIC	SYSCODE	STATCODE	STATEROL	STATEROL	STATESEG	NINEONE	TOWNSHI	RANGENC	SECTION
2	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
3	17	25149	823	Mason City/C	1307730	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4	17	25150	824	Mason City/C	4007188	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
5	17	25151	825	Mason City/C	1665283	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
6	17	25152	826	Mason City/C	84888.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
7	17	25153	827	Mason City/C	563420.8	S	1671	17	1	2	0	0	0018	105 US 18		0	00	0
8	17	25154	828	Mason City/C	329566.8	S	1673	17	1	2	0	0	0018	106 US 18		0	00	0
9	17	25155	829	Mason City/C	309754.4	S	1023	17	1	2	0	0	0018	108 US 18		0	00	0
10	17	25156	830	Mason City/C	427130.7	S	913	17	1	2	0	0	0018	109 US 18		0	00	0
11	17	24807	831	Mason City/C	333806.1	S	1461	17	1	2	0	0	0018	110 US 18		0	00	0
12	17	24808	832	Mason City/C	1460406	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13	17	24809	833	Mason City/C	591178.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	17	24810	834	Mason City/C	404452.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15	17	24811	835	Mason City/C	413368.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
16	17	24812	836	Mason City/C	35457.22	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17	17	24813	837	Mason City/C	430812.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18	17	24814	838	Mason City/C	326641.2	S	1142	17	1	2	0	0	0018	130 US 18		0	00	0
19	17	24815	839	Mason City/C	47116.15	S	588	17	1	2	0	0	0018	134 US 18		0	00	0
20	17	24816	840	Mason City/C	42494.09	S	121	17	1	2	0	0	0018	135 US 18		0	00	0
21	17	24817	841	Mason City/C	213008.3	S	905	17	1	2	0	0	0018	137 US 18		0	00	0
22	17	24961	842	Mason City/C	496693.3	S	1757	17	1	2	0	0	0018	140 US 18		96	21	8
23	17	24962	843	Mason City/C	366941.2	S	342	17	1	2	0	0	0018	150 US 18		96	21	8
24	17	24963	844	Mason City/C	321145.1	S	1327	17	1	2	0	0	0018	170 US 18		96	21	8
25	17	24964	845	Mason City/C	314097.3	S	474	17	1	3	0	0	0122	180 IOWA 122		96	21	8
26	17	24965	846	Mason City/C	1079976	S	907	17	1	3	0	0	0122	200 IOWA 122		96	21	8
27	17	24966	847	Mason City/C	343535.4	S	476	17	1	3	0	0	0122	205 IOWA 122		96	21	8
28	17	24967	848	Mason City/C	763832.4	S	249	17	1	3	0	0	0122	210 IOWA 122		96	21	8
29	17	24968	849	Mason City/C	436491.9	S	681	17	1	3	0	0	0122	220 IOWA 122		96	21	8
30	17	24969	850	Mason City/C	357132	S	1463	17	1	3	0	0	0122	230 IOWA 122		96	21	8
31	17	24970	851	Mason City/C	1056587	S	1647	17	1	3	0	0	0122	235 IOWA 122		96	21	8
32	17	24971	852	Mason City/C	305560.1	S	1019	17	1	3	0	0	0122	240 IOWA 122		96	21	9
33	17	24972	853	Mason City/C	334044.8	S	1127	17	1	3	0	0	0122	250 IOWA 122		96	21	9
34	17	24973	854	Mason City/C	361504.3	S	797	17	1	3	0	0	0122	260 IOWA 122		96	21	9
35	17	24974	855	Mason City/C	1623058	S	1572	17	1	3	0	0	0122	270 IOWA 122		96	21	9
36	17	24975	856	Mason City/C	1311100	S	1574	17	1	3	0	0	0122	280 IOWA 122		96	21	9
37	17	24976	857	Mason City/C	1044700	S	1576	17	1	3	0	0	0122	290 IOWA 122		96	21	9
38	17	24977	858	Mason City/C	255646.5	S	1144	17	1	3	0	0	0122	300 IOWA 122		96	21	9
39	17	24978	859	Mason City/C	334389.8	S	478	17	1	3	0	0	0122	310 IOWA 122		96	21	10

Figure 18: Direct Lane VLOOKUP Process in Excel

The VLOOKUP process in Excel reduced the dataset and provided only one MSLINK for each corridor. After this process was finished for all five years, the direct lane spreadsheets were uploaded into ArcGIS and joined to the traffic data shapefile. This created a new layer within ArcGIS that consisted of the roadway characteristics from both the GIMS Traffic and Direct Lane datasets. The GIMS Road info layer was then joined based on MSLINK to the layer that consisted of the Traffic and Direct Lane data. Once again, this process was done for all five years. The priority corridors now had information on most of its roadway characteristics.

3.5 Iowa DOT Crash Database

The crash database is a geocoded shapefile maintained by the Iowa DOT, which contains statewide data on police-reported crashes. Each crash has a unique identifier known as the Crash Key that provides specific characteristics for a particular crash. Several characteristics of crashes can be identified using the database. The dataset for this study included 90 different crash characteristics, which provided details such as the total number of crashes, type of crash, and type of severity (Iowa Department of Transportation Motor Vehicle Division's Office of Driver Services, 2015).

For both corridor datasets, crash data were imported into ArcGIS as a shapefile for the five-year analysis period from 2010 to 2014. A Select by Location tool with a distance of 50 feet was executed to create separate shapefiles for each year of the study period. This helped to identify the crashes that were 50 feet or less from each corridor of interest. The selected crashes were exported for each year and spatially joined to each dataset. The data was then exported into an Excel spreadsheet where more information on the type of crashes could be identified. A series of COUNTIF statements were executed to determine crash characteristics. Crash characteristics included number of total crashes, type of crashes and type of injury. Figure 19 provides an example of the detailed crash information using the series of COUNTIF statements in Excel.

Location	Crash_Total	NonCollision	HeadOn	RearEnd	Angle	Broadside	SideswipeSame	SideSwipeOpposite	Unknown	Other	Crash_Fatal
Coralville - US 6 south of I-80	173	10	1	110	6	21	18	3	0	4	0
Dryersville - US 20 East of 332nd Ave	15	5	0	1	0	3	2	0	0	0	1
Dryersville - US 20 East of 332nd Ave	15	5	0	1	0	3	2	0	0	0	1
Dryersville - US 20 East of 332nd Ave	15	5	0	1	0	3	2	0	0	0	1
Dryersville - US 20 East of 332nd Ave	15	5	0	1	0	3	2	0	0	0	1
Dryersville - US 20 East of 332nd Ave	15	5	0	1	0	3	2	0	0	0	1
Dubuque - US 20 Menard Ct to Fremount Ave	95	2	0	72	4	8	7	0	0	0	0
Dubuque - US 20 Fremount Ave to Mississippi River	86	4	1	68	1	2	9	0	0	1	0
Dubuque - US 20 Fremount Ave to Mississippi River	86	4	1	68	1	2	9	0	0	1	0
Dubuque - US 20 Fremount Ave to Mississippi River	86	4	1	68	1	2	9	0	0	1	0
Dubuque - US 20 Menard Ct to Fremount Ave	95	2	0	72	4	8	7	0	0	0	0
Dubuque - US 20 Menard Ct to Fremount Ave	95	2	0	72	4	8	7	0	0	0	0
Adel - US-169 South of US-6	8	0	0	2	2	3	1	0	0	0	0
Adel - US-169 South of US-6	8	0	0	2	2	3	1	0	0	0	0
Adel - US-169 South of US-6	8	0	0	2	2	3	1	0	0	0	0
Marion - IA 100 West of 1st Avenue	94	0	1	50	19	17	5	1	0	0	0
Marion - IA 100 West of 1st Avenue	94	0	1	50	19	17	5	1	0	0	0
Marion - IA 100 West of 1st Avenue	94	0	1	50	19	17	5	1	0	0	0
Marion - IA 100 West of 1st Avenue	94	0	1	50	19	17	5	1	0	0	0
Coralville - US 6 south of I-80	173	10	1	110	6	21	18	3	0	4	0
Coralville - US 6 south of I-80	173	10	1	110	6	21	18	3	0	4	0
Coralville - US 6 south of I-80	173	10	1	110	6	21	18	3	0	4	0
Davenport - Kimberly Road East of NW Blvd	204	8	1	124	17	31	19	2	0	0	0
Davenport - Kimberly Road East of NW Blvd	204	8	1	124	17	31	19	2	0	0	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Des Moines-US 6 Euclid Ave west of 2nd Ave	72	6	1	36	7	11	7	1	0	1	0
Granger - IA 141/IA415 Interchange Area	22	11	0	2	1	3	1	0	0	1	1
Granger - IA 141/IA415 Interchange Area	22	11	0	2	1	3	1	0	0	1	1
Mason City/Clear Lake - IA 122 East of I-35 Interchange	126	13	0	76	15	11	8	1	0	1	1

Figure 19: Crash Fields in Excel

3.6 Iowa DOT Intersection Database

The intersection database was provided by the Institute for Transportation (InTrans) at Iowa State University as a GIS shapefile that provides detailed information on each intersection across the state. Due to the size and complexity of this database, the information is not collected on an annual basis like other various datasets. However, the database is updated regularly to reflect the most recent intersection information. In the attribute table of the shapefile, each intersection has a unique identifier (ID 2007) that provides specific characteristics for a particular intersection. Intersection characteristics includes the following:

- Intersection Geometry- Indicates whether the intersection is a Y, T, or Cross-intersection
- School Zone- Indicates whether the intersection is present in a school zone
- Signal Type- Indicates the type of traffic control such as a stop sign, signal, yield, or no signal.
- Lighting- Indicates whether there is lighting present at the intersection (intersection lighting), or in an area close to the intersection, but not directly at the intersection (destination lighting).

The intersection database was provided as a shapefile and imported into ArcGIS. A Select by Location tool with a distance of 50 feet was executed in order to identify the intersection that are 50 feet or less from each corridor of interest. Figure 20 is an example of the Select by Location tool used to identify the intersections along each corridor. The data was then exported as a new layer and spatially joined to the shapefiles that included Road Info, Traffic and Direct lane data for all five years. Intersection data was the same for all five years.

Google Earth for each corridor, the place marks were saved as a KML file and uploaded into a GIS map of Iowa. Figure 22 displays the place marks that were uploaded into GIS.

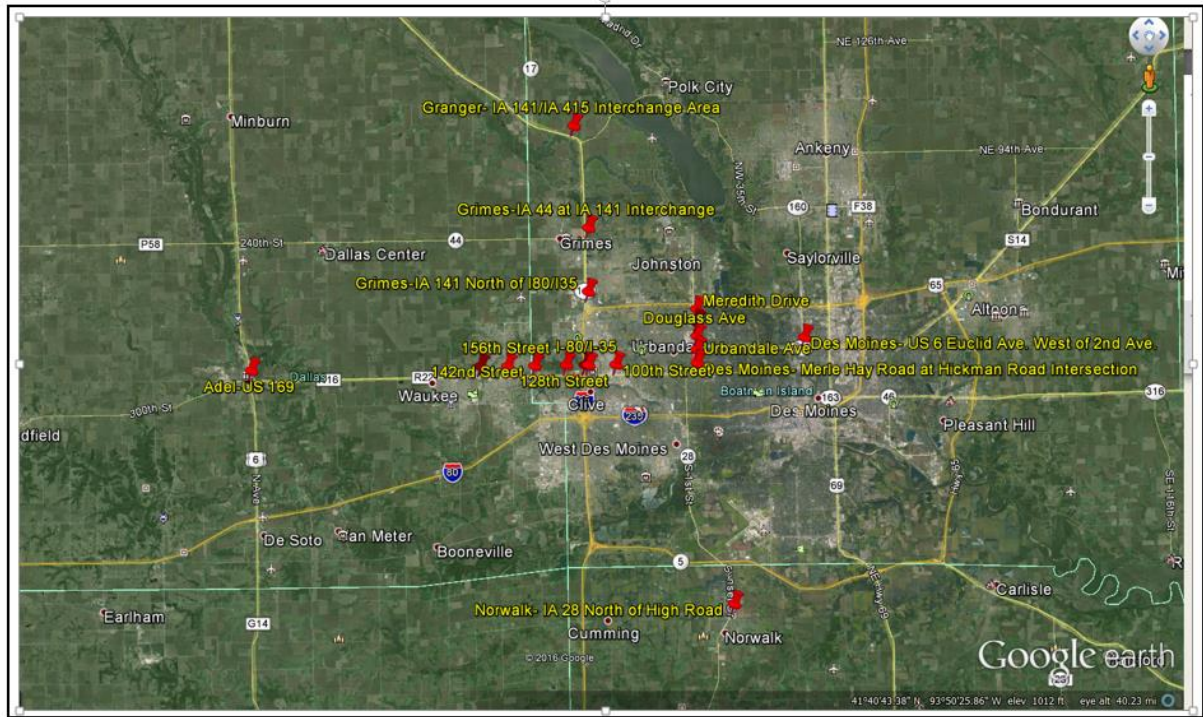


Figure 21: Corridors Place Marked into Google Earth

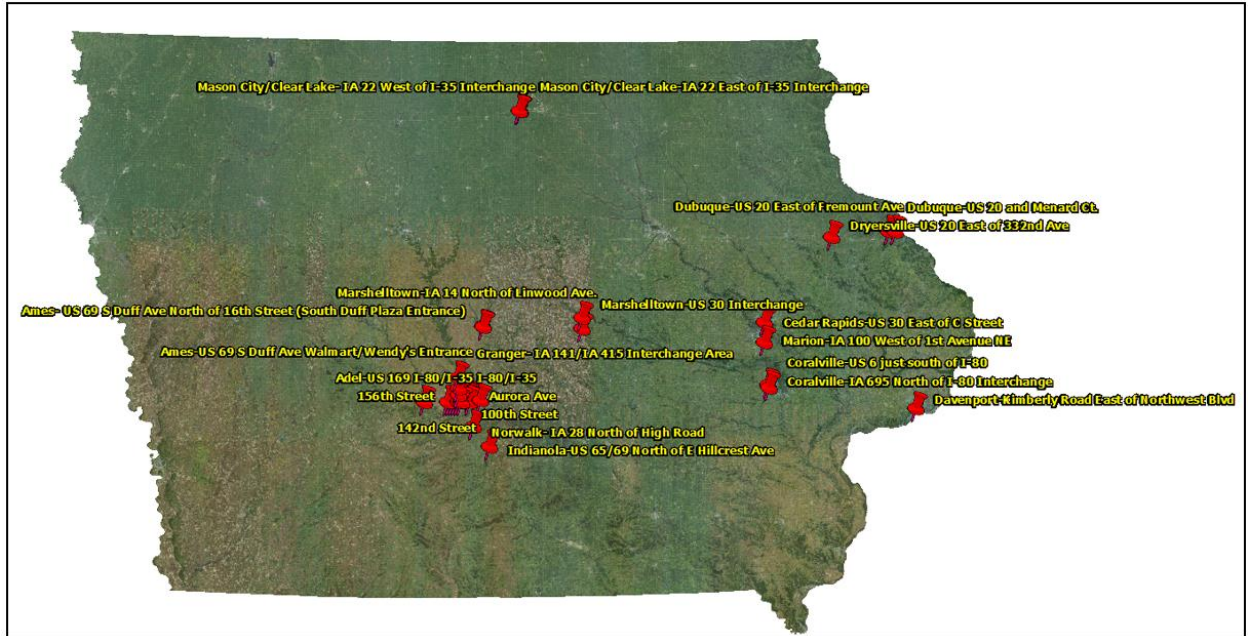


Figure 22: Google Earth Place Marks Uploaded into GIS

The Iowa DOT access point shapefile was then uploaded as a layer into the GIS map. A quality assurance and quality control assessment (QA/QC) was needed in order to ensure that the driveway data collected from the access point file was accurate. The QA/QC conducted determined that the access point data was incomplete and most of the corridors had partial to no access point data where driveways are located. This required new access points to be manually collected in GIS. Figure 23 displays a corridor with partial access point data and Figure 24 displays a corridor with no access point data though driveways are prevalent.



Figure 23: Partial Access Point Data

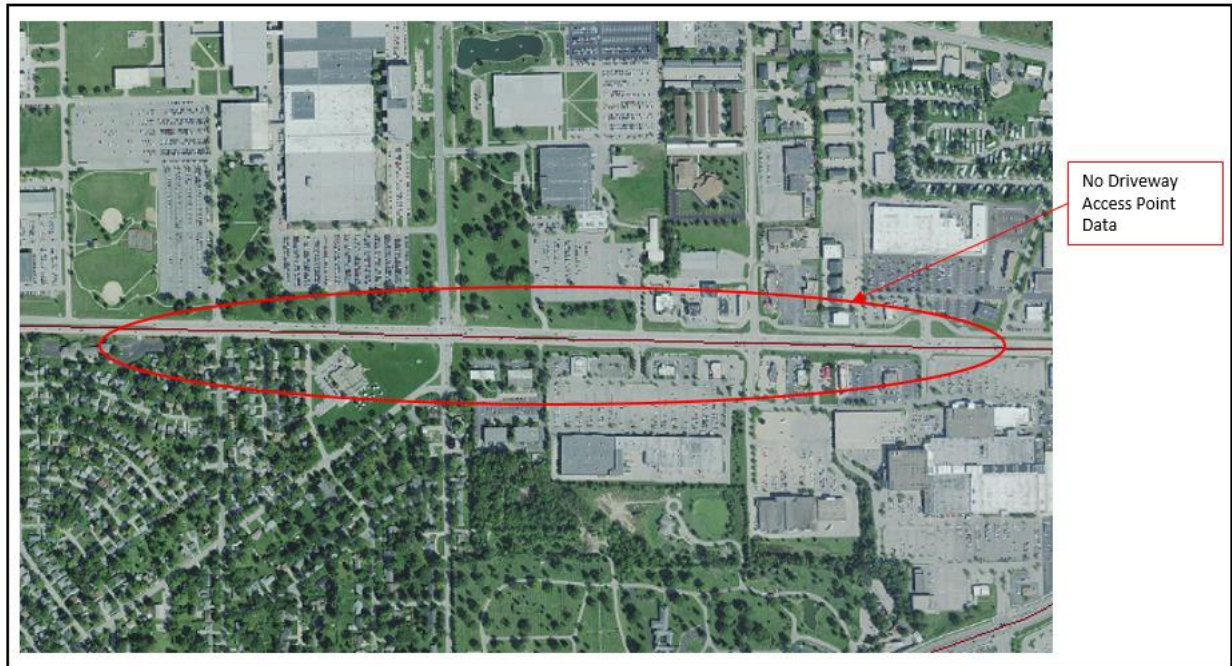


Figure 24: No Access Point Data

Once the QA/QC review of the access point data was completed, new access points were manually entered into GIS at each corridor location through a process known as digitizing. Digitizing points in GIS allows new features to be created when data is missing or inaccurate. Figure 25 is an example of a corridor where new access points were digitized. The

pink represents the new access points. As points were digitized at all locations, characteristics of each driveways were also collected and documented into the attribute table of the shapefile.



Figure 25: Digitized Access Points

Data was documented in the attribute table for each driveway and included the following:

- Type of Facility: This field indicated whether the individual driveway being assessed was connected to one of the type of properties below.
 - Commercial- Property used solely for business purposes. Includes restaurants, grocery stores, malls, etc.
 - Residential-Property used solely for living purposes. Includes apartments, single-family homes, townhomes, etc.
 - Recreational- Property used for recreational purposes. Includes parks, churches, sports clubs, lakes, etc.
 - Agricultural- Property used for agricultural purposes or a ditch leading to an open field. Includes silos, barns, and cornfields.

- Rt_In- This field is a binary indicator identifying whether or not a driver has the ability to make a right turn into the driveway.
- Rt_Out- This field is a binary indicator identifying whether or not a driver has the ability to make a right turn out the driveway.
- Lft_In- This field is a binary indicator identifying whether or not a driver has the ability to make a left turn into the driveway.
- Lft_Out- This field is a binary indicator identifying whether or not a driver has the ability to make a left turn out the driveway.
- Th_In- This field is a binary indicator identifying whether or not a driver has the ability to enter the driveway to a driveway or road directly opposite.
- Th_Out- This field is a binary indicator identifying whether or not a driver has the ability to exit the driveway to a driveway or road directly opposite.
- RT Prohibited- This field is a binary indicator identifying whether or not right turns are prohibited.
- LT Prohibited- This field is a binary indicator identifying whether or not left turns are prohibited.
- Full Movement- This field is a binary indicator identifying whether or not left turns are prohibited.

CHAPTER 4: METHODS, RESULTS, AND DISCUSSION

This chapter presents an overview of the statistical methods applied as a part of this study. This is followed by details of the two primary analyses conducted as a part of this study, the first of which focused on priority corridors and the second of which focused on crossroad corridors at service interchanges.

4.1 Statistical Methods

Safety performance functions (SPFs) were estimated to ascertain the effects of access management-related features (e.g. driveway density) on crash rates. SPFs are crash prediction models, which can be used to estimate the average number of crashes at a location as a function of exposure (e.g. segment length and AADT) and roadway characteristics. The Highway Safety Manual (HSM) (American Association of State Highway and Transportation Officials, 2010) defines several different ways in which SPFs can be used. For this study, SPFs are used to determine the safety effects of access point density and other existing roadway characteristics on crashes.

Crashes are examples of count data and are best modeled by using Poisson or negative binomial regression models. Poisson and negative binomial models belong to a category of models known as generalized linear models (GLM). In GLMs, regression coefficients and the standard error are estimated by maximizing the likelihood or log-likelihood of the parameters for the data observed. Although Poisson models can be used for count data, their distribution restricts the variance and mean to be equal. In general, site-specific crash counts tend to violate this assumption. Typically, the variance tends to be greater than the mean, meaning the data are overdispersed. To account for the overdispersion, crash counts should be modeled using

negative binomial regression models. A negative binomial approach models the expected number of crashes in each roadway segment as a function of one or more explanatory variables. Thus, in this study SPF's were estimated using the negative binomial model framework and taking the general form:

$$N_{pred} = e^{(\beta_0 + \beta_1 \times \ln(AADT) + \beta_2 X_2)} \times L$$

Where:

N_{pred} = Total Number of Crashes or Access Management Crashes

β_0 = Intercept

β_1 = Coefficient for the Natural Log of AADT

β_2 = Coefficient for various roadway characteristics

X_2 = Vector of Roadway Characteristics

L = Segment Length

Both AADT and segment length were log-transformed when included in each model. Length was also used as an offset variable, which means its coefficient was constrained to one. This introduces an explicit assumption that crashes will increase proportionately with segment length. Separate models were estimated for the total number of crashes found in the priority corridor and crossroad corridor analysis. Several variables can be included in an SPF, and their coefficients represent the impact that variable has on the total number of crashes. For example, if the coefficient of a variable has a negative number then the variable would be associated with a decrease in total crashes. Similarly, if the coefficient has a positive number then the variable would be associated with an increase in total crashes.

Random effects models were developed to account for the fact that similar data was included for multiple years in each dataset. The random effects modeling framework is able to account for the potential correlation in crash counts across years. The goal in a random effect

analysis is to estimate the mean of a distribution of effects. In the negative binomial regression model, it is assumed that all the variables are independently and identically distributed (IID), which is potentially problematic because of the repeated observations within the dataset.

As mentioned in previous chapters, although much of the data was collected for a five-year period, a large amount of information was consistent from year to year. In particular, data such as roadway geometry did not change within the five-year study period. In addition, while there are a total of 285 segments included in the priority corridor dataset, this includes only 57 unique corridors. Each of the 57 corridors is included five times in the dataset (once for each year of data). Repeated observations present a potential violation of the IID assumption, which could result in biased or inefficient parameter estimates. A random effect model was used in order to determine the true effect of repeated observations on the data. The random effect model can account for this repetition and determine its true effect on the variables impact on crashes by relaxing the IID assumption. As a result, random effect models were estimated using the negative binomial model framework. The statistical software known as R Studio was used in order to develop the random effect linear regression models.

4.2 Priority Corridor Data Summary

Summary statistics are provided for the segment-level priority corridor dataset in Table 2. The variables shown are significant to this study and provide details regarding the minimum, maximum, mean, and standard deviation of each.

Table 2: Summary Statistics for Significant Variables-Priority Corridors

Variables	Minimum	Maximum	Mean	Std. Deviation
Average Annual Daily Traffic	4220.00	36633.49	18673.11	7925.65
Average Speed Limit (mph)	29.05	65.00	47.06	11.13
Length	0.50	1.97	1.24	0.36
Total Crashes	1	137	26.36	23.53
Number of Lanes	2	6	4.08	0.85
Signalized Intersections Per Mile	0	4.9	1.65	1.37
Unsignalized Intersections Per Mile	0	14.0	3.32	3.18
Unsignalized Access Points Per Mile	.74	118.1	19.12	23.64
Commercial Driveways Per Mile	0.00	56	9.34	11.47
Commercial Driveway Percentage	0	1.0	.46	.3100
Driveways Per Mile	0	106.1	15.80	21.29

Table 2 shows that the maximum number for the AADT within the data is 36633.49 and the minimum is 4220.00. In Table 8, the lowest speed limit (mph) is 29 and the highest is 65. It is important to note the speed limit values are a weighted average of adjacent segments. This means that not all the various speed limits within the data were the typical speeds such as 25, 30, 35, and so on. Some of the corridors were in areas with a high amount of residential property, which accounts for the data having minimum speeds around 25. A maximum speed limit of 65 is used on divided roadways and urban freeways in Iowa. Some of the corridors

were divided roadways and urban freeways, which accounts for the data having maximum speeds at 65. The maximum length within the data is 1.97 miles. This is because the segment level dataset was used for the analysis and as mentioned in chapter 3.1, segment level data was combined and then separated to make each corridor's length a maximum of only 2 miles.

For signalized intersections per mile, the total number of signalized intersections at every corridor was divided by the length of every corridor. Unsignalized intersections per mile, and unsignalized access points per mile were calculated somewhat similarly to signalized intersections per mile. Unsignalized intersections per mile was calculated by dividing the number by the length for all unsignalized intersection categories. For example, the total number of stop controlled, yield controlled, and other type of intersections was divided by the length of the corridor. This created new columns in Excel named stop controlled intersections per mile, yield controlled intersections per mile, and other type of intersections per mile. The value represented for each was then added together for every corridor creating the unsignalized intersections per mile data. Unsignalized access points per mile was calculated summing the values of stop controlled intersections per mile, yield controlled intersections per mile, other type of intersections per mile, and driveways per mile. Driveways per mile was calculated by taking the number of driveways divided by the corridor length. Commercial driveway percentage was calculated by dividing commercial driveways per mile by unsignalized access points per mile.

The relationship between access point density and crash rates was documented once the final dataset was assembled and finalized. Figure 26 through 31 are graphs displaying the relationship between access point density and crash rates. This information is based on the corridor level dataset showing the relationship between access point density and crash rates for

each corridor. The crash data is for a five-year period (2010 to 2014) and the mile point signifies the length of the corridor. The access points represent both the intersection and driveway data at each location.

Figure 26 and Figure 27 are best examples of two corridors where it is clearly shown that access point density and crashes have a positive relationship. The overall outcomes from the graphs show that there is a positive relationship between access point density and crash rates. In other words, as the number of access points increase, crash rates increase. This is supported by similar research conducted by Brown and Tarko, (1999) and Preston et al., (1998) where the relationship between access point density and crash rates were found to have a positive relationship.

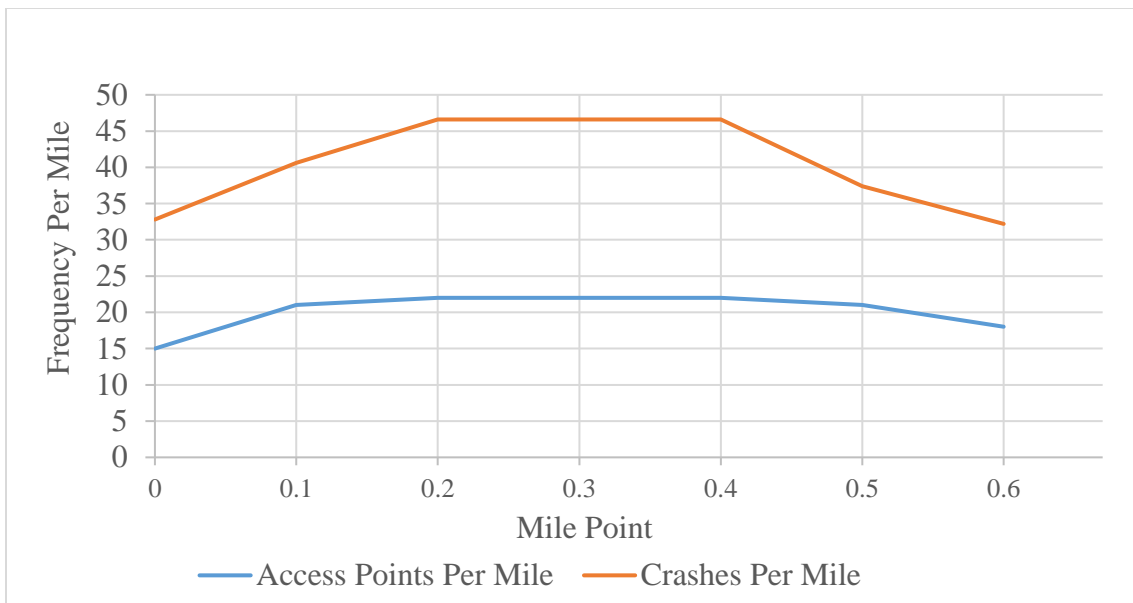


Figure 26: Ames-US 69 North of S 16th Street

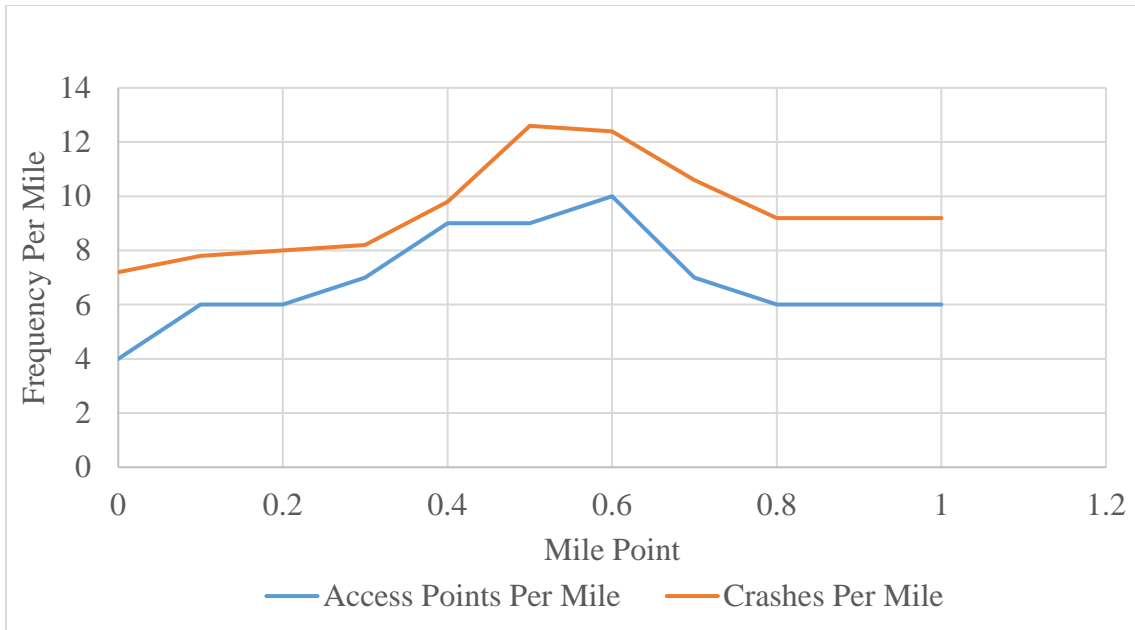


Figure 27: Des Moines- US 6 Hickman Road 156th Street to 142nd Street

Although many of the corridors show a positive relationship between access points and crashes, there are a few that show a counterintuitive trend as crashes are going in the opposite direction of access points. This can be attributed to various different reasons. Figure 28 is an example of a counterintuitive trend. Crashes continue to increase although the number of access points are decreasing. The corridor in Figure 28 is an expressway with a high speed limit at 65 miles per hour (mph). Expressways have a high level of access control resulting in less access points. Expressways generally have higher speed limits and motorists that travel on these roads tend to travel at very high speeds. This means that the increase in crashes could likely be due to the high-posted speed limits.

The purpose of this analysis was to provide an initial assessment of the access point density and crash rate relationship. Further analysis was required in order to understand this relationship. Additional figures of each corridor displaying the relationship between access point density and crash rates can be found in the appendix.

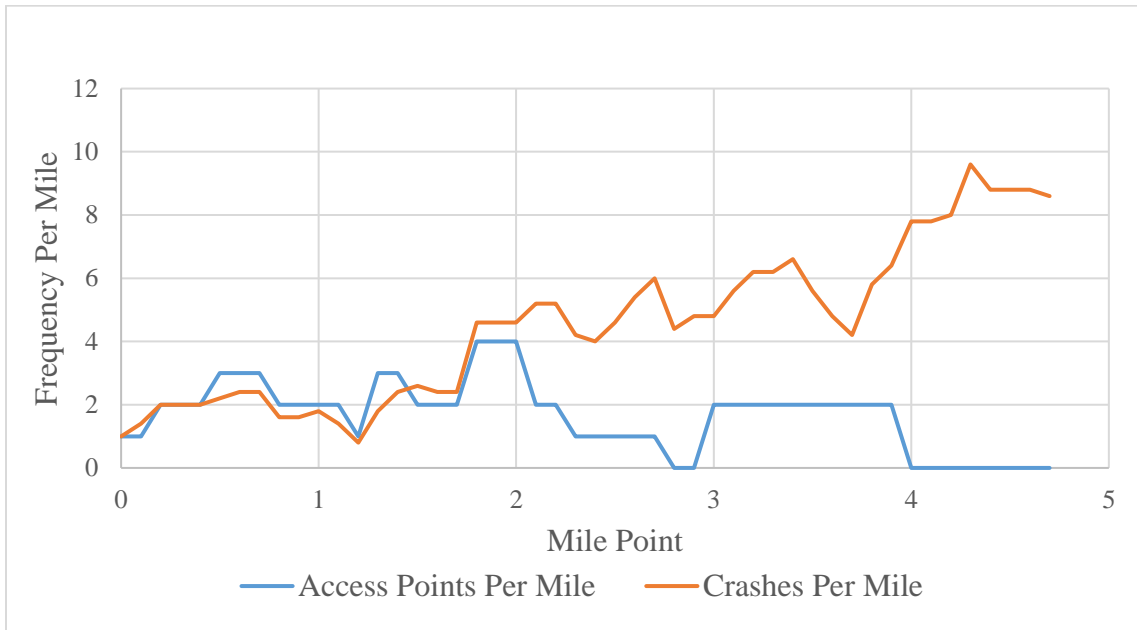


Figure 28: Cedar Rapids-US 30 east of C Street

4.3 Crossroad Corridor Data Summary

Summary statistics are provided for the dataset in Table 3. These statistics represent all five years of data. The variables shown are significant to this study and provide details regarding the minimum, maximum, mean, and standard deviation of each.

Table 3: Summary Statistics for Significant Variables-Crossroad Corridors

Variables	Minimum	Maximum	Mean	Std. Deviation
Annual Average Daily Traffic	15.0	36254.4	5441.0	6193.6
Speed Limit (MPH)	22.4	60.9	47.3	9.8
Length	0.0	0.5	0.5	0.1
Total Crashes	0.0	60.0	3.6	7.0
Signalized Intersections Per Mile	0.0	16.7	0.7	1.6
Total Driveways Per Mile	0.0	122.4	11.9	16.3
Full Turning Movements at Total Driveways Per Mile	0.0	122.4	10.5	14.8
Restricted Turning Movements at Off-Ramp Driveways Per Mile	0.0	75.1	1.2	5.6
Full Turning Movements at Non-Residential Access Points Per Mile	0.0	68.1	9.8	13.1
Full Turning Movements at Residential Access Points Per Mile	0.0	126.4	3.7	13.1
Restricted Turning Movements at Off-Ramp Residential Access Points Per Mile	0.0	72.5	0.2	2.9
Restricted Turning Movements at Off-Ramp Non-Residential Access Points per Mile	0.0	75.1	1.0	4.8
First Access Point Distance	1.0	2640.0	745.3	581.3
Divided Road	0	1	.29	.452

Table 3 shows the lowest average speed limit is 22.4 and the highest is 60.9. The speed limit values are a weighted average of all the segments combined to make this dataset. This means that not all the various speed limits within the data were the typical speeds such as 25, 30, 35, and so on. The corridors varied between rural, urban, and suburban areas consisting of commercial and/or residential property. This meant that speed limits would also vary within the dataset. Although most of the data collected for each corridor extended past a half mile, this dataset only focused on analyzing the corridor up to a half mile. This made the maximum length for each corridor 0.5 miles.

Total full turning movement driveways per mile refers to all the driveways along the corridor that allow full movement turns (i.e. Right-in, right-out, left-in, left-out). Full movements (non-residential) access points per mile refers to corridors that have mostly non-residential access points (i.e. commercial, field access, etc.) and allow full turning movements. Full movements (residential) access points per mile refers to corridors that have mostly residential access points and allow full turning movements. Restricted movements (off-ramp side, residential) access points per mile refers to corridors in the direction of the off ramp that are mostly residential access points and do not allow left-in and left-out movements. Restricted movement (off-ramp side, non-residential) access points per mile refers to corridors in the direction of the off ramp that are mostly non-residential (i.e. commercial, field access, etc.) access points and do not allow left in and left-out movements.

The maximum number for full turning movements at residential access points per mile is higher than total driveways per mile and total full turning movement driveways per mile because this variable includes stop controlled intersections. Full turning movements at non-residential access points per mile also includes stop controlled intersections.

4.4 RESULTS AND DISCUSSION

4.4.1 Results for Priority Corridors

A random effect negative binomial model was developed for total crashes. As noted previously, the random effect models accounts for within-site correlation resulting from repeated observations of the same locations in the dataset over a five-year period. The MSLINK field was used as the ID variable (refer to 3.4) to identify the repeated observations. Table 4 provides the results of the random effect model for total crashes. Figure 29 through 31 go into detail of the effect each variable in Table 4 has on total crashes. For the ranges of each variable in Figures 29 through 31 where no traffic volumes were available, the results were extrapolated (shown by the dashed portion).

Table 4: Random Effect Model for Total Crashes-Priority Corridors

Parameter	Estimate	Std. Error	P-Value
Intercept	-5.001	1.127	<0.001
log(AADT)	0.754	0.119	<0.001
Unsignalized access points per mile	0.005	0.002	0.038
Signalized intersections per mile	0.312	0.057	<0.001
Speed limit 55 mph and above	-0.448	0.176	0.011

As expected, the density of access points is one of the variables showing a significant impact. The parameter estimate for unsignalized access points indicates that increasing the density of unsignalized access points by one per mile is associated with a 0.5 percent increase in total crashes. This is consistent with previous research conducted in the same area, such as

research by Brown and Tarko (1999) indicating that segments with more frequent access points experience more crashes.

Figure 29 displays the effect of unsignalized access points per mile by AADT on total crashes. There are four categories shown: no unsignalized access points and increments of 5, 10, and 20 unsignalized access points per mile.

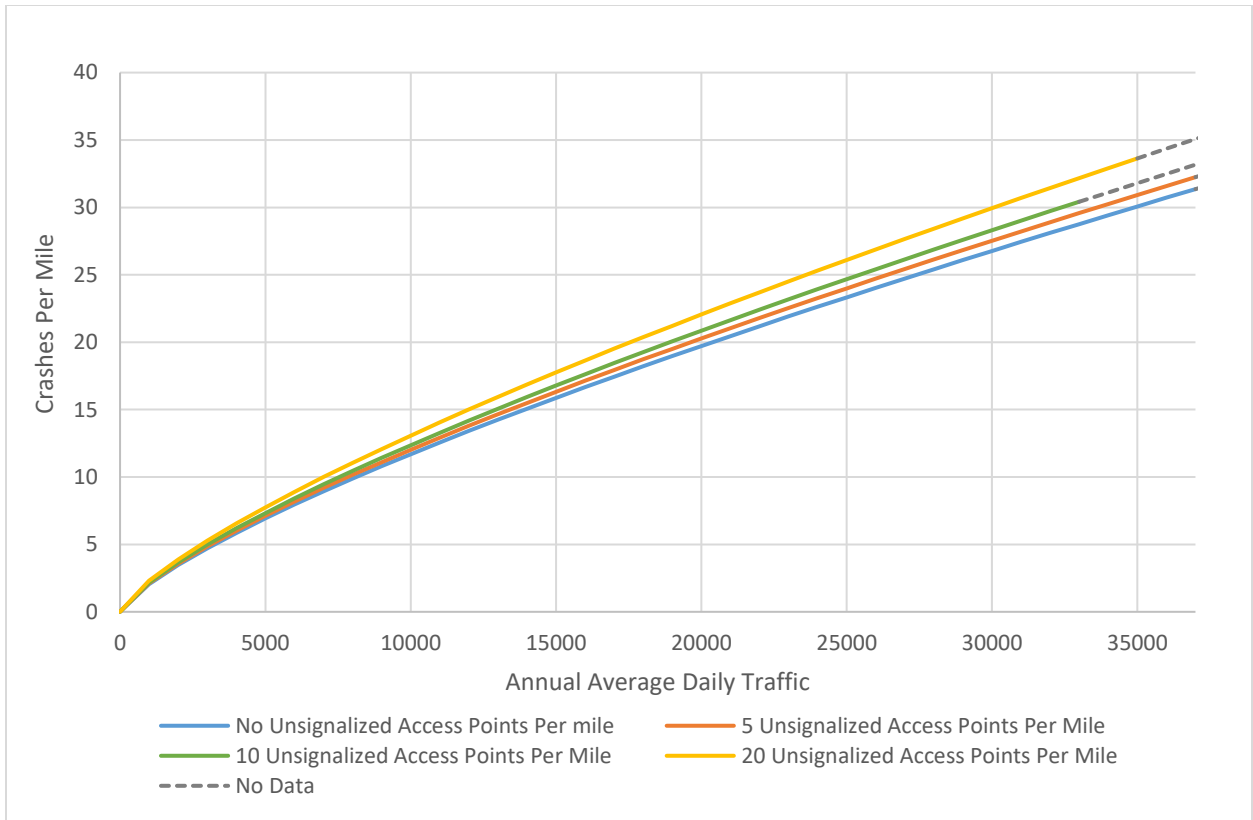


Figure 29: Crashes per Mile vs. AADT by Unsignalized Access Points for Total Crashes

Signalized intersections are associated with a much more pronounced increase in crashes. As the density of signalized intersections per mile on a roadway increases, the possibility of a crash occurring increases. Papayannoulis et al.. (2000) found that in urban/suburban areas of five states, crashes are affected by the increase in signalized access point density.

Figure 30 displays the effect of signalized intersections per mile by AADT on total crashes. There are four categories shown, which include no signalized intersections and increments of two, four, and six signalized intersections per mile. As the number of signalized intersections increase, crashes also begin to increase. The differences between the four categories are rather pronounced as an increase of one signalized intersection per mile results in a 36 percent increase in total crashes.



Figure 30: Crashes per Mile vs. AADT by Signalized Intersections per Mile for Total Crashes

Roadways with speed limits of 55 mph or above experience fewer crashes. While this may seem counterintuitive, this is likely reflective of general differences in the functionality of roadways with different speed limits. For example, roadways with higher speeds are generally of a higher function class and, therefore, are likely to have fewer access points compared to roadways posted at lower limits.

Roughly, 35 percent of the data was collected in corridors that were expressways. Expressways tend to have higher speeds hence fewer access points. Expressways, freeways, and other principal arterials are roadway types with higher functional classes, higher speed limits, and limited land access connections. They require higher levels of access control to allow traffic to operate safely and more efficiently over long distances at posted speeds (Williams, et al. 2014). Figure 31 displays the average crash rates by corridors with speed limits less than 55 mph and speed limits of 55 mph and above.

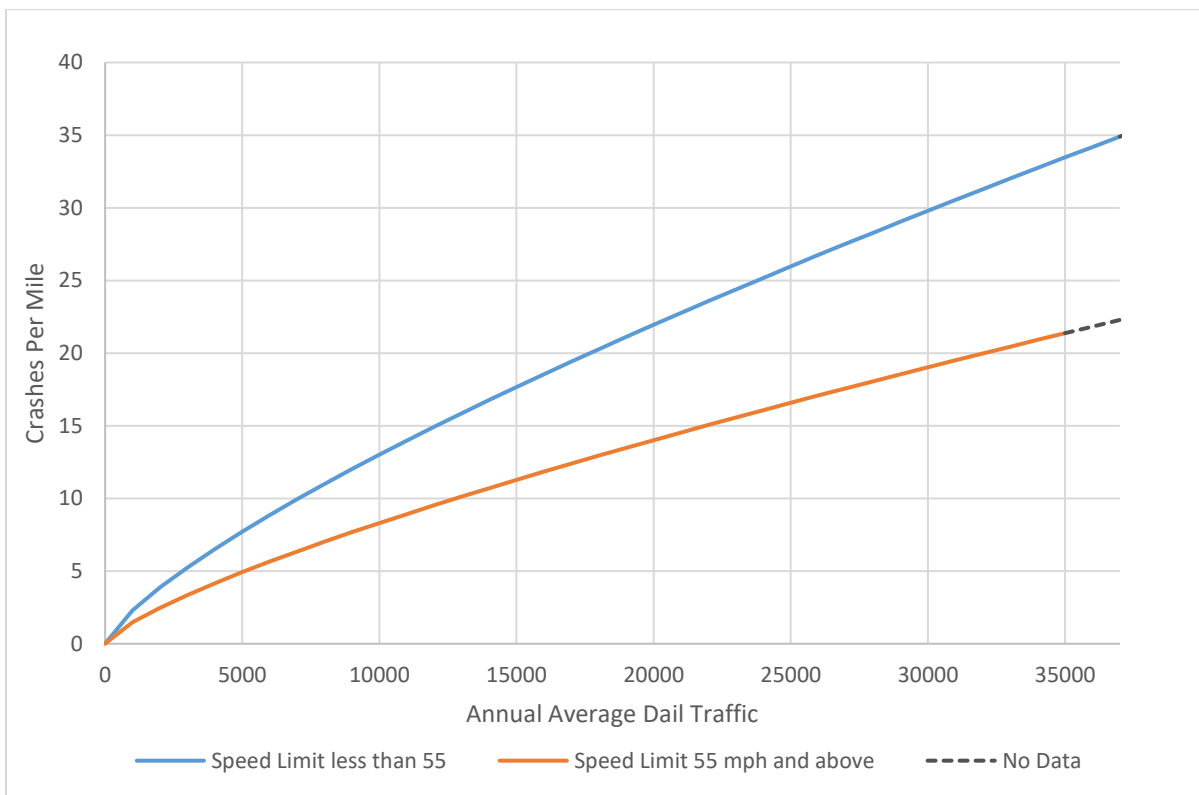


Figure 31: Crashes per Mile vs. AADT by Speed Limit

4.4.2 Results for Crossroad Corridors

This section summarizes a similar series of analyses that were conducted for the crossroad corridors. Table 5 provides the results of the random effect model for total crashes. Figure 32 through 37 go into greater detail of the effect each variable in Table 5. For the ranges for each variable in Figure 32 through 37 where no traffic volumes were available, the results were extrapolated (shown by the dashed portion).

Table 5: Random Effect for Total Crashes-Crossroad Corridors

Parameter	Estimate	Std. Error	P-value
Intercept	7.127	0.3036	<0.001
log(AADT)	0.914	0.0380	<0.001
Full movement (non-residential) access points per mile	0.006	0.002	0.008
Full movement (residential) access points per mile	0.005	0.001	0.007
Restricted movement (off-ramp side, non-residential) access points per mile	0.003	0.004	0.491
Restricted movements (off-ramp side, residential) access points per mile	-0.000	0.007	0.929
Signalized intersections per mile	0.195	0.018	<0.001
Divided (1 if yes and 0 otherwise)	0.269	0.070	<0.001
Off-ramp first access point within 300 ft. (1 if yes and 0 otherwise)	0.348	0.107	0.001
Off-Ramp first access point between 300 to 1200 ft. (1 if yes and 0 otherwise)	0.145	0.082	0.08
Speed limit 40.0 mph and below	0.392	0.088	<0.001
Speed limit between 40.1 to 50 mph	0.192	0.074	0.010

Based on the results from Table 5, eight variables are significant. Crashes were significantly influenced by the density of access points and the level of traffic volume introduced by these access points. Denser networks of traffic signals were found to be associated with significantly more crashes than segments with fewer signals. Crashes were

affected by the frequency of stop-controlled intersections and driveways as well. Crash risks were also elevated at restricted movement (e.g., right-in/right-out) access points. These increases were more pronounced when the access points tended to be non-residential (e.g., commercial, industrial).

The first variable, full movement (non-residential) access points per mile has a positive coefficient indicating that a one percent increase in full movement (non-residential) access points are associated with a 0.6 percent increase in total crashes. The second variable, full movements (residential) access points per mile is similar to the first having a positive coefficient indicating that a one percent increase in full movement (residential) access points are associated with a 0.5 percent increase in total crashes. The results for both variables is consistent with studies that have been previously conducted. In previous research, full turning movements, including left turns, have been documented to be associated with an increase in crashes. Dixon et al.. (2015) found that managing conflicting maneuvers at driveways helps to reduce the number of crashes that may occur due to turning vehicles. Left turns in particular are the cause for most driveway-related crashes. Figure 7 in Chapter 2.3 is an example of a driveway that allows full turning movements. The figure shows that the percentage of driveway crashes are higher where left turn movements are present.

Figure 32 displays the relationship between crashes and the density of full movement, non-residential access points per mile on total crashes. There are four categories shown, ranging from no access points to 60 per mile in increments of 20 per mile.

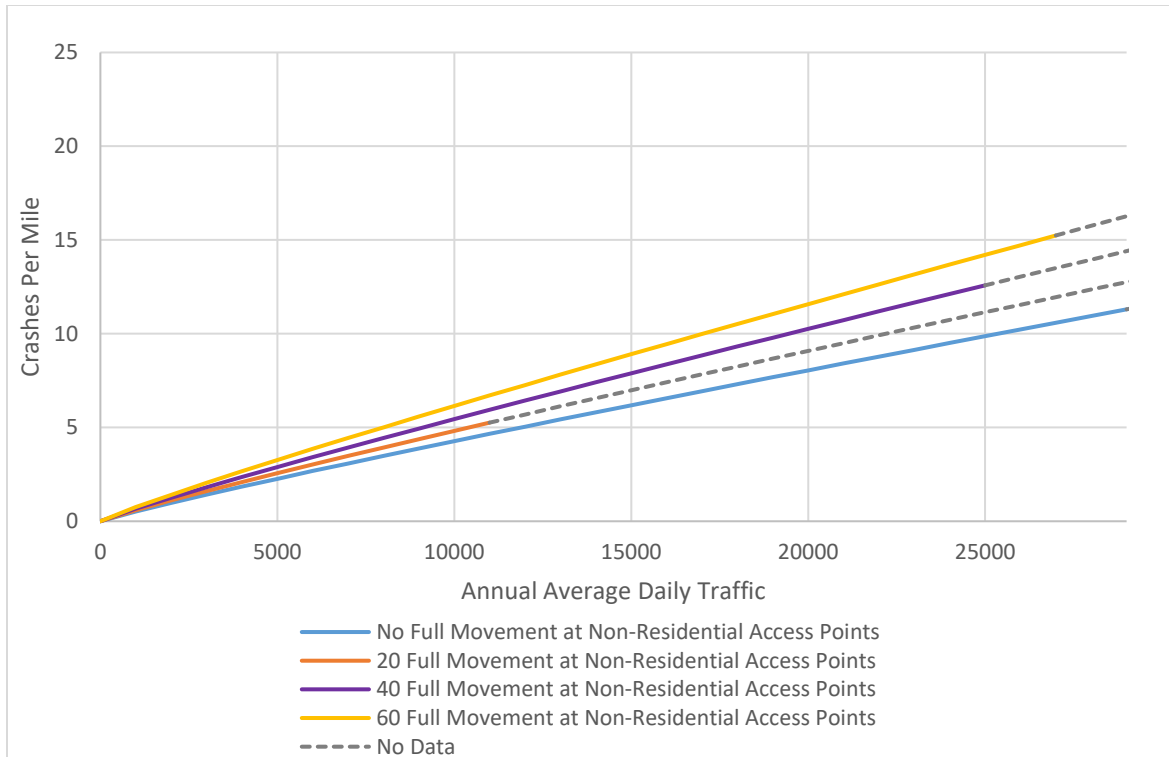


Figure 32: Crashes per Mile vs. AADT by Full Movement (Non-Residential) Access Points per Mile

Figure 33 displays how crashes vary with respect to the frequency of full movement residential access points per mile. Again, separate categories are shown, ranging from zero to 60 full turning movements per mile at residential access points. The effects were similar, but less pronounced for residential access density (compared to non-residential).

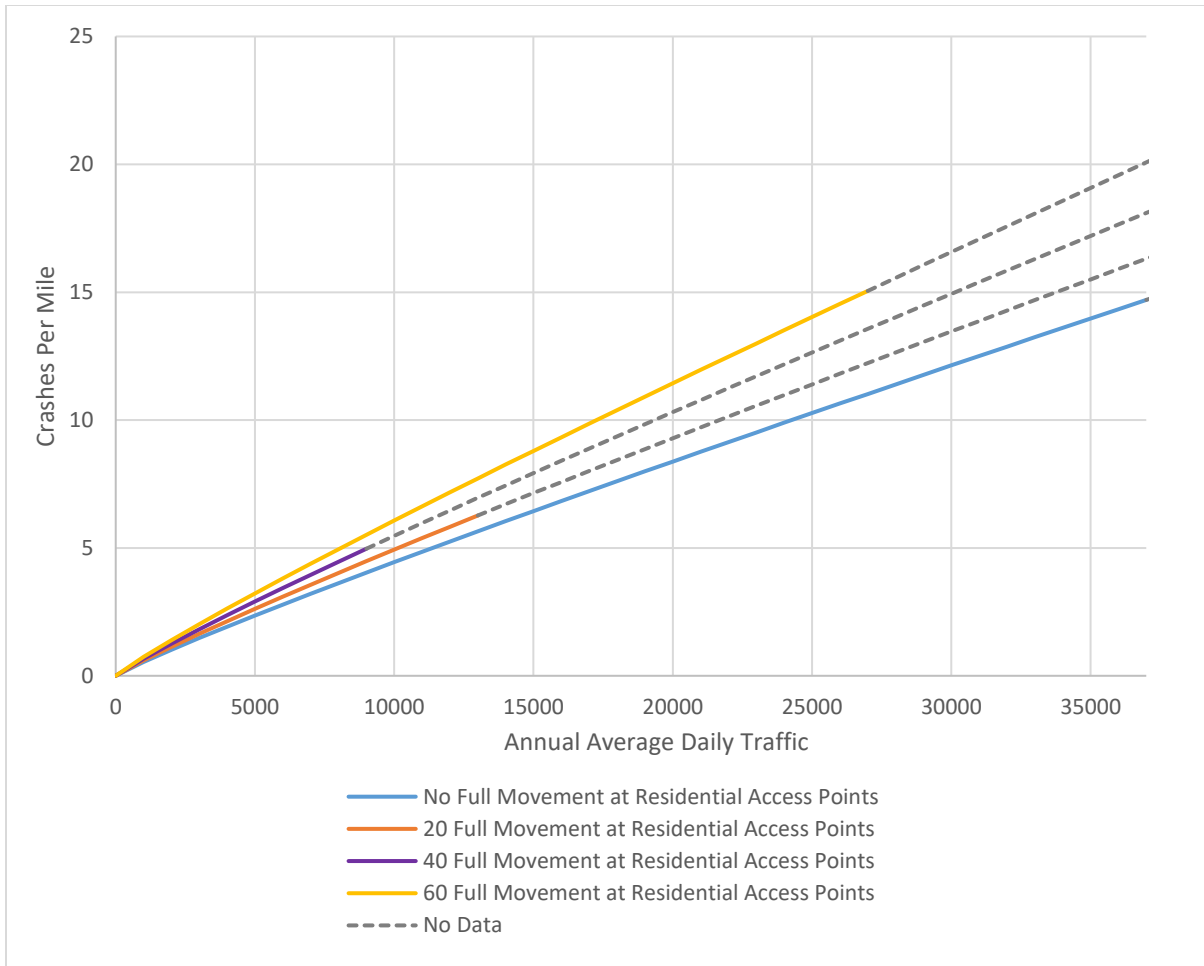


Figure 33: Crashes per Mile vs. AADT by Full Movement (Residential) Access Points per Mile

Signalized intersections have a positive coefficient indicating that a one percent increase is associated with a 21 percent increase in total crashes. The more signalized intersections per mile on a roadway, the higher the possibility of an increase in crashes. Wang et al. (2013) conducted a study to determine the effect of signal spacing, geometric design, access features, and traffic characteristics on total crash occurrence on 161 suburban road segments in China. The results determined that signalized intersection density is positively correlated with crash occurrence on suburban arterials. The total crash rate increases as signalized intersection density increases.

Figure 34 displays the effect of signalized intersections per mile by AADT on total crashes. There are five categories shown: no signalized intersections, two signalized intersections, four signalized intersections, six signalized intersections, and eight signalized intersections. As the number of signalized intersections increase, crashes also begin to increase. Roadways with eight signalized intersections per mile are predicted to have a higher number of crashes compared to roadways with no signalized intersections per mile.

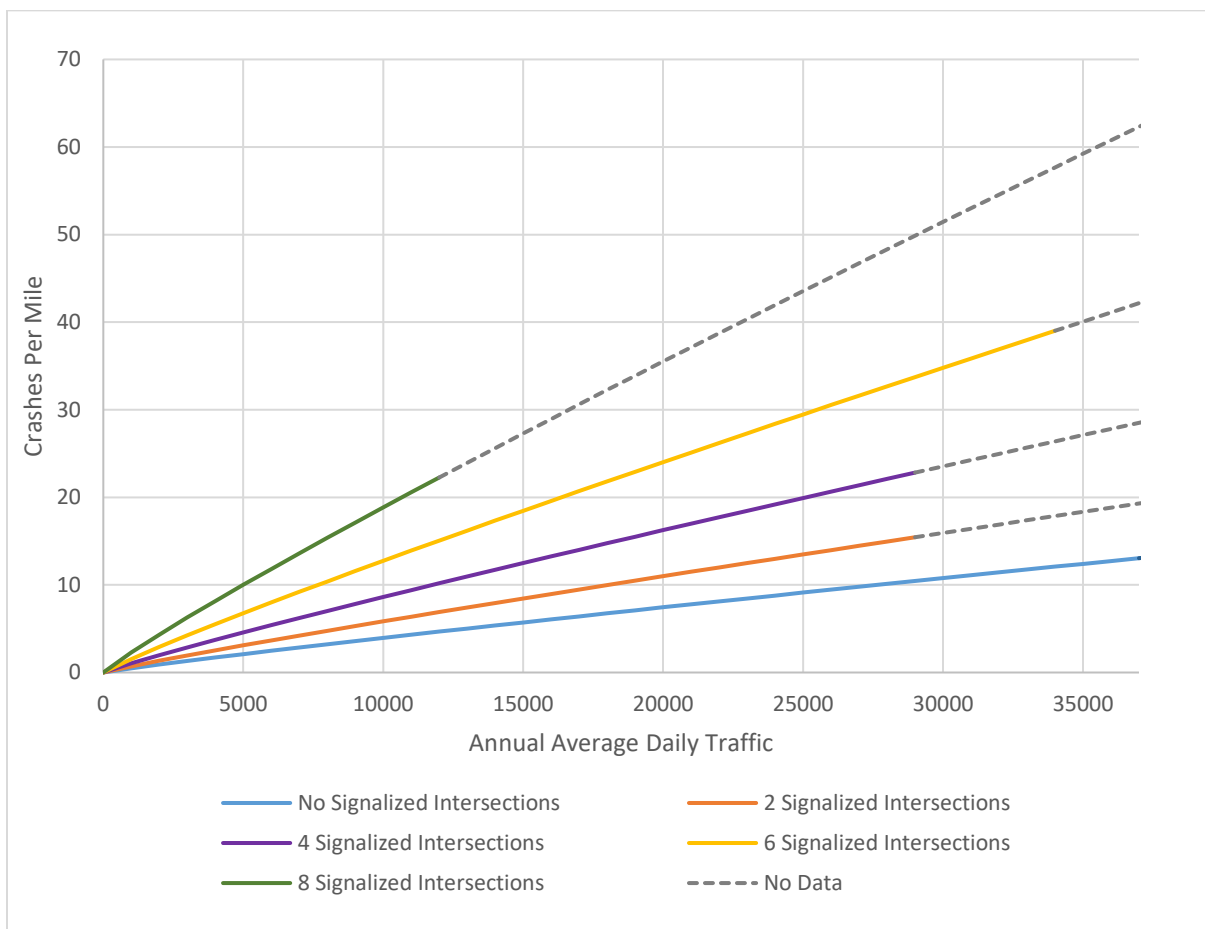


Figure 34: Crashes per Mile vs. AADT by Signalized Intersections per Mile for Total Crashes

Access points that are 300 feet and below from the off ramp have a positive coefficient at 0.34. Access points between 300 to 1200 feet from the off ramp also have a positive coefficient of 0.14. These coefficients indicate that the distance between the first access point

and the off ramp plays a significant role on the effect of total crashes. If the distance to the first access point is further away from the off ramp, crashes appear to reduce. This is demonstrated by the coefficients for both first access point variables. The first access point at 300 feet and below is associated with a 40 percent increase in total crashes, whereas if the first access point is between 300 to 1200 feet, it is associated with only a 15 percent increase in total crashes. This result is similar to a study conducted by Jacobson et al.. (1999) that evaluated five highways in Texas to develop recommended spacing between an exit ramp and a downstream driveway along a frontage road. The results determined that the crash rate increases significantly (roughly two-to-three times as frequent) for driveways located within 100 feet or less of the downstream entrance ramp. There would likely be safety-related benefits in requiring greater distances between driveways and downstream entrance ramps.

Figure 35 displays the effect of the off-ramp first access point distance by AADT on total crashes. There are three categories shown: first access point 300 feet or below, first access point between 300 to 1200 feet, and first access point more than 1200 feet. As the distance of the first access point from the off-ramp increases crashes are predicted to decrease.

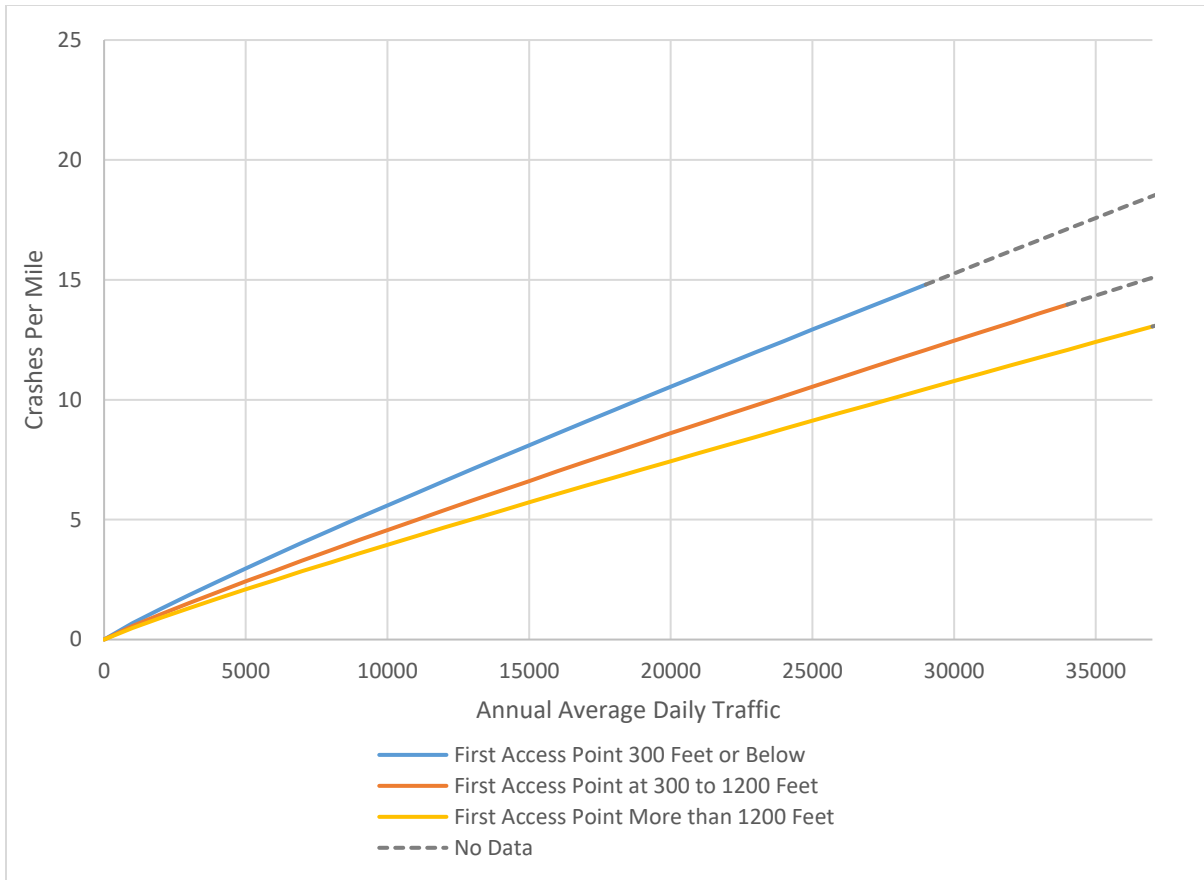


Figure 35: Crashes per Mile vs. AADT by Off-Ramp First Access Point Distance

Speed limits that are 40 mph and below have a positive coefficient at 0.39. Speed limits between 40 to 50 mph have a positive coefficient at 0.19. These coefficients indicate that as the speed limit increases the crash rate begins to decrease. This is demonstrated by the percent reduction in total crashes as the speed limit changes. Speed limits that are 40 mph and below are associated with a 47 percent increase in total crashes whereas speed limits between 40 and 50 mph are associated with a 20 percent increase in total crashes. This is expected, given that roadways with higher speeds are more likely to have fewer access points compared to roadways with lower speeds.

Figure 36 displays the effect of speed limits by AADT on total crashes. There are three categories shown, speed limits less than or equal to 40 mph, speed limits between 40 to 50

mph, and speed limits more than 50 mph. Crashes are predicted to decrease as speed limit increases. This again reiterates that lower speed limits tend to introduce more access points, which creates the opportunity for more crashes.

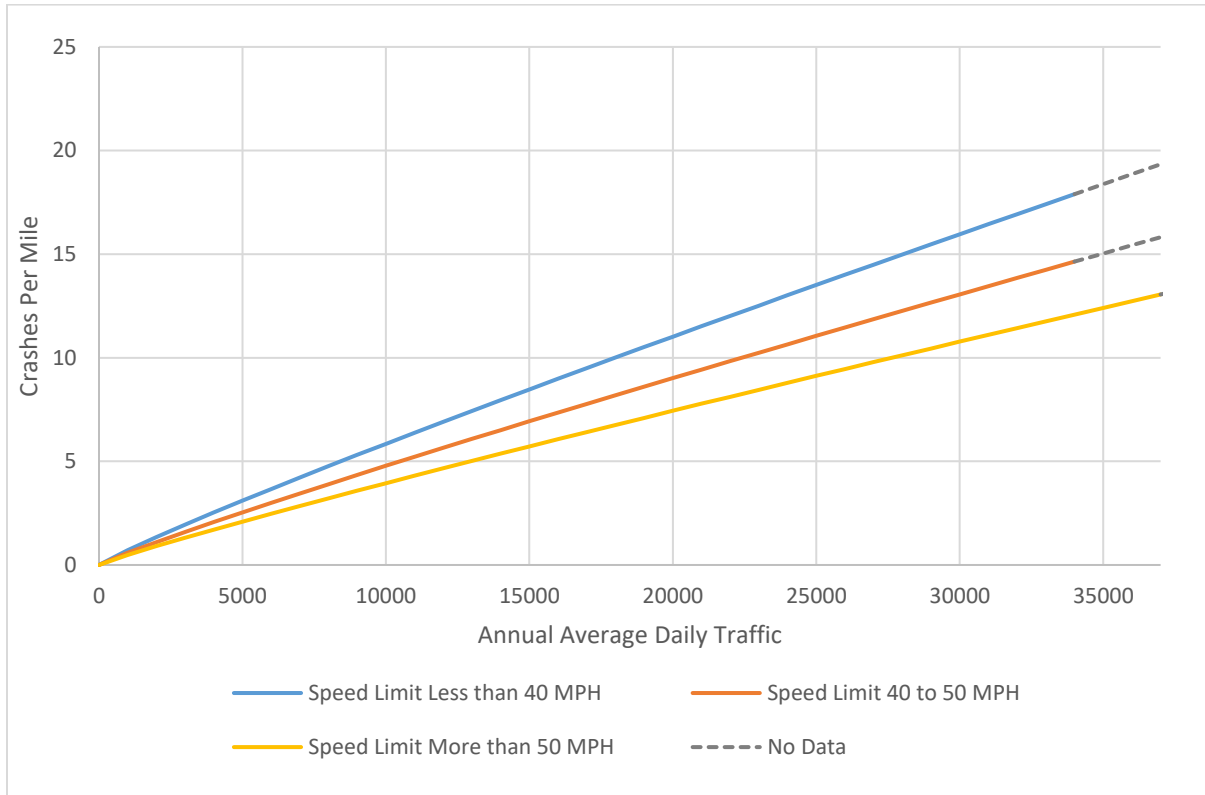


Figure 36: Crashes per Mile vs. AADT by Speed Limit for Total Crashes

“Divided” is an indicator variable with a positive coefficient stating that divided roads are associated with a 29 percent increase in total crashes. A corridor was classified as divided if there was a median present. This result does not appear to be consistent with previous studies that have been conducted focusing on access points and divided roads. Eisele and Frawley conducted a study on ten corridors in Texas to estimate relationships between crash rates and access point densities and the presence of raised medians or two-way left-turn lanes. The results determined the relationship between access points and crash rates increases slightly

more on roadways without raised medians. Installing a raised median decreases the number of conflict points from 1,220 to 300, a decline of roughly 75 percent.

Although several variables from this model resulted in being significant, a few variables of interest did not show a significant relationship with respect to crashes. Specifically, the density of restricted movement access points per mile. These types of turning movement restrictions would include left-turn-in-only and left-turn-out-only.

This result was different than expected because previous studies have determined that restricting left turn movements can have a significant impact on reducing total crashes. Chowdhury et al. (2003) conducted a study in Ohio that evaluated the safety and operational impacts of restricting direct left turns from a driveway. The results indicated that left-turning crashes represented a high percentage of the total number of crashes. Conflict points appear to reduce when a restriction is placed on left-turning movements. This suggested that reducing or restricting left-turning vehicles at unsignalized driveways could possibly decrease crashes.

Figure 37 displays the relationship between crashes and the density of restricted movements and non-residential access points on the same side of the road as the freeway off-ramp. In general, these results show marginal differences, which were not statistically significant as noted previously. Restricted-movement residential access points showed no impact as a part of the analysis.

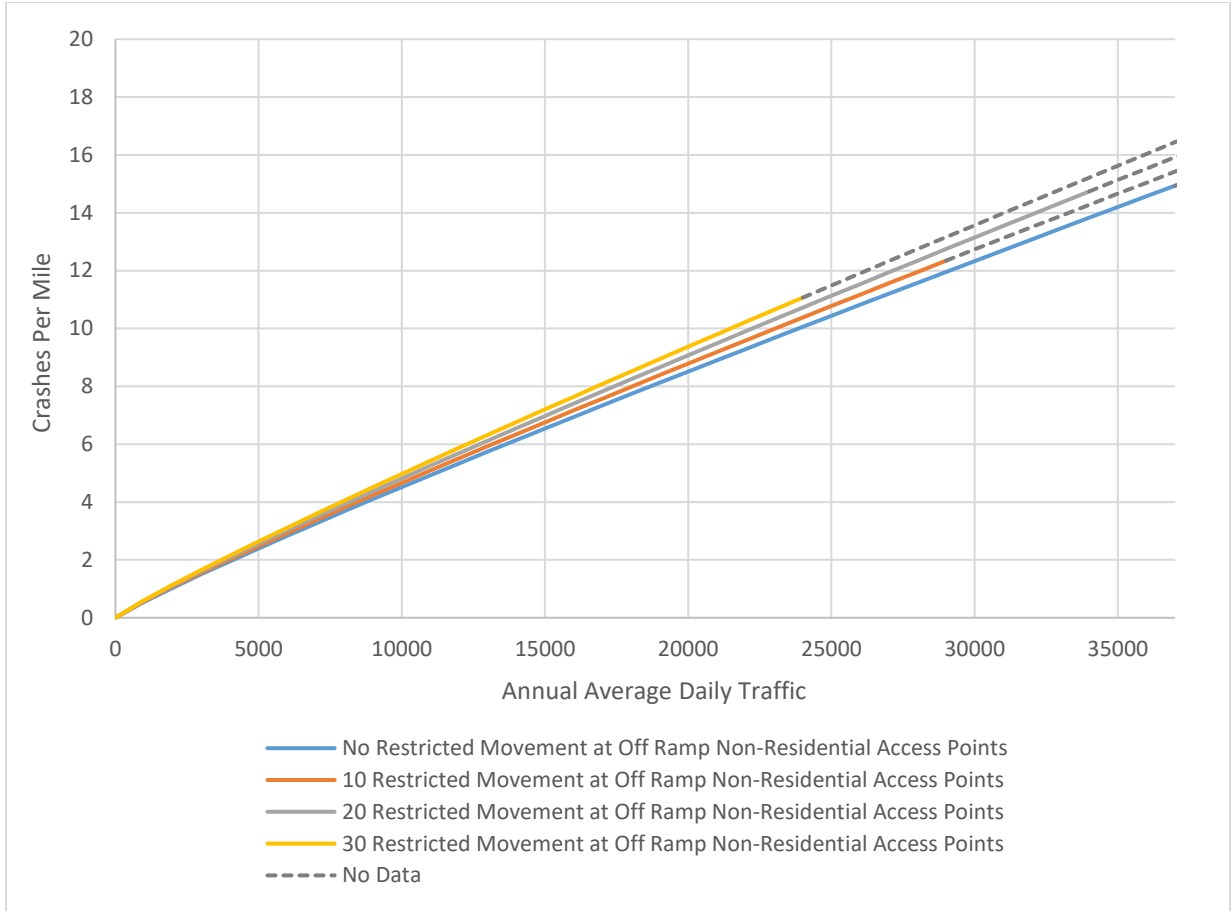


Figure 37: Crashes per Mile vs. AADT by Restricted Movements (Off-Ramp Side, Non-Residential) Access Points

CHAPTER 5: CONCLUSIONS

The purpose of this study was to identify how access point density, type, and spacing relate to the rate of crashes among roadways in Iowa. Two separate datasets were assembled, with the first focusing on a series of high-growth, “priority corridors” throughout the state of Iowa and the second dataset including “crossroad corridors” in the immediate vicinity of Iowa’s service interchanges.

An extensive dataset was developed for each corridor type in order to examine differences in safety performance based on the level of access management. Detailed driveway data were manually collected, including location, land use (e.g., residential, commercial), and driveway type (e.g., full-movement, right-in/right-out). Information was also obtained as to the presence and types of intersections along each corridor. Access points, traffic crash, and roadway geometry data were integrated for a five-year analysis period (2010-2014).

A statistical analysis was conducted for both corridor types, which involved the estimation of a series of safety performance functions (SPFs) to ascertain how crashes varied with respect to access management-related characteristics (e.g. intersection and driveway density) while controlling for other pertinent factors for both corridor types. These SPFs consisted of random effect negative binomial models, which allowed for consideration of within-site correlation over the five-year study period.

Numerous features were considered as a part of the statistical analysis. Within both contexts, crashes were found to increase with the density and type of access points along both corridor types. For the priority corridors dataset, crashes increased with the density of signalized intersections and unsignalized access points (i.e., intersections and driveways). Crashes increased by approximately 36.6 percent for each additional signalized intersections

per mile while each additional lower-volume unsignalized access point per mile was associated with a 0.5-percent increase. Crashes were significantly lower on corridors with speed limits of 55 mph and above, which is likely a reflection of differences in the design of these higher functional class urban/suburban arterials. For example, these higher functional class roadways would include higher speed limits, as well as lower access density, wider lanes and shoulders, and other differences. Crashes also increased with volume, with a one-percent increase in volume resulting in approximately a 0.8-percent increase in crashes. This inelastic effect may be reflective of congestion levels on these respective corridors.

For the crossroad corridors dataset, additional access-related details were collected, allowing for a more detailed investigation of the safety-access relationship. This analysis focused on the first 0.5 miles from the crossroad ramp terminal at each service interchange. Differences in crash rates were exhibited based on both the density and type (i.e., full movement or restricted movement) of access point along the corridor. In addition, the location of the first access point after the crossroad terminal was shown to have a very pronounced impact. Increasing the number of full movement driveways by one per mile resulted in a 0.6-percent increase if the driveway was non-residential (i.e., commercial or industrial) versus 0.5-percent for residential driveways. If the driveways restricted left-turns into or out of the development, the effects were dampened. Each restricted movement non-residential access points increased crashes by 0.3 percent while no significant impact was shown with respect to residential restricted movement access points. As in the case of the priority corridors, crashes were markedly higher on corridors with denser traffic. An additional signalized intersection (per mile) along a corridor was associated with a 21.5 percent increase in crashes. Interestingly, there were also very large increases in crashes based upon the proximity of the first access

point. For example, if the first access point was located within 300 feet of the off-ramp, crashes increased by 41.6 percent. If the first access were between 300 and 1200 feet, the corridor-wide crash rate increased by 15.6 percent. While there is a natural relationship between the location of the first access point and the corridor-wide access density, the results of the statistical analysis showed these results to be largely independent of one another. This suggests the location of the first access point is particularly important. The crossroad corridors, similar to the priority corridors, also showed more frequent crashes on low-speed roadways as crash rates were highest on corridors with limits of 40 mph and below and lowest on corridors posted at greater than 50 mph. Crashes were also found to increase by 0.9-percent for every one-percent increase in volume on these corridors.

Ultimately, the results of the analyses for both datasets demonstrate that access point density plays an important role in traffic safety, particularly on high-density urban/suburban corridors and near service interchanges. The increases in crashes were most pronounced as the volume of traffic using each access point increased. For example, signalized intersections exhibited the largest impact, followed by full-movement unsignalized intersections and driveways, and then restricted movement driveways.

This study provides an important framework that can be used to provide guidance for access management policies on the Iowa roadway network. However, a few limitations should be addressed. First, the analyses focused on crashes in both directions of travel along each study corridor. This is largely due to the nature of the Iowa DOT Geographic Information Management System (GIMS) and the Iowa DOT crash database, which created issues for attempting a directional analysis. Consequently, some of the potential safety impacts of driveways may be muted by the fact that both directions of travel are considered.

Differences were observed with respect to the intensity of development for each driveway. Additional insights could be gained by collecting additional traffic volume data specific to each access point. The Iowa DOT currently maintains an intersection database, which includes annual traffic volume estimates for the entire public road system. However, such data is not available for driveways. One approach would be to utilize Institute for Transportation Engineers (ITE) Trip Generation Manual (Institute for Transportation Engineers, 2012) for estimating these driveway volumes.

Another area that warrants further investigation is the effectiveness of turning movement prohibition in reducing crashes at restricted movement access points. The crossroad corridor analysis did, in fact, show that there tended to be fewer crashes on corridors with restricted-movement (as opposed to full-movement) access points. However, it is challenging to determine at a more precise level of detail the impacts at individual access points due to imprecision in the crash location process, as well as limited numbers of crashes at non-intersection driveways over the five-year study period.

In conclusion, access management plays a critical role in the safety performance of a roadway. This is particularly true of higher volume corridors in urban/suburban areas and near service interchanges. This study provides useful guidance that can assist in planning-level decisions focused on issues such as the location and spacing of signalized intersections and driveways.

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APPENDIX PRIORITY CORRIDORS ACCESS POINT DENSITY AND CRASH RELATIONSHIP

This appendix provides detailed information regarding each priority corridor analyzed as a part of this study. A picture is provided of each corridor followed by a graph that displays the relationship between access point density and crash rates along the corridor.

- US 169 South of US 6: Located in the city of Adel and Dallas County, Iowa. The AADT along this corridor is 5,900 and the length of the corridor is 1.01 miles. The corridor currently includes 21 driveway access points and 5 intersections.

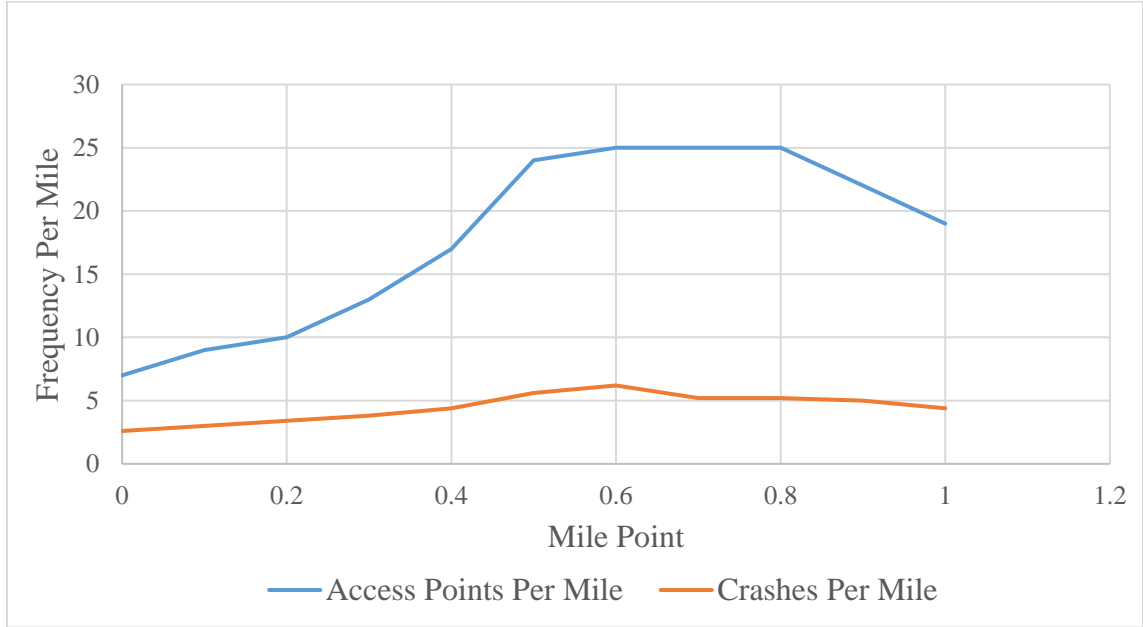
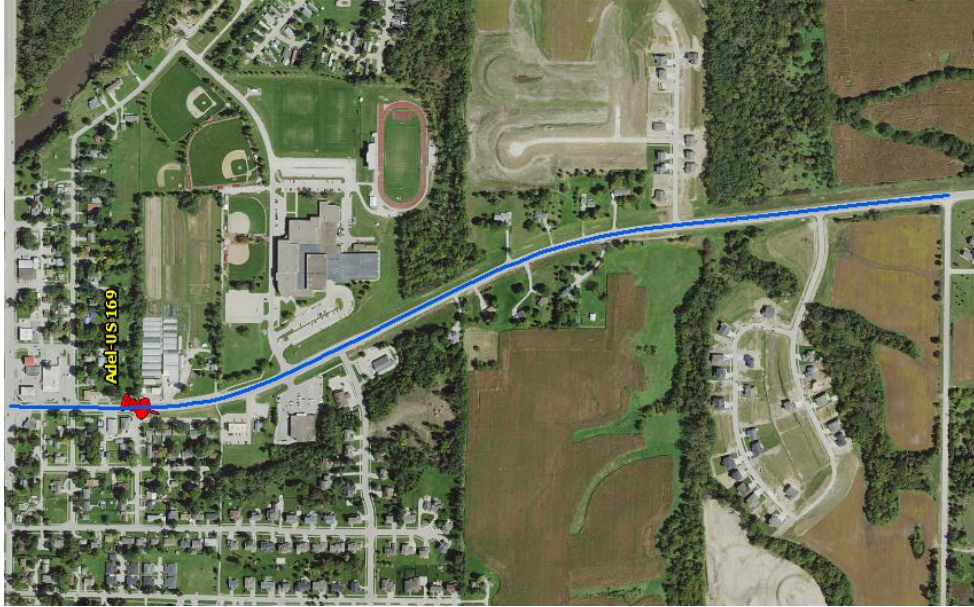


Figure A1: Adel- US 169 South of US 6

- US 69 South Duff Ave North of S. 16th Street: Located in the city of Ames and Story County, Iowa. Home to the Iowa State University Cyclones. The AADT along this corridor is 25,056 and the length of the corridor is 0.62 miles. The corridor currently includes 19 driveway access points and 3 intersections.

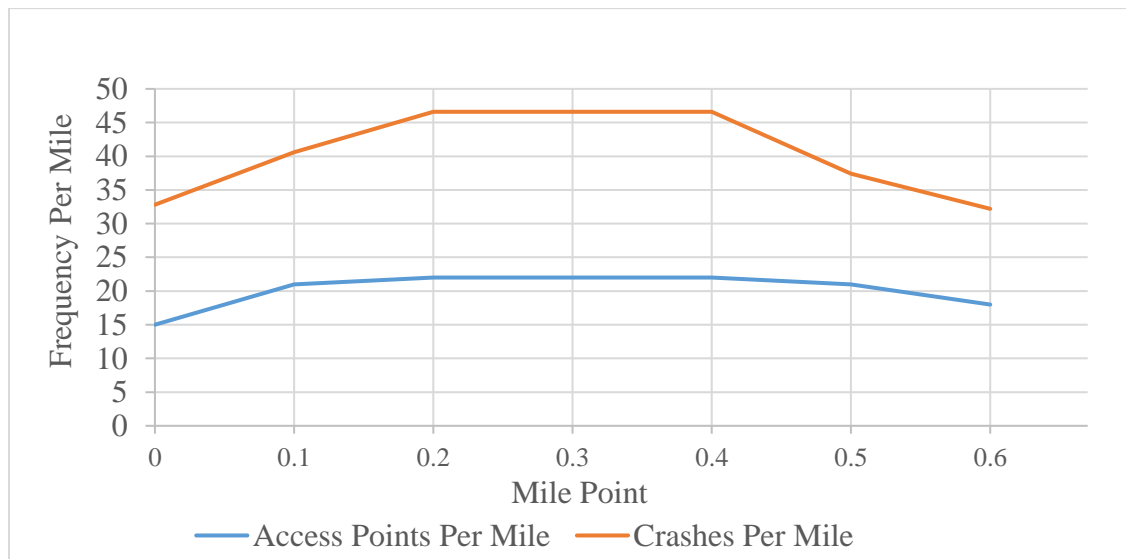


Figure A2: Ames- US 69 North of S 16th Street

- US 30 East of C Street: Located in the city of Cedar Rapids and Linn County, Iowa. The AADT along this corridor is 20,262 and the length of the corridor is 4.74 miles. The corridor currently includes four driveway access points and eight intersections.

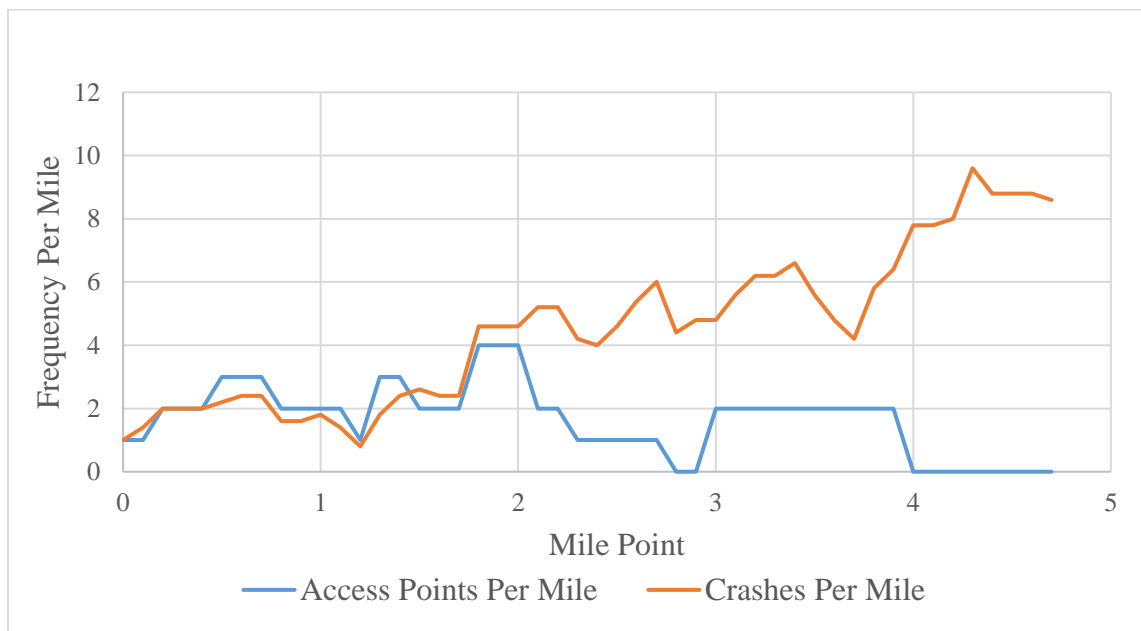


Figure A3: Cedar Rapids-US 30 East of C Street

- IA 965 North of I-80 Interchange: Located in the city of Coralville and Johnson County, Iowa. The AADT along this corridor is 36,633 and the length of the corridor is 1.94 miles. The corridor currently includes two driveway access points and five intersections.

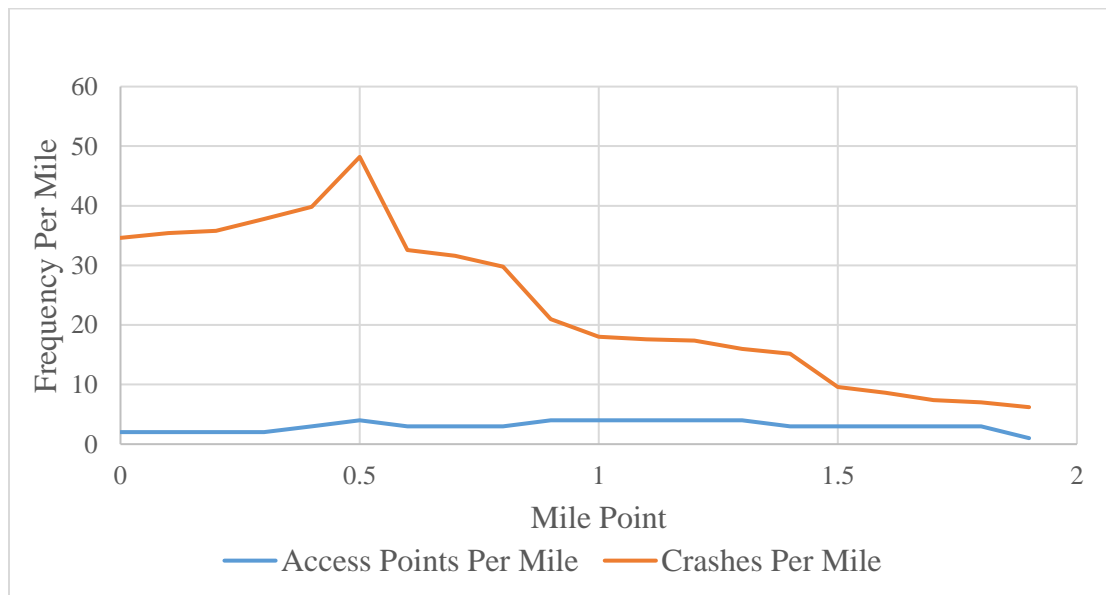
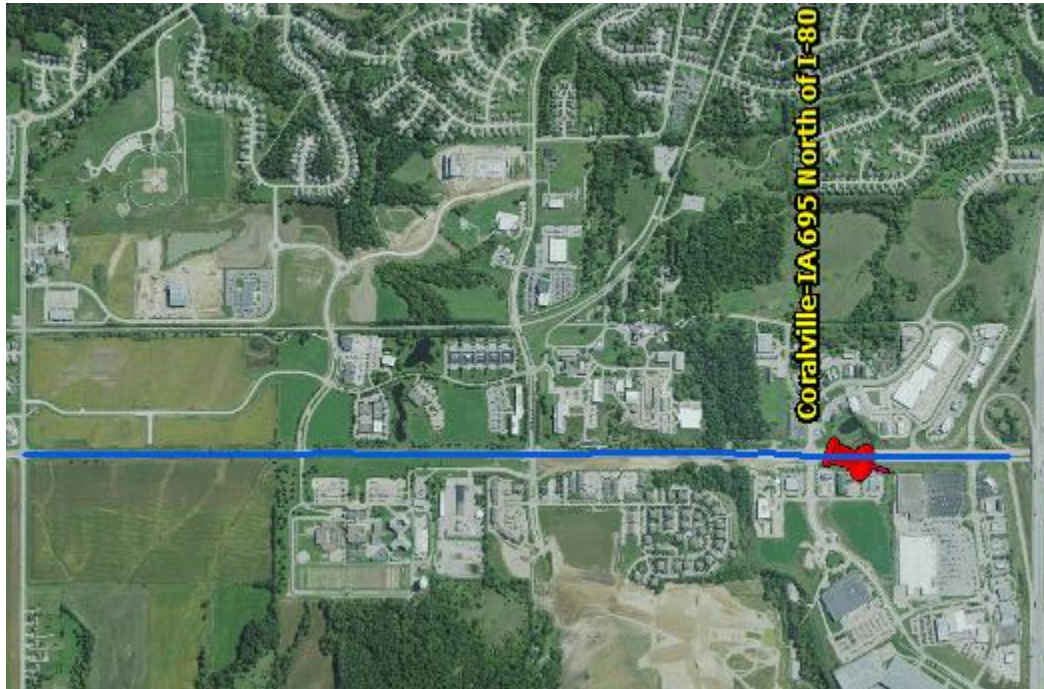


Figure A4: Coralville-IA 695 North of I-80 Interchange

- US 6 south of I-80: Located in the city of Coralville and Johnson County, Iowa. AADT along this corridor is 21,752 and the length of the corridor is 4.68 miles. The corridor currently includes 61 driveways and 15 intersections.

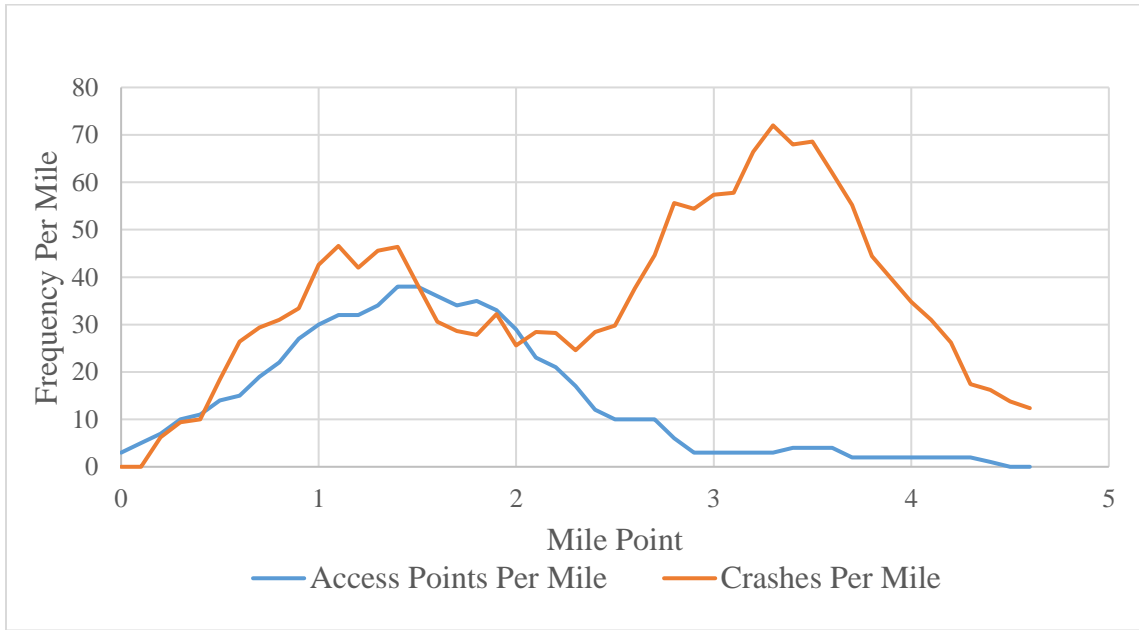
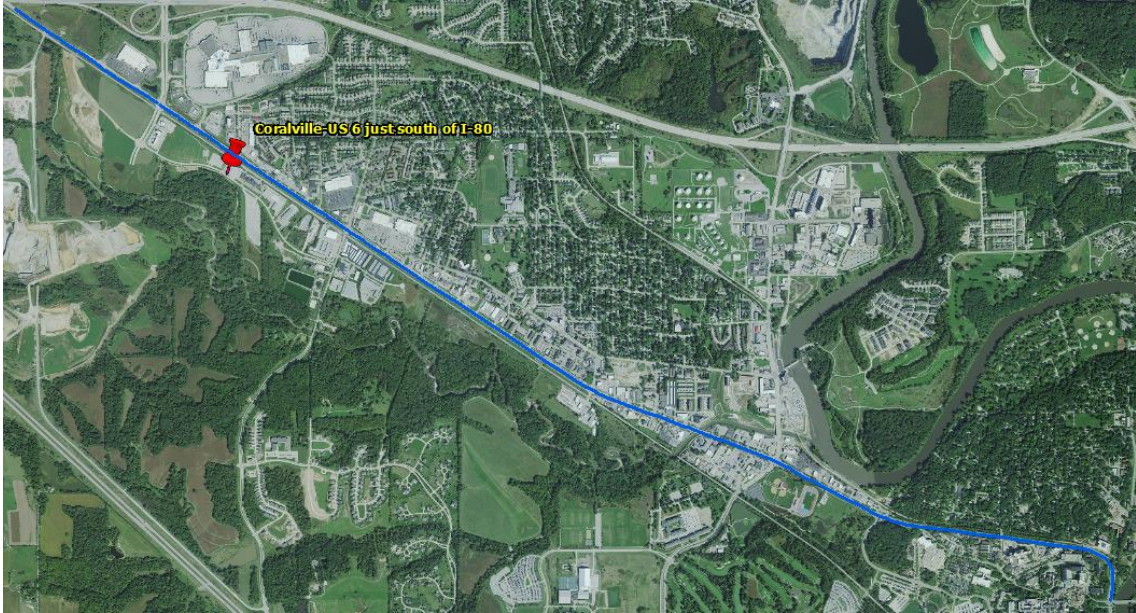


Figure A5: Coralville- US 6 South I-80

- Kimberly Road East of NW Blvd: Located in the city of Davenport and Scott County, Iowa. The AADT along this corridor is 21,754 and the length of the corridor is 4.47 miles. The corridor currently include 59 driveways and 18 intersections.

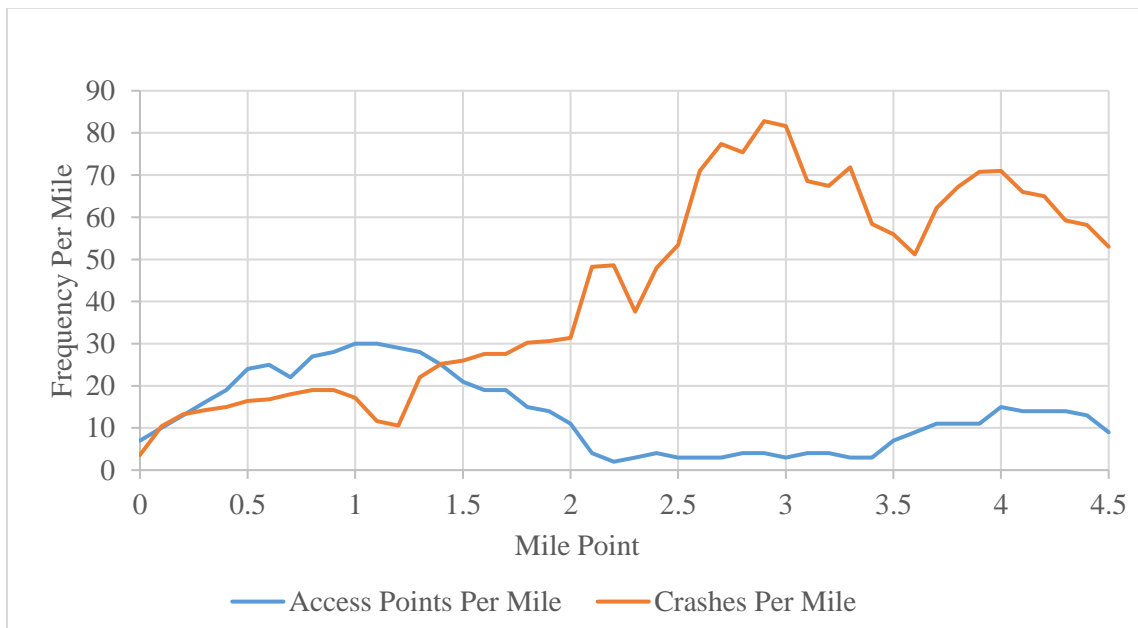
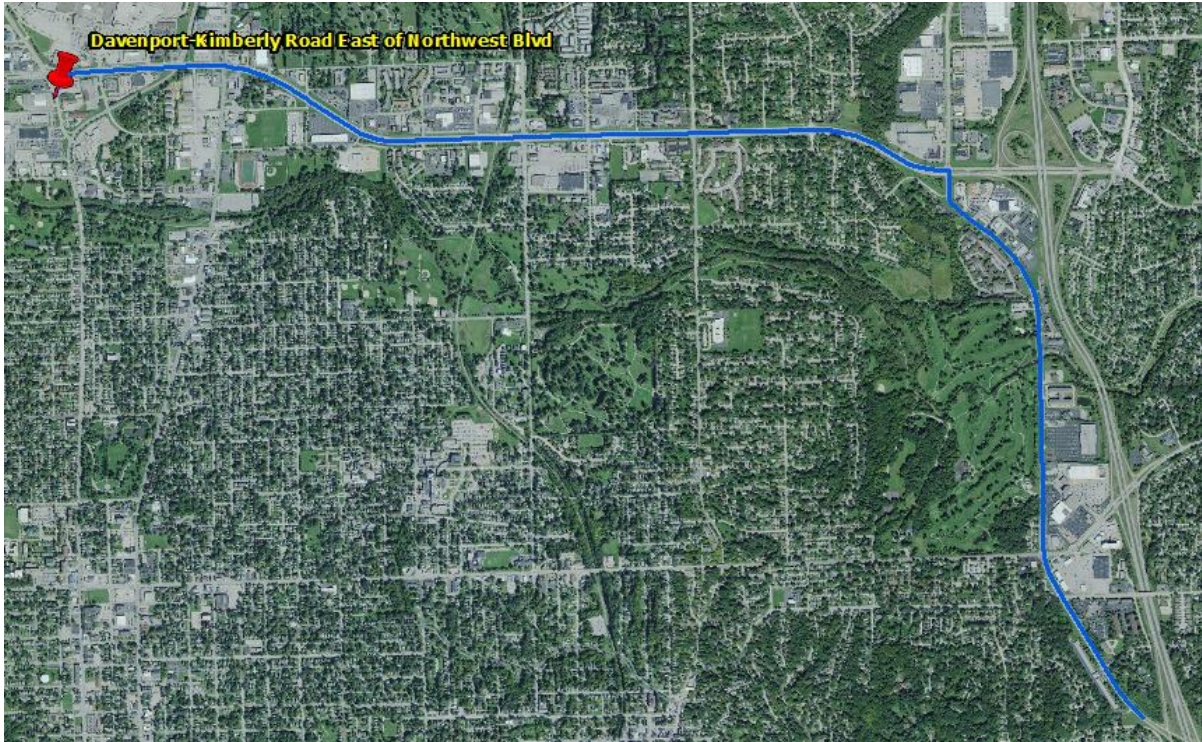


Figure A6: Davenport- Kimberly Road East of NW Blvd

- Merle Hay Road (Aurora Ave to Meredith Drive): Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 27,600 and the length of the corridor is 0.50 miles. The corridor currently includes eight driveways and three intersections.

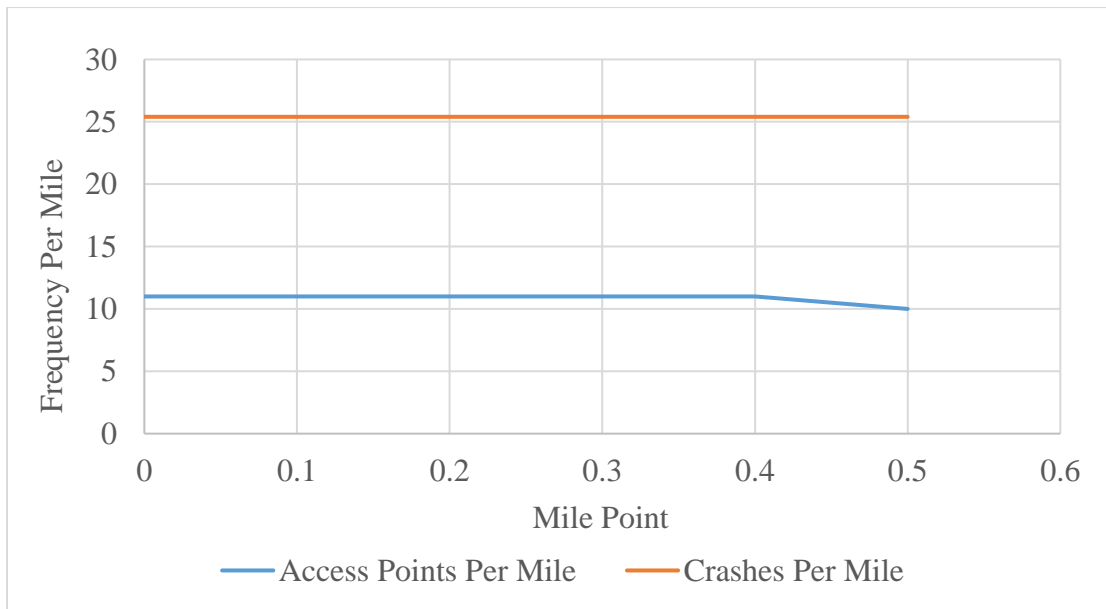


Figure A7: Des Moines- Merle Hay Road Aurora Ave to Meredith Dr.

- Merle Hay Road at Hickman Intersection - East to 44th Street: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 16,302 and the length of the corridor is 1.14 miles. The corridor currently includes 75 driveways and 17 intersections.

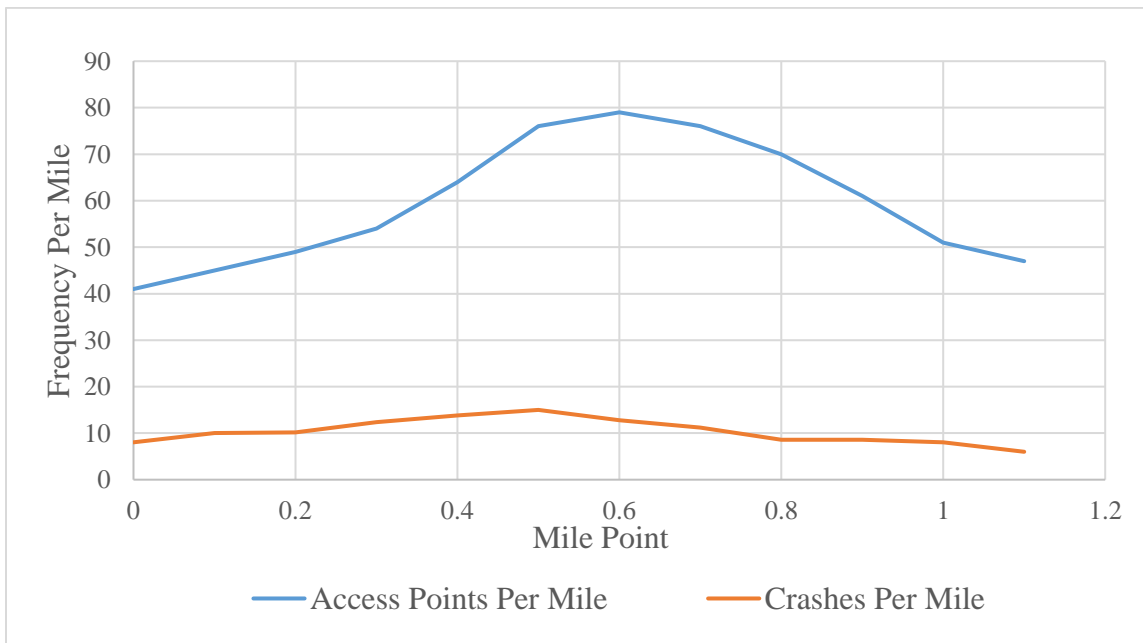
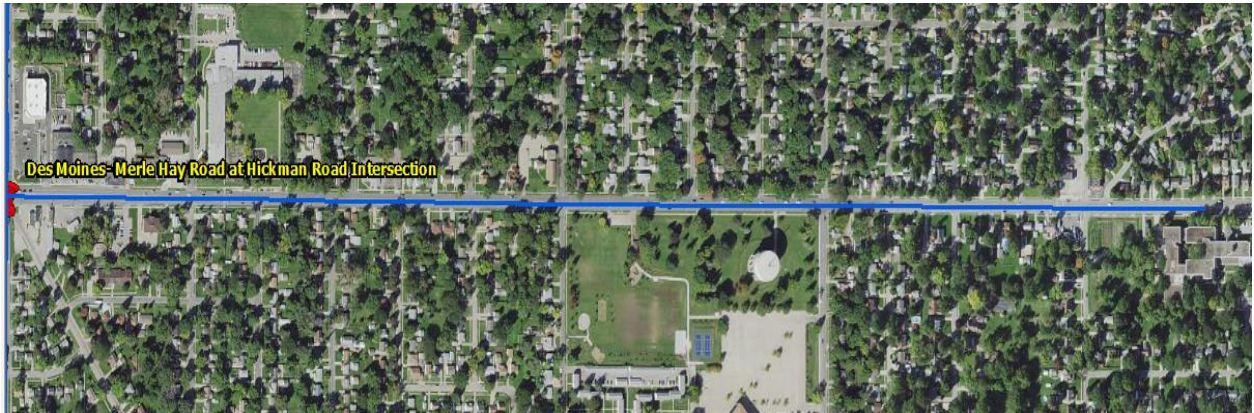


Figure A8: Des Moines-Merle Hay Road East to 44th Street

- Merle Hay Road at Hickman Intersection - North to Urbandale Ave: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 22,400 and the length of the corridor is 0.50 miles. The corridor currently includes 32 driveways and 5 intersections.

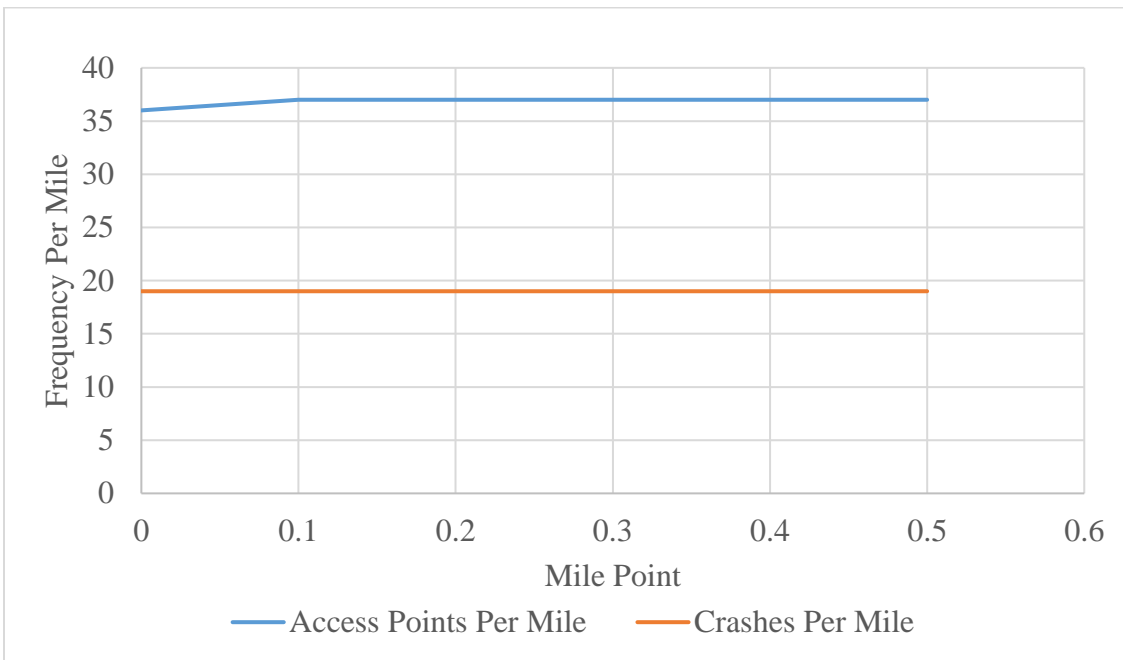


Figure A9: Des Moines-Merle Hay Road North to Urbandale Ave

- Merle Hay Road at Hickman Intersection - South to University Ave: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 8,887 and the length of the corridor is 0.99 miles. The corridor currently includes 106 driveways and 14 intersections.

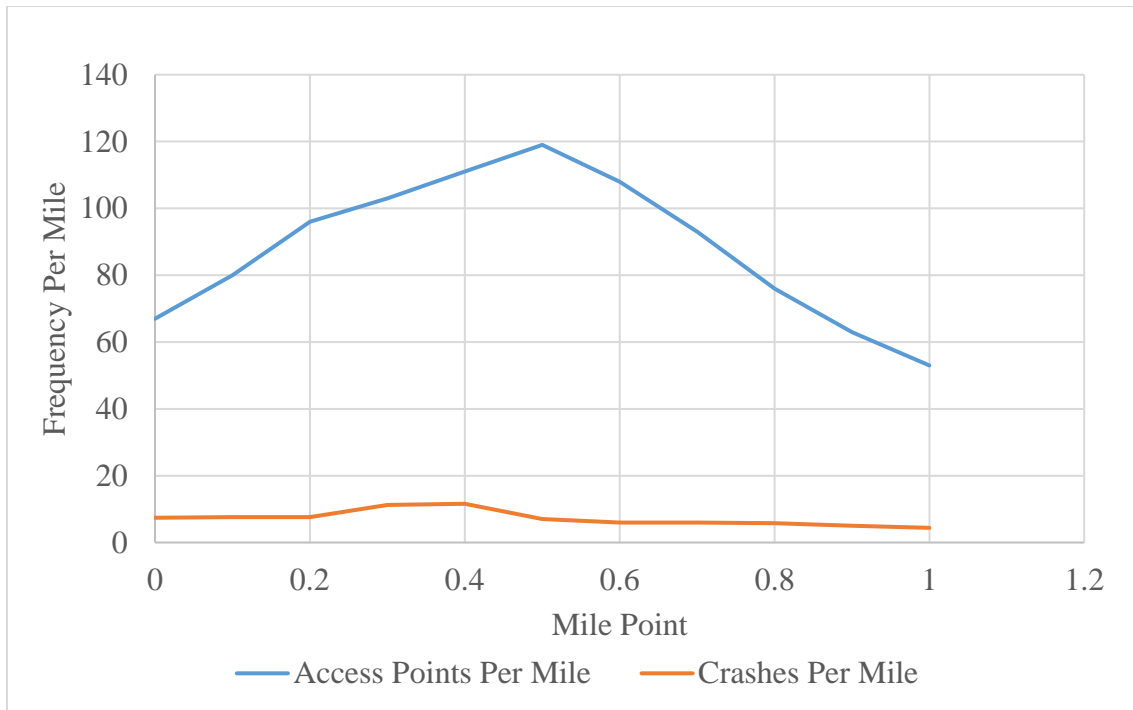


Figure A10: Des Moines- Merle Hay Road South to University Ave

- Merle Hay Road at Hickman Intersection - West to 73rd Street: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 19,764 and the length of the corridor is 1.08 miles. The corridor currently includes 35 driveways and 11 intersections.

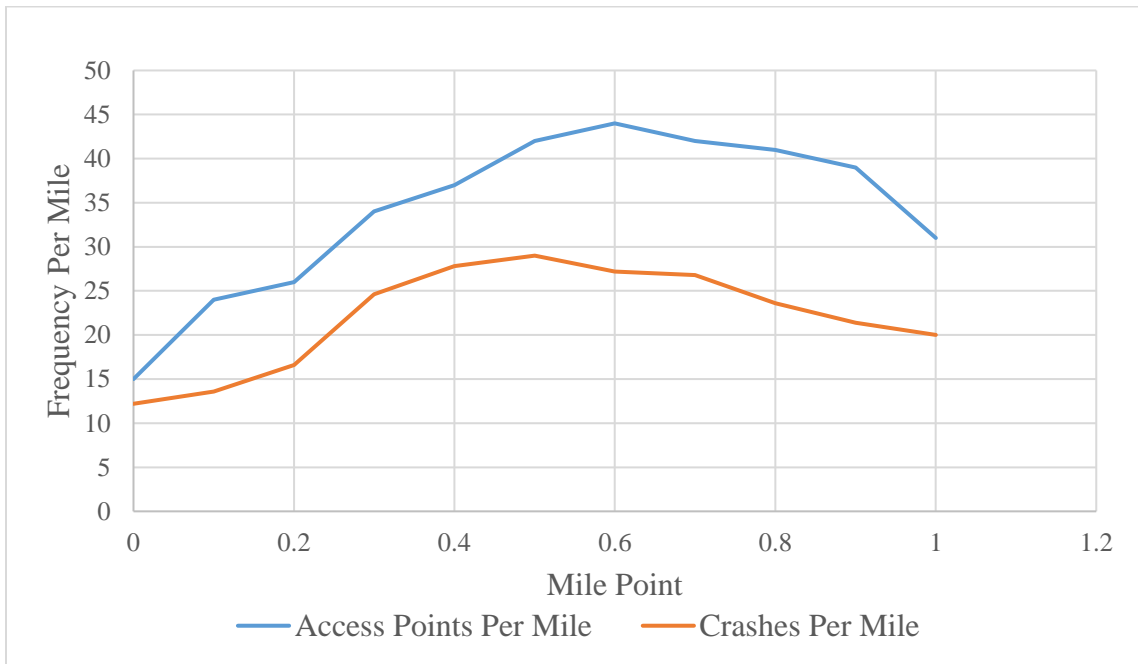


Figure A11: Des Moines- Merle Hay Road West to 73rd Street

- Merle Hay Road South of Douglass Ave: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 22,400 and the length of the corridor is 0.50 miles. The corridor currently includes 33 driveways and 3 intersections.

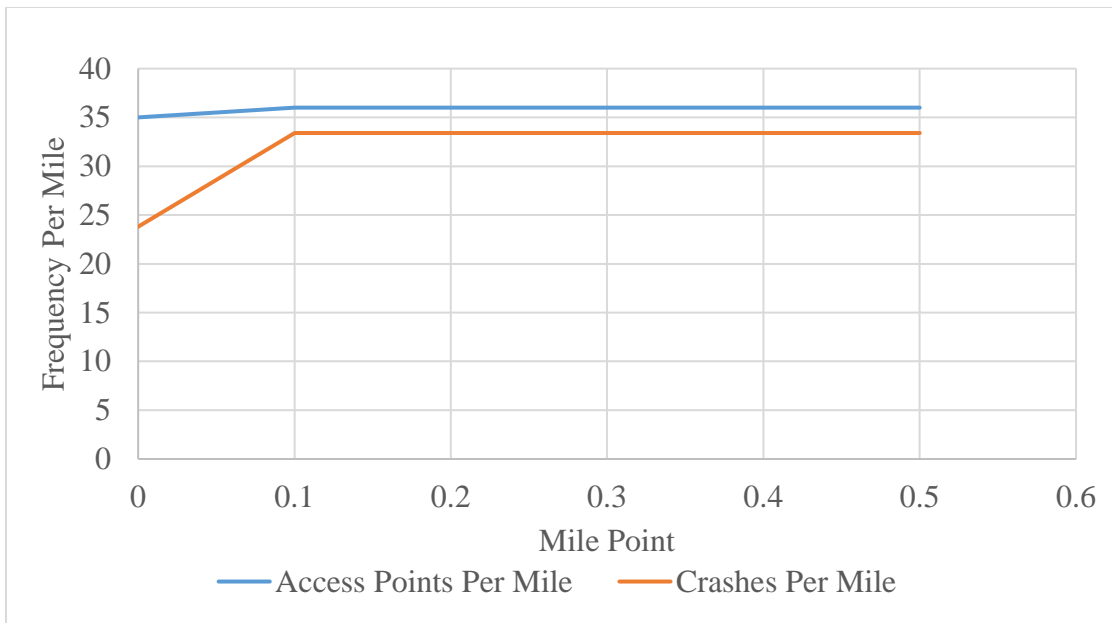


Figure A12: Des Moines- Merle Hay Road South of Douglass Ave

- US 6 Hickman Road 156th St to 142nd St: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 27,900 and the length of the corridor is 1.00 miles. The corridor currently includes five driveways and five intersections.

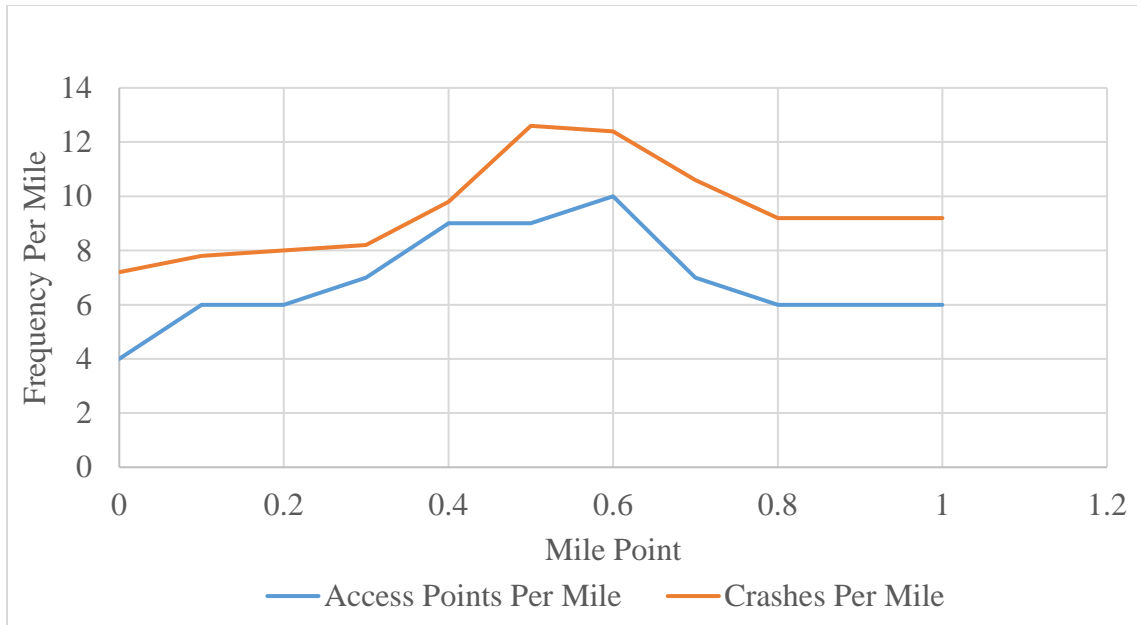


Figure A13: Des Moines- US Hickman Road 156th Street to 142nd Street

- US 6 Hickman Alice’s Road Intersection, 156th St: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 23,600 and the length of the corridor is 1.00 miles. The corridor currently includes seven driveways and five intersections.

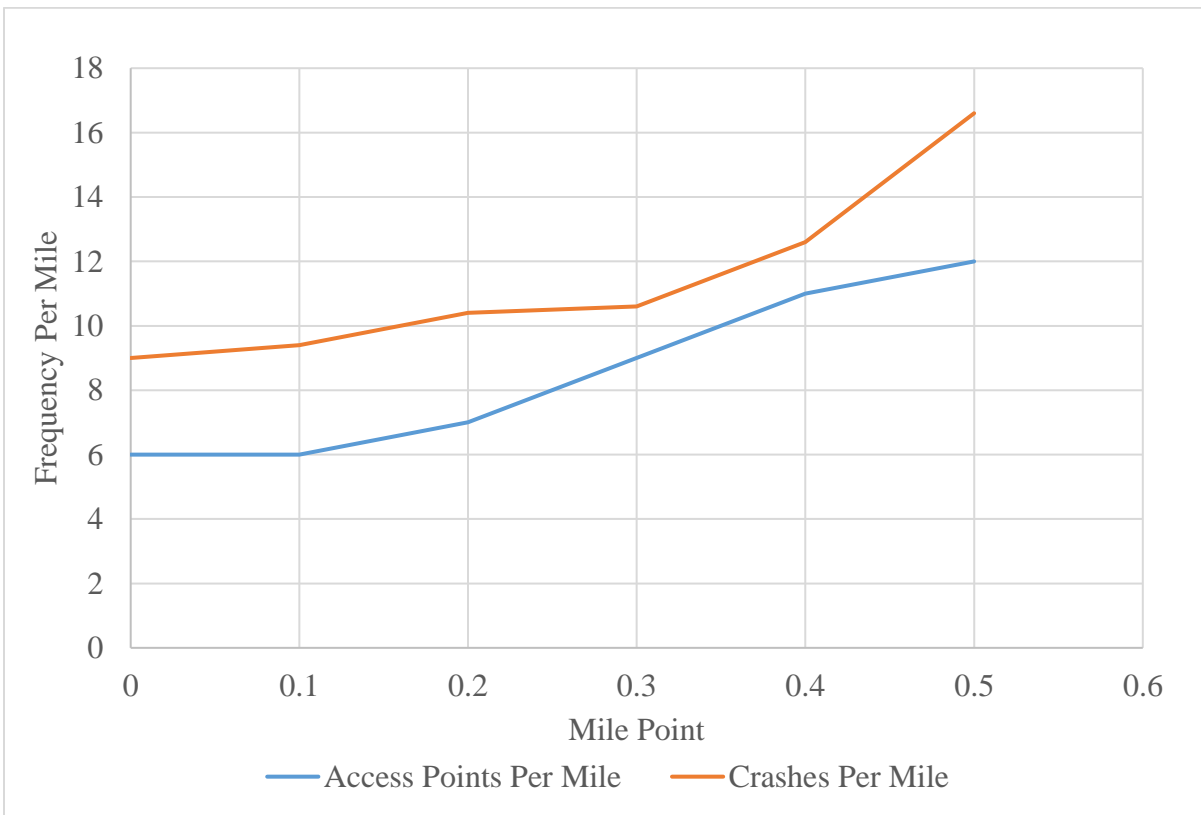


Figure A14: Des Moines-US 6 Hickman Road at Alice’s Road Intersection to 156th Street

- US 6 Hickman Alice’s Road Intersection, 280th St: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 4,220 and the length of the corridor is 0.99 miles. The corridor currently includes 16 driveways and 1 intersection.

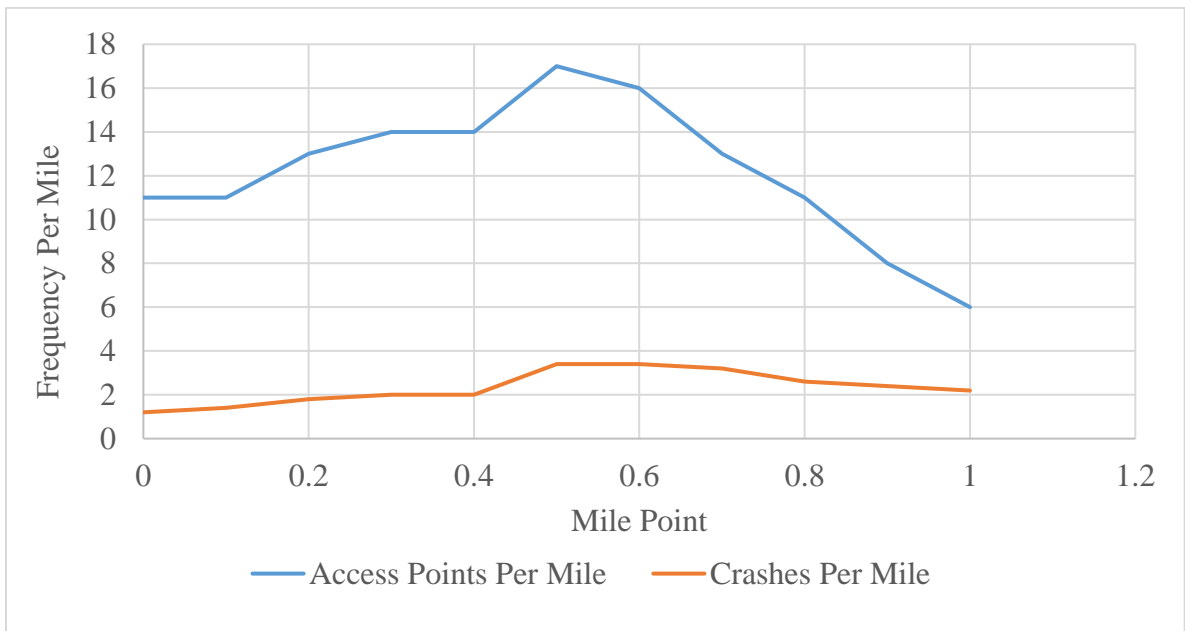
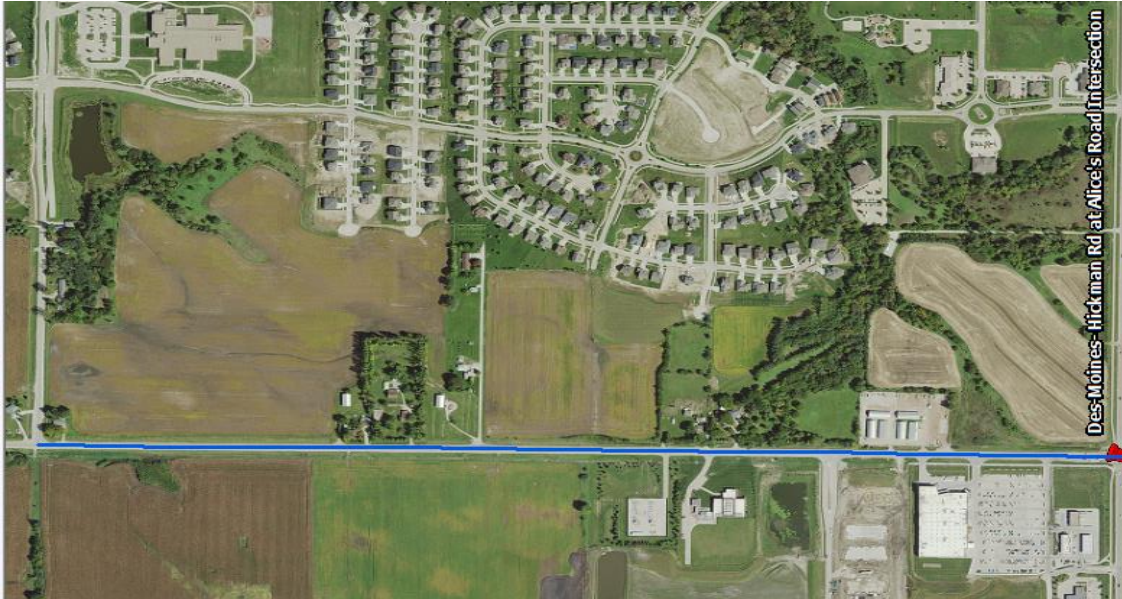


Figure A15: Des Moines- US 6 Hickman Road at Alice’s Road Intersection to 280th Street

- US 6 Hickman Alice’s Road Intersection, University Ave: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 6,775 and the length of the corridor is 1.01 miles. The corridor currently includes 10 driveways and 6 intersections.

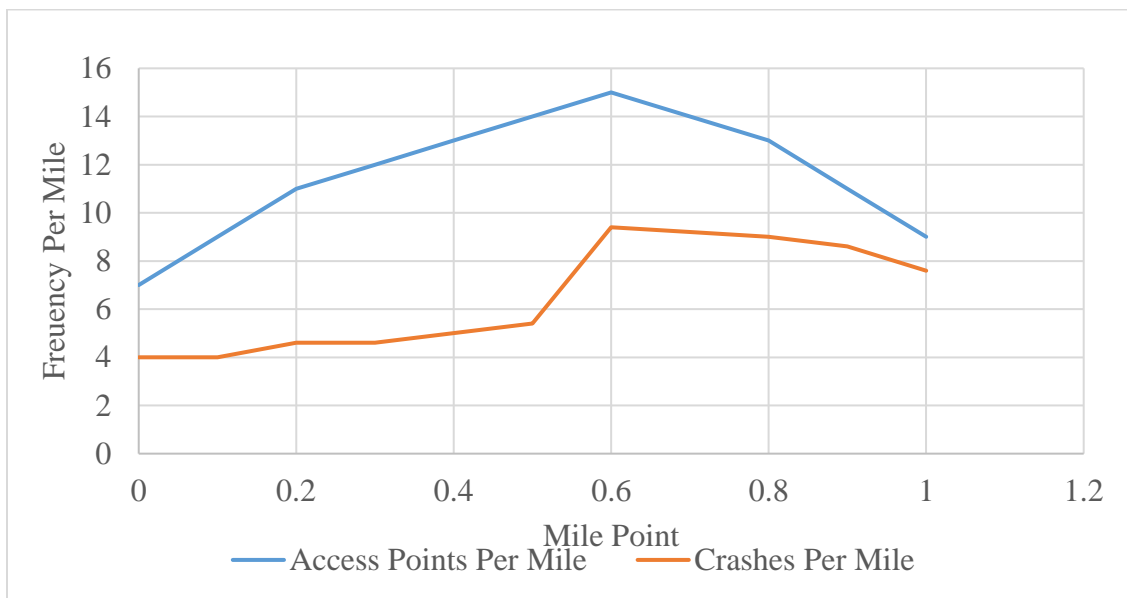


Figure A16: Des Moines- US 6 Hickman Road at Alice's Road Intersection to University Ave

- US 6 Hickman Alice’s Road Intersection, Warrior Lane: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 22,000 and the length of the corridor is 1.00 miles. The corridor currently includes three driveways and five intersections.

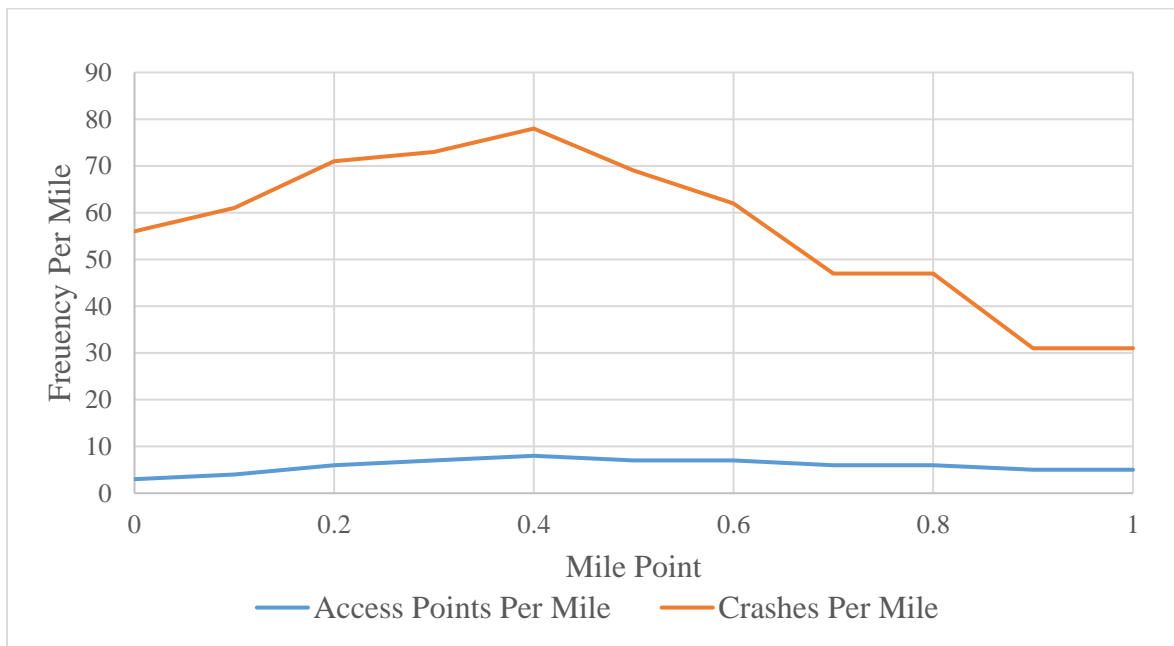


Figure A17: Des Moines- US 6 Hickman Road at Alice’s Road Intersection to Warrior Lane

- US 6 Euclid Ave West of 2nd Ave: Located in the city of Des Moines and Polk County, Iowa. The AADT along this corridor is 19,956 and the length of the corridor is 2.04 miles. The corridor currently includes 103 driveways and 14 intersections.

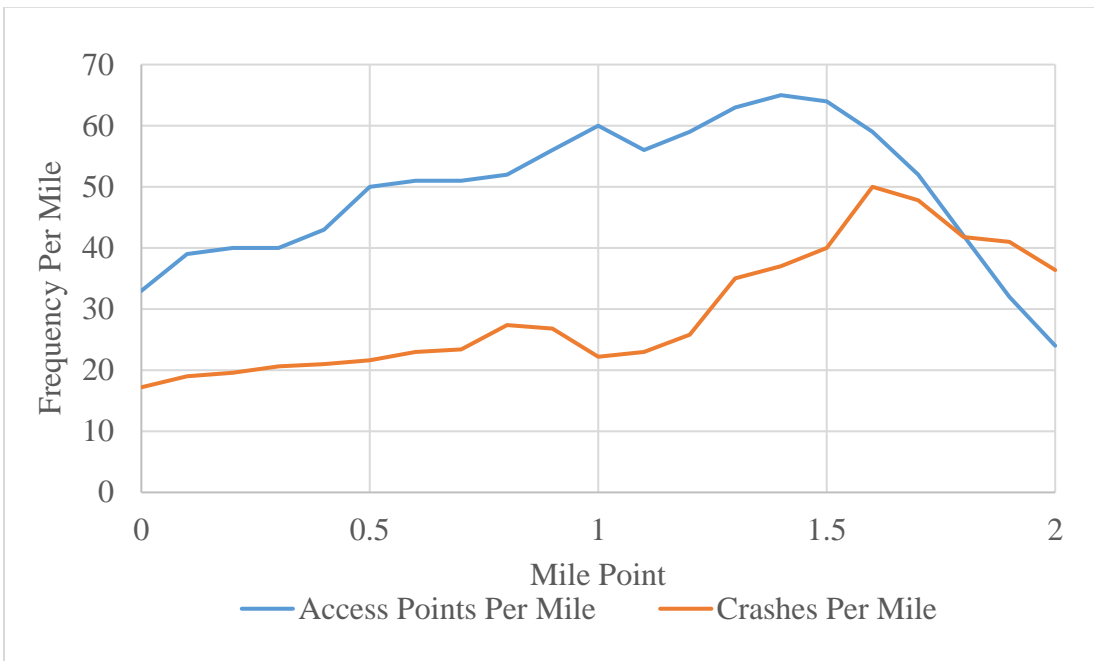


Figure A18: Des Moines US 6 Euclid Ave West of 2nd Ave

- US 6 20 East of 332nd Ave: Located in the city of Dyersville of Eastern Delaware and Western Dubuque county, Iowa. The AADT along this corridor is 8,854 and the length of the corridor is 2.39 miles. The corridor currently includes one driveway and four intersections.

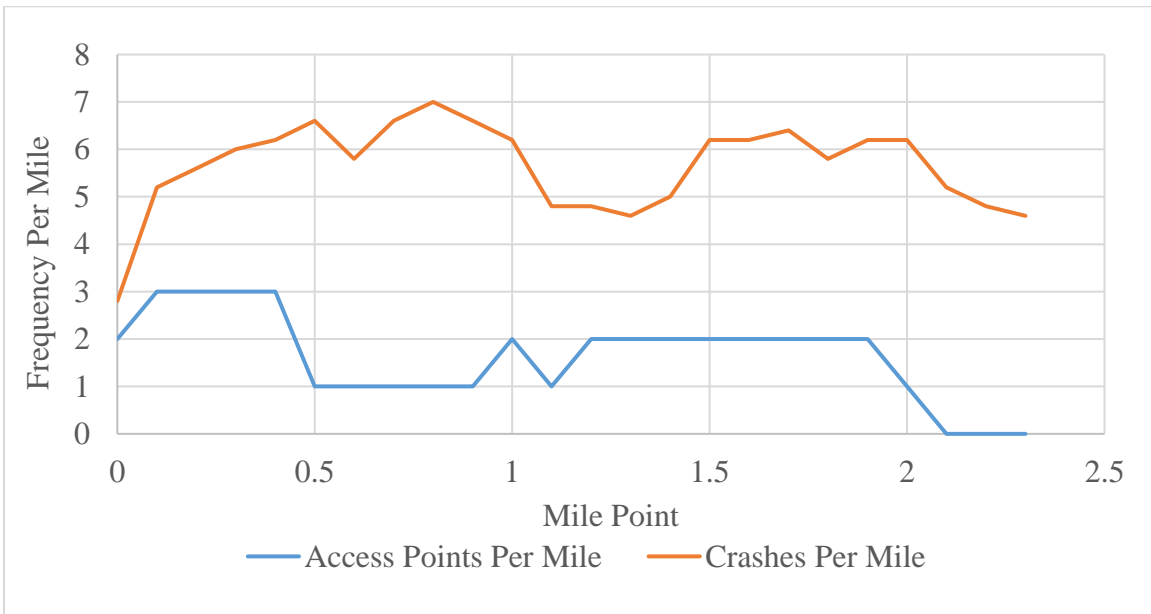


Figure A19: Dyersville- US 20 East of 33nd Ave

- US 20 Fremont Ave to Mississippi River: Located in the city of Dubuque and Dubuque County, Iowa. The AADT along this corridor is 30,715 and the length of the corridor is 1.76 miles. The corridor currently includes no driveways and five intersections.

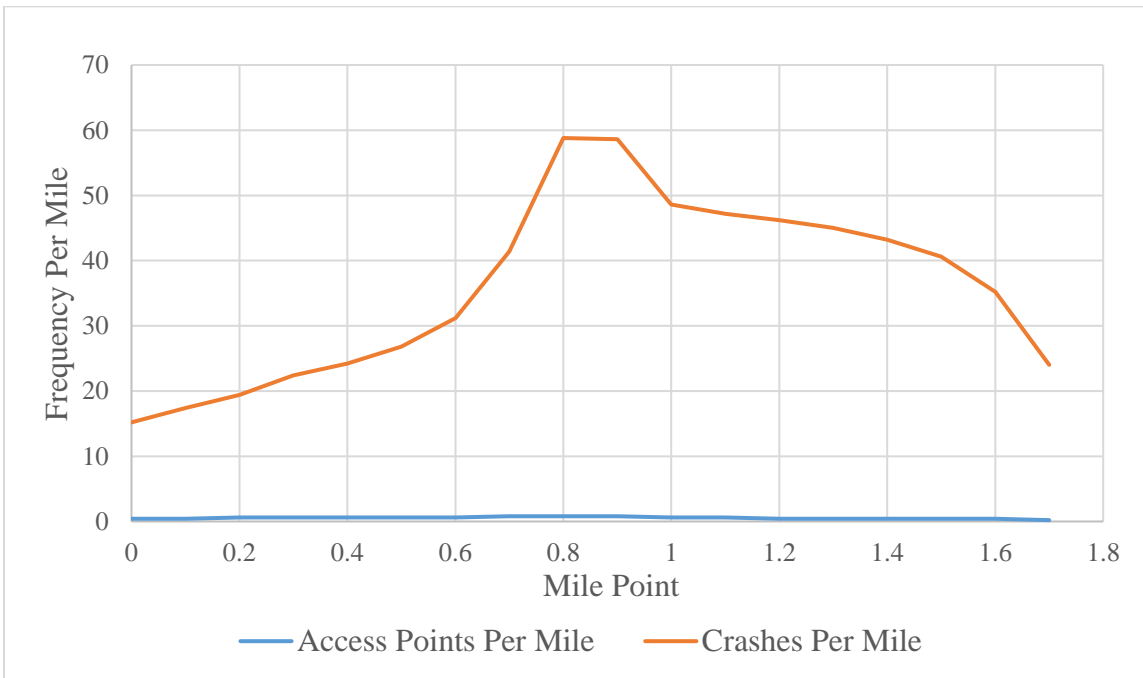


Figure A20: Dubuque- US 20 Fremont Ave to Mississippi River

- US 20 Menard Ct. to Fremont Ave: Located in the city of Dubuque and Dubuque County, Iowa. The AADT along this corridor is 31,538 and the length of the corridor is 2.26 miles. The corridor currently includes 8 driveways and 10 intersections.

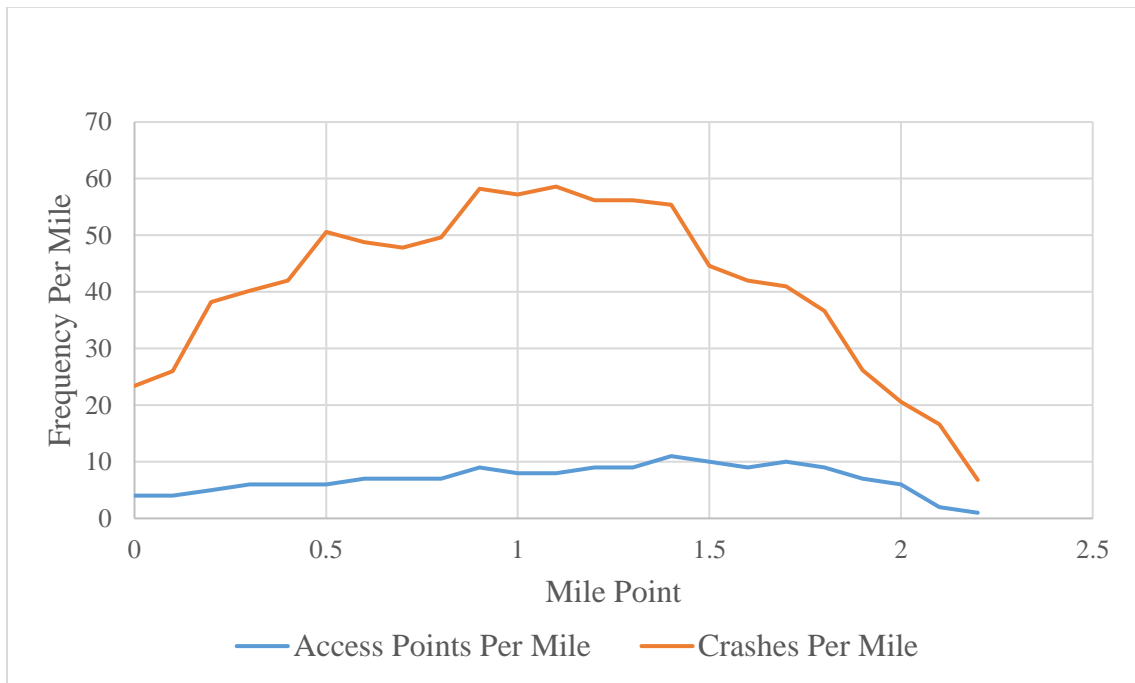


Figure A21: Dubuque- US 20 Menard Ct to Fremont Ave

- IA 141/IA 415 Interchange Area: Located in the city of Granger of Dallas and Polk County, Iowa. The AADT along this corridor is 16,018 and the length of the corridor is 3.15 miles. The corridor currently includes two driveways and four intersections.

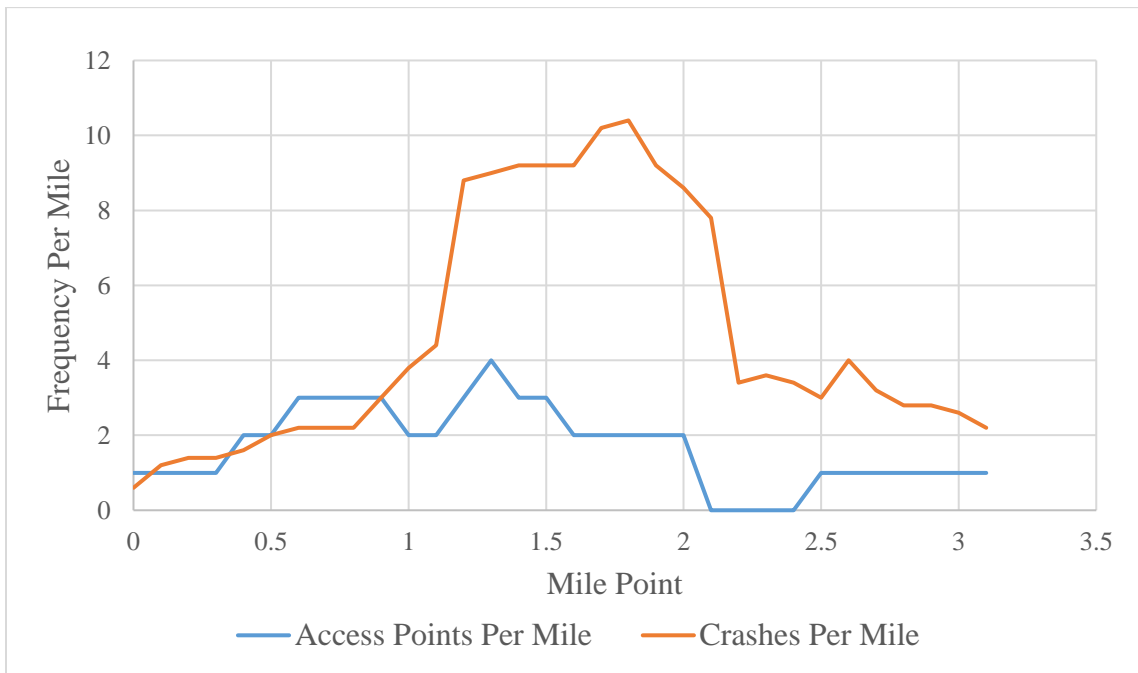


Figure A22: Granger-IA141/IA 415 Interchange Area

- IA 141 North of I-80/I-35: Located in the city of Grimes of Dallas and Polk County, Iowa. The AADT along this corridor is 30,245 and the length of the corridor is 2.44 miles. The corridor currently includes five driveways and six intersections.

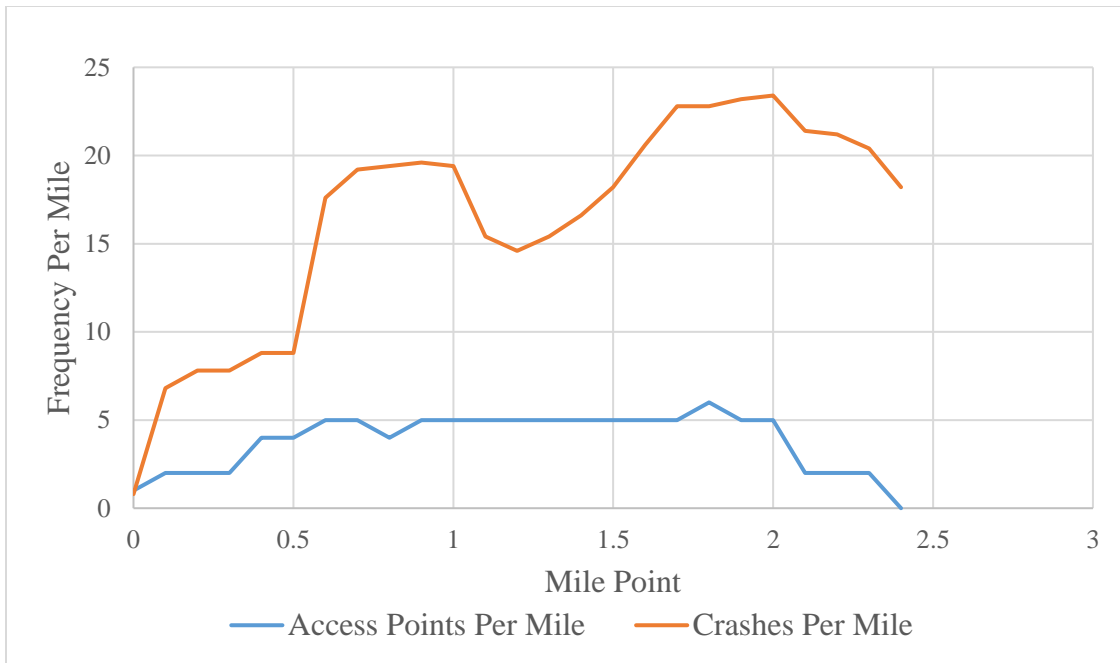


Figure A23: Grimes-IA 141 North of I-80/I-35

- IA 44 at IA 141 Interchange to 70th Ave: Located in the city of Grimes of Dallas and Polk County, Iowa. The AADT along this corridor is 5,545 and the length of the corridor is 1.96 miles. The corridor currently includes 16 driveways and 9 intersections.

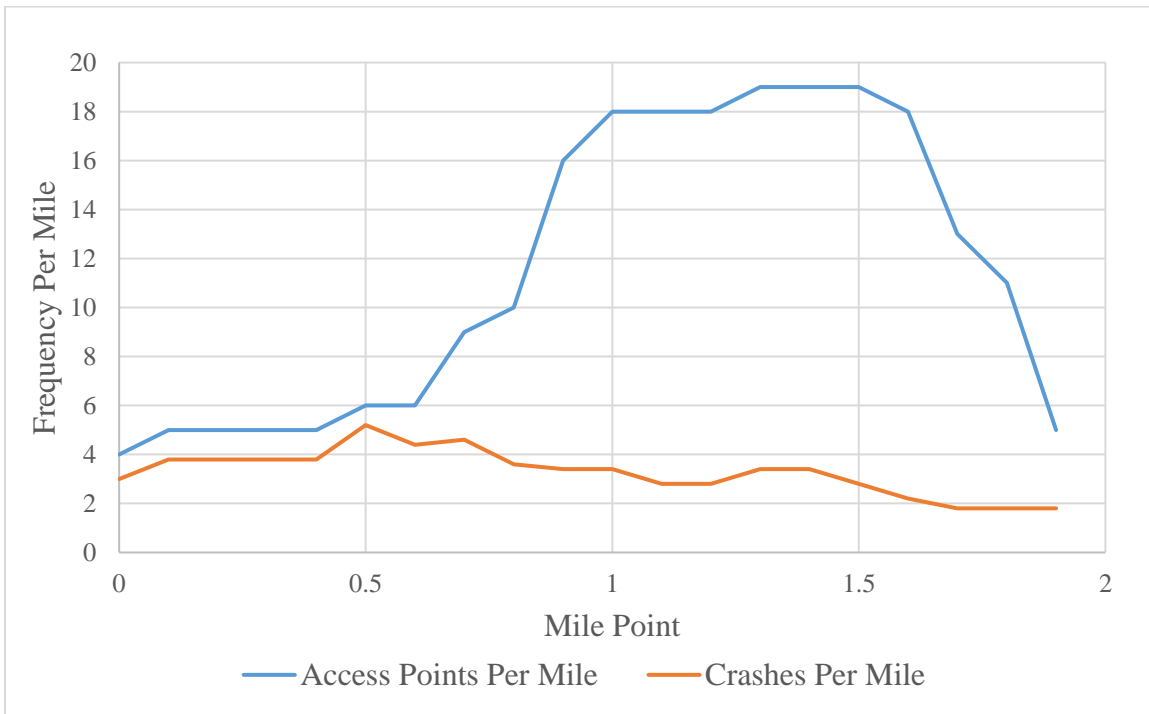
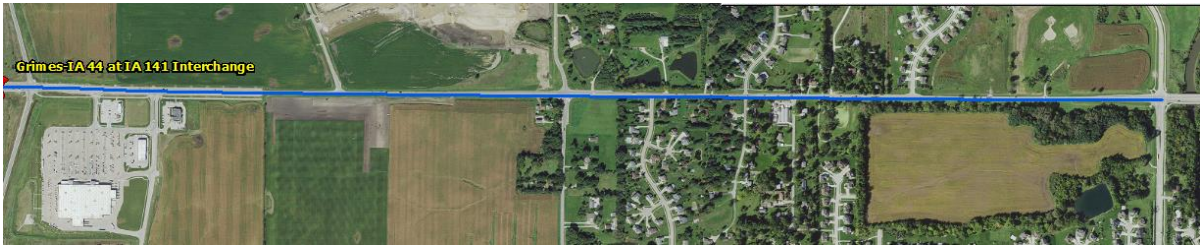


Figure A24: Grimes- IA 44 at IA 141 Interchange to 70th Ave

- IA 44 at IA 141 Interchange to Maplewood Dr.: Located in the city of Grimes of Dallas and Polk County, Iowa. The AADT along this corridor is 10,903 and the length of the corridor is 1.30 miles. The corridor currently includes 32 driveways and 13 intersections.

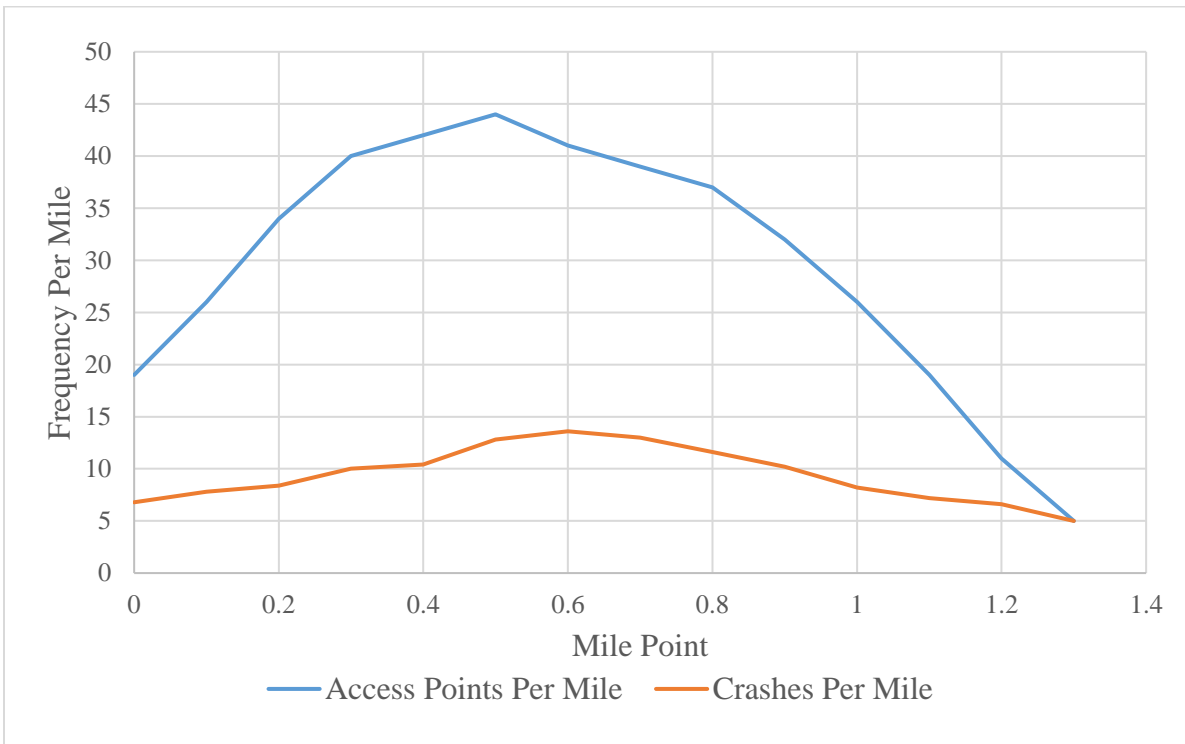
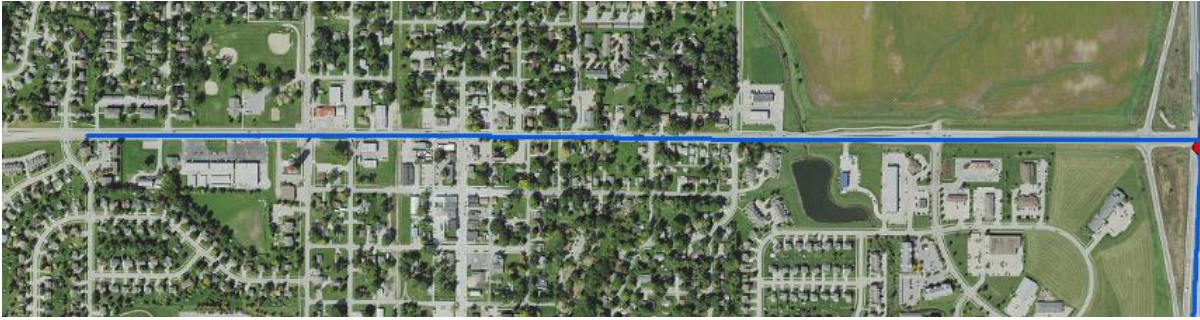


Figure A25: Grimes- IA 44 at IA 141 Interchange to Maplewood Dr.

- IA 44 at IA 141 Interchange to Towner Drive.: Located in the city of Grimes of Dallas and Polk County, Iowa. The AADT along this corridor is 19,029 and the length of the corridor is 2.54 miles. The corridor currently includes seven driveways and five intersections.

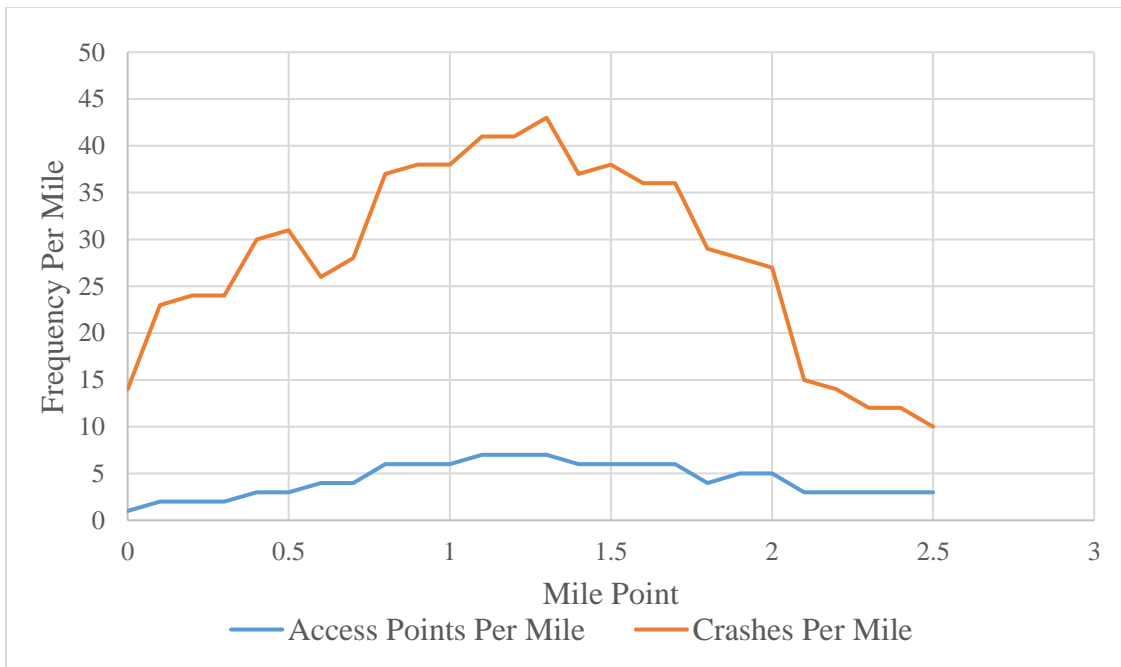
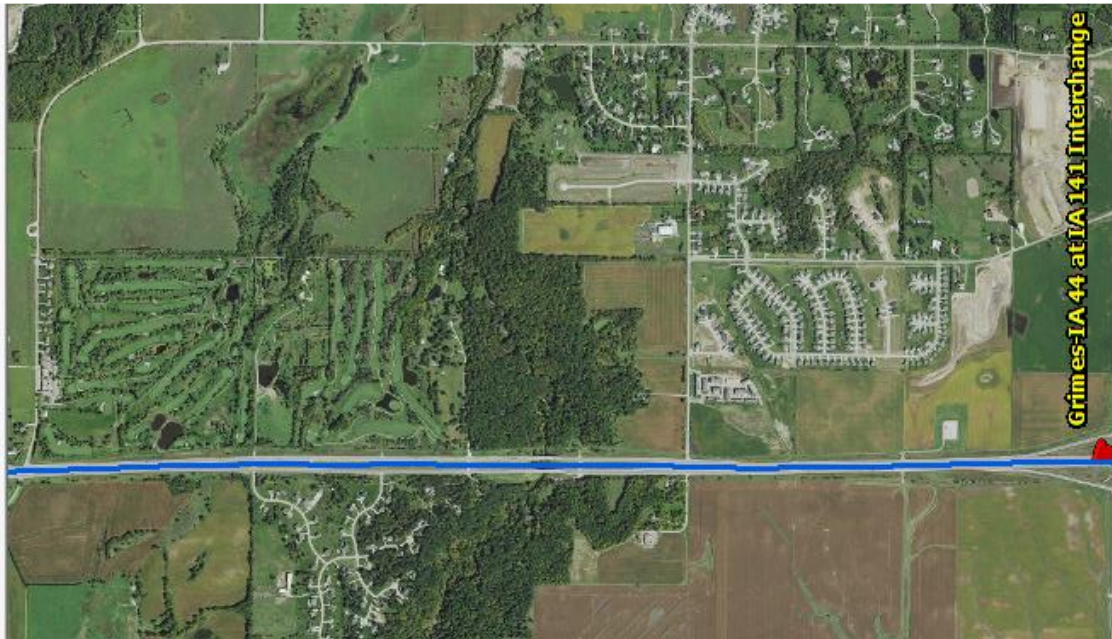


Figure A26: Grimes-IA 44 at IA 141 Interchange to Towner Dr.

- I-80/I-35 to 100th St.: Located in the city of Urbandale in Dallas and Polk County, Iowa. The AADT along this corridor is 31,153 and the length of the corridor is 1.08 miles. The corridor currently includes 4 driveways and 10 intersections.

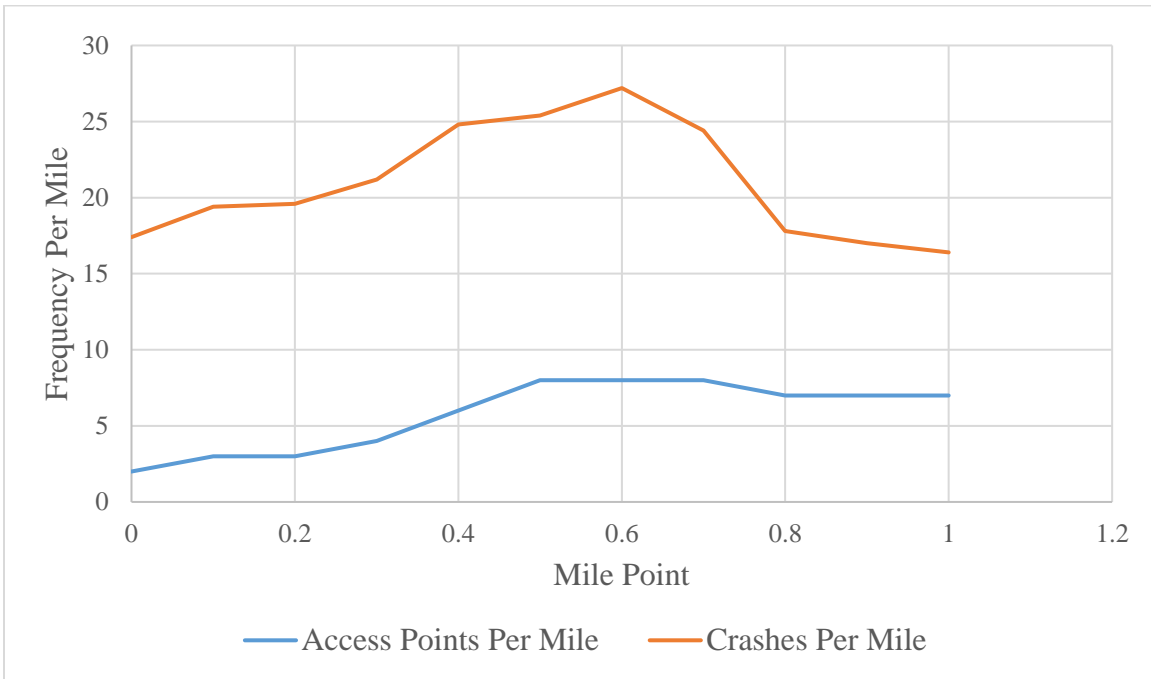


Figure A27: Urbandale-I 80/I 35 to 100th Street

- I-80/I-35 to 128th St.: Located in the city of Urbandale of Dallas and Polk County, Iowa. The AADT along this corridor is 34,399 and the length of the corridor is 0.77 miles. The corridor currently includes nine driveways and two intersections.

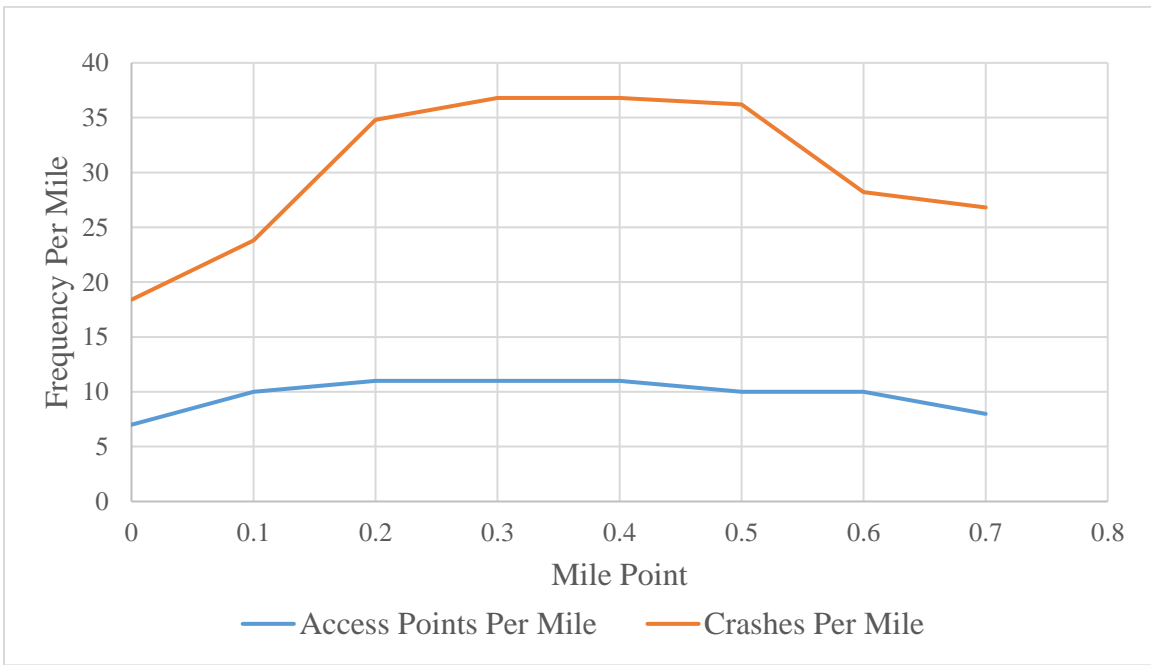


Figure A28: Urbandale- I 80/I 35 to 128th Street

- US 65/69 North of East Hillcrest Ave: Located in the city of Indianola and Warren County, Iowa. The AADT along this corridor is 19,600 and the length of the corridor is 1.01 miles. The corridor currently includes eight driveways and two intersections.

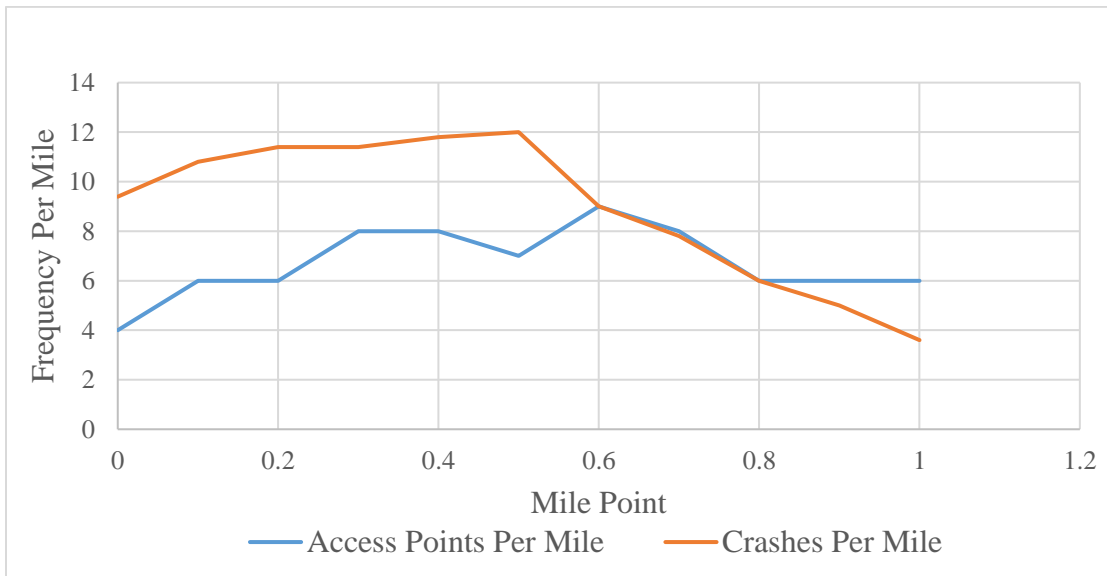


Figure A29: Indianola US 65/69 North of Hillcrest Ave

- IA 100 West of 1st Ave: Located in the city of Cedar Rapids and Linn County, Iowa. The AADT along this corridor is 25,189 and the length of the corridor is 2.71 miles. The corridor currently includes eight driveways and eight intersections.

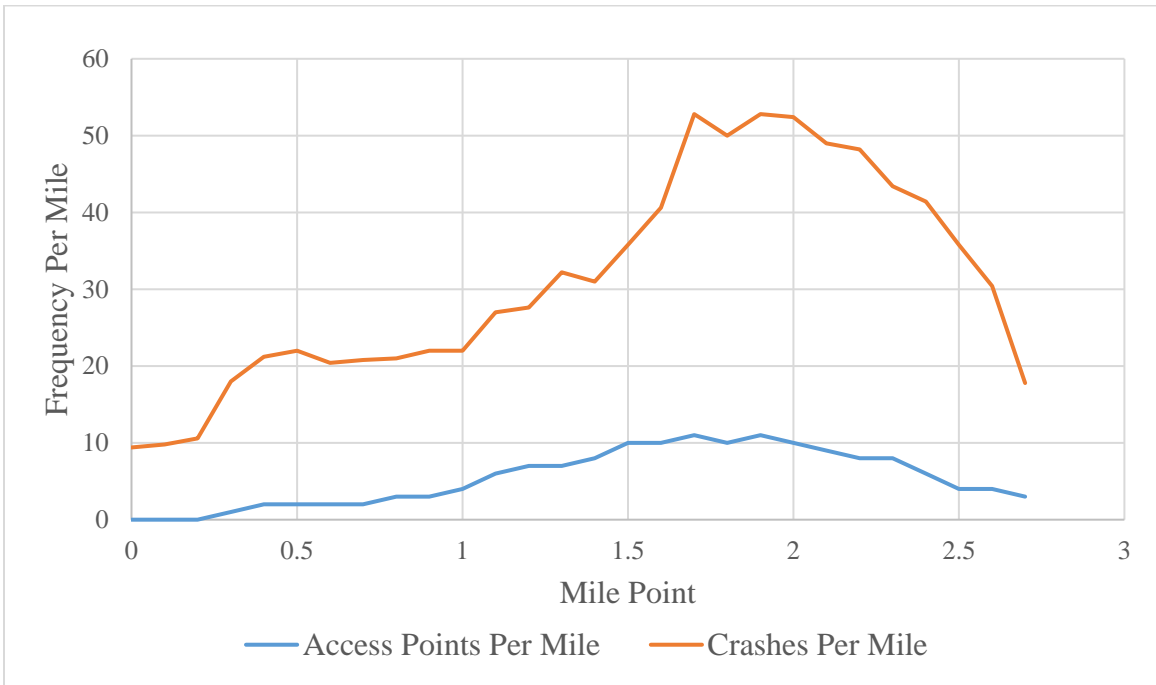
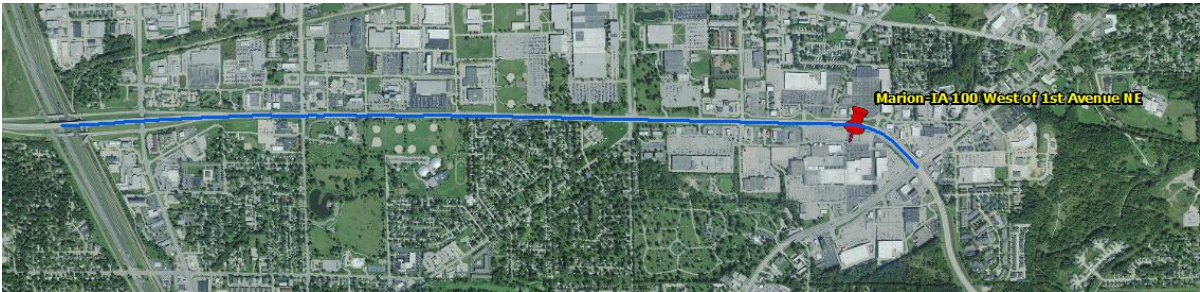


Figure A30: Marion- IA 100 West of 1st Ave

- IA 14 North of Linwood Ave: Located in the city of Marshalltown and Marshall County, Iowa. The AADT along this corridor is 6,402 and the length of the corridor is 1.26 miles. The corridor currently includes 19 driveways and 4 intersections.

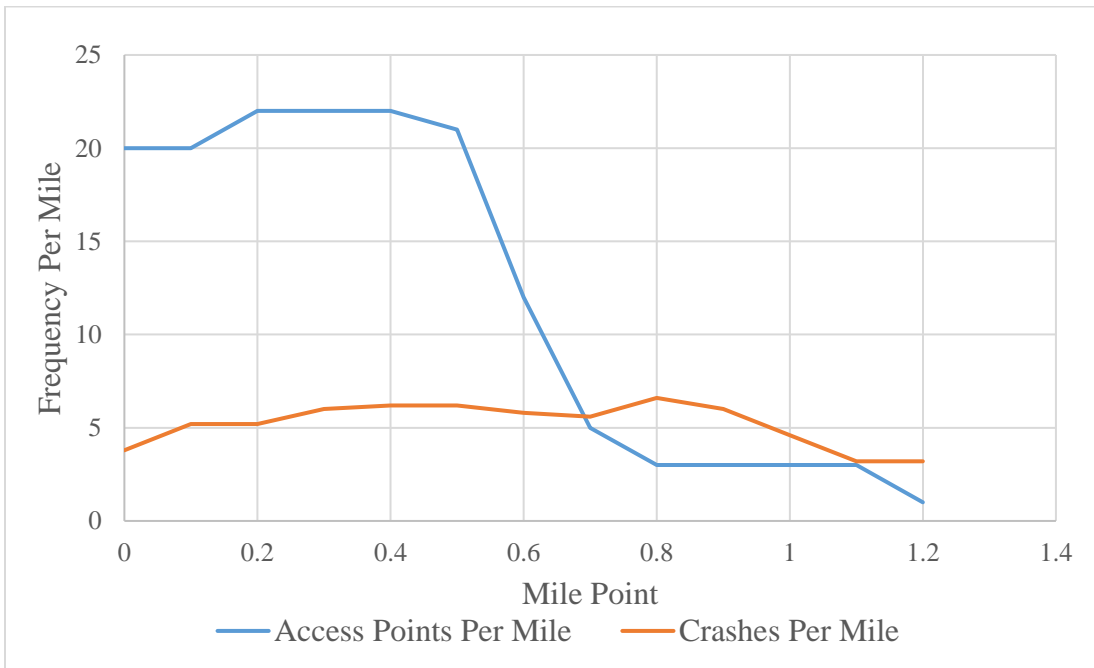


Figure A31: Marshalltown- IA 14 North of Linwood Ave

- US 30 Interchange: Located in the city of Marshalltown and Marshall County, Iowa. The AADT along this corridor is 6,402 and the length of the corridor is 1.26 miles. The corridor currently includes 36 driveways and 21 intersections.

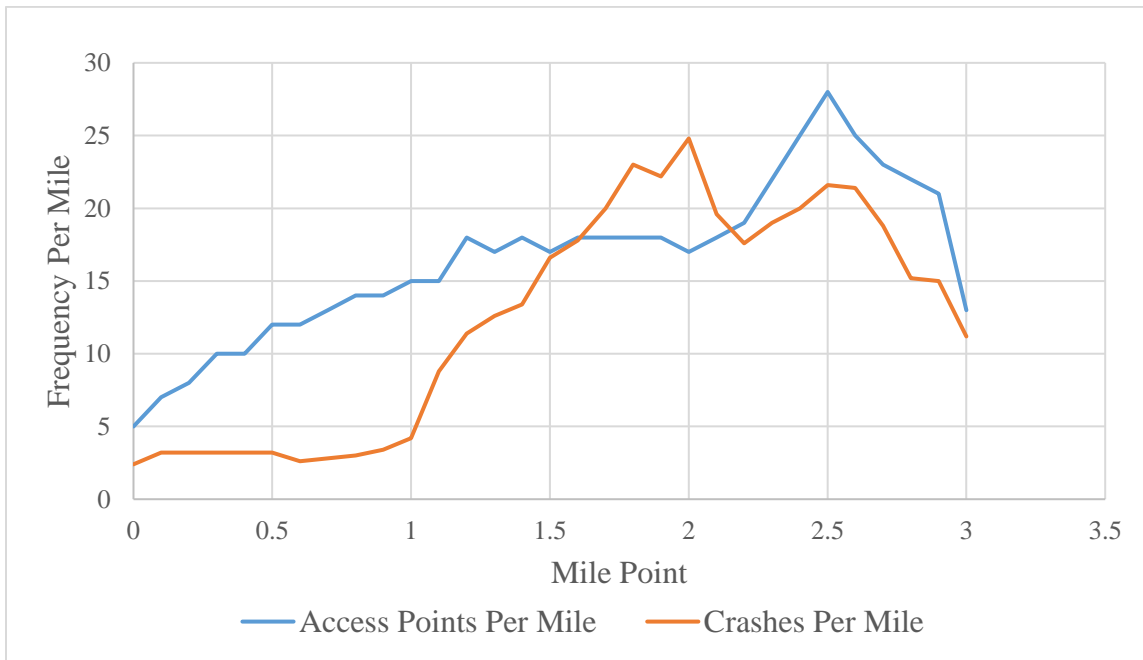
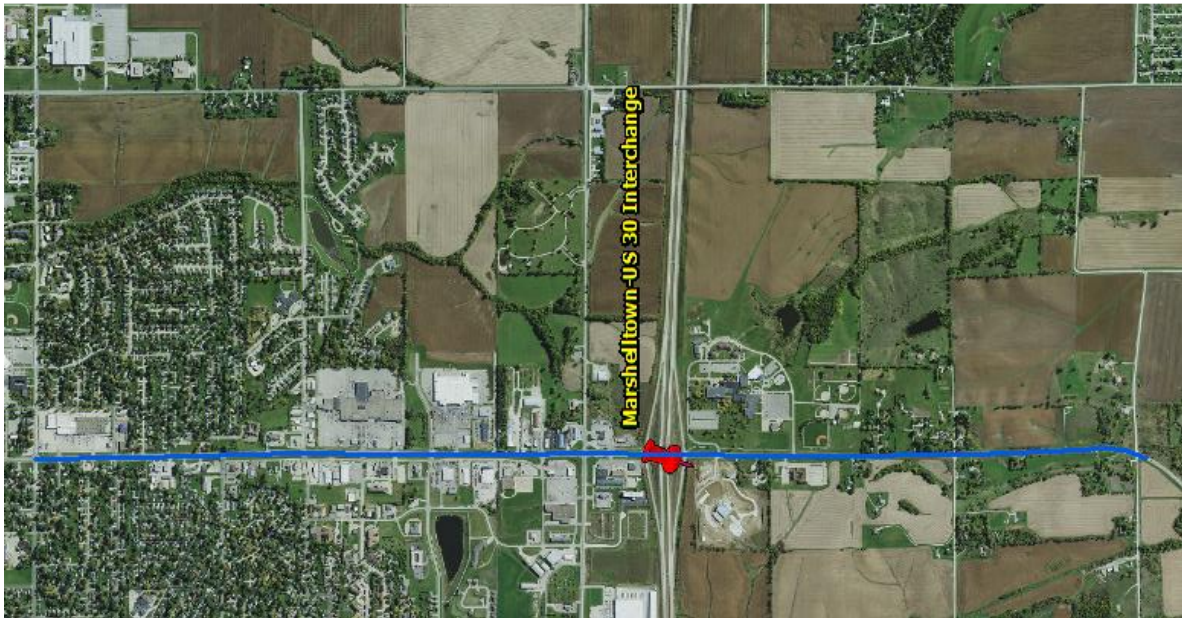


Figure A32: Marshalltown-US 30 Interchange

- IA 122 East of I-35 Interchange: Located in Mason City/Clear Lake and Cerro Gordo County, Iowa. The AADT along this corridor is 16,463 and the length of the corridor is 7.57 miles. The corridor currently includes 62 driveways and 34 intersections.

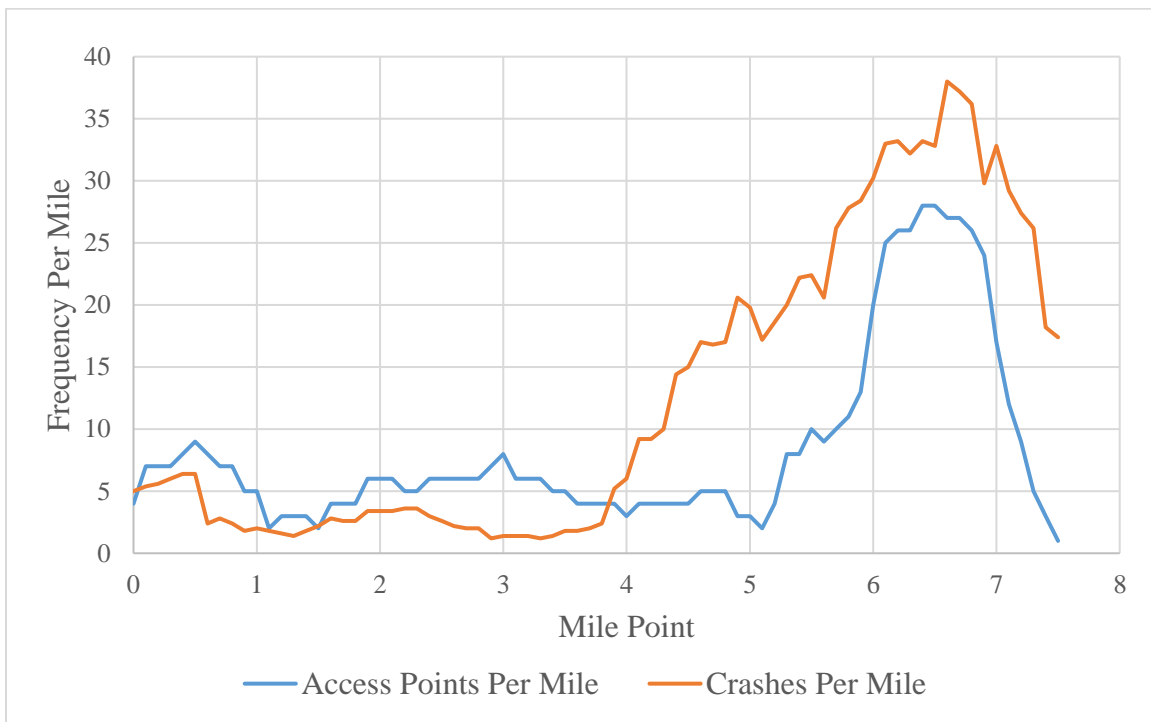


Figure A33: Mason City/Clear Lake- IA 122 East of I 35 Interchange

- IA 122 East Bound (EB)-Way: Located in Mason City/Clear Lake and Cerro Gordo County, Iowa. The AADT along this corridor is 7,098 and the length of the corridor is 0.85 miles. The corridor currently includes 39 driveways and 13 intersections.

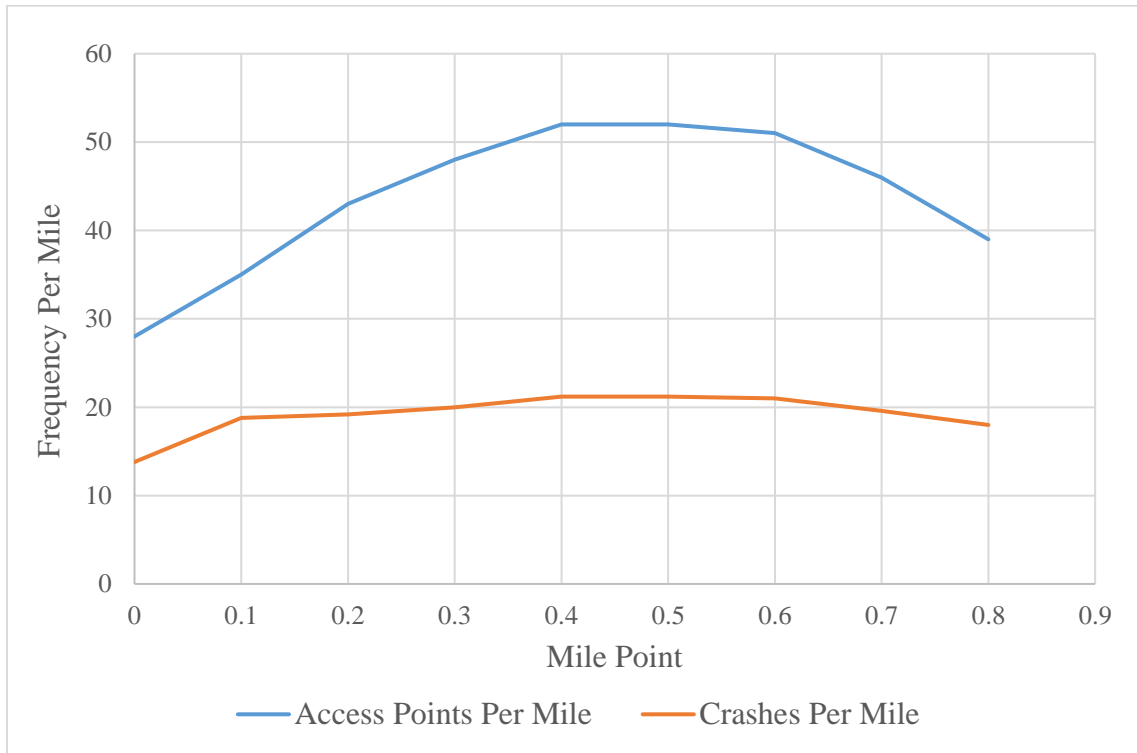


Figure A34: Mason City/Clear Lake- IA 122 Eastbound One-Way

- IA 122 West Bound (WB)-Way: Located in Mason City/Clear Lake and Cerro Gordo County, Iowa. The AADT along this corridor is 9,331 and the length of the corridor is 0.78 miles. The corridor currently includes 28 driveways and 12 intersections.

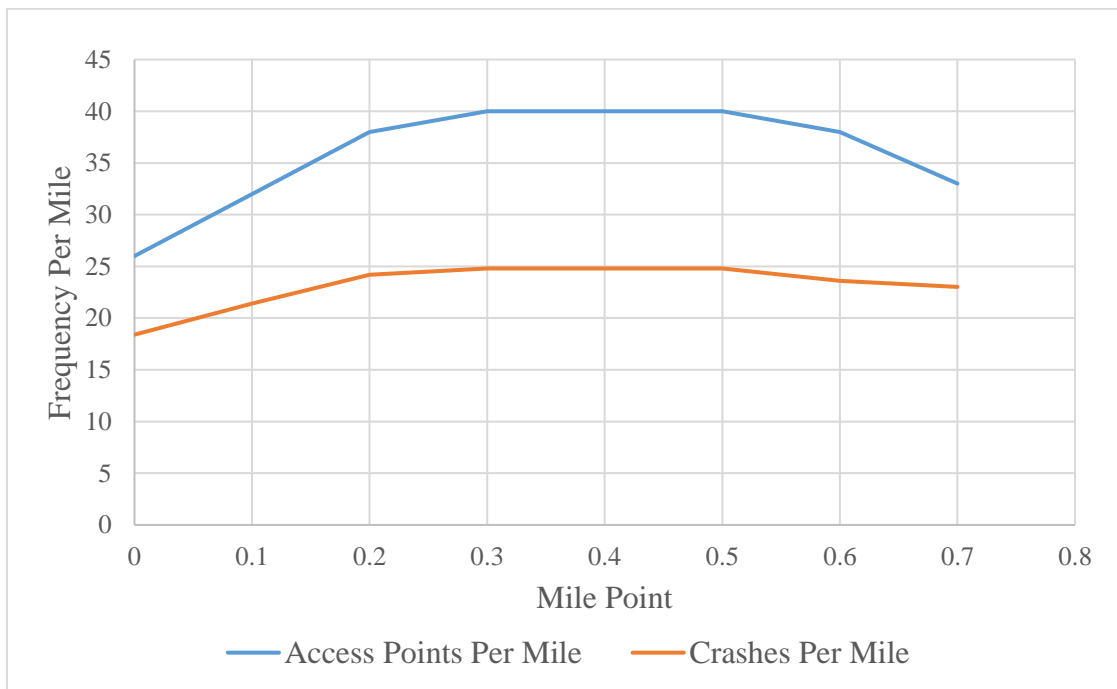


Figure A35: Mason City/ Clear Lake IA 122 Westbound One-Way

- IA 122 West 5 Interchange: Located in Mason City/Clear Lake and Cerro Gordo County, Iowa. The AADT along this corridor is 13,778 and the length of the corridor is 2.69 miles. The corridor currently includes 34 driveways and 16 intersections.

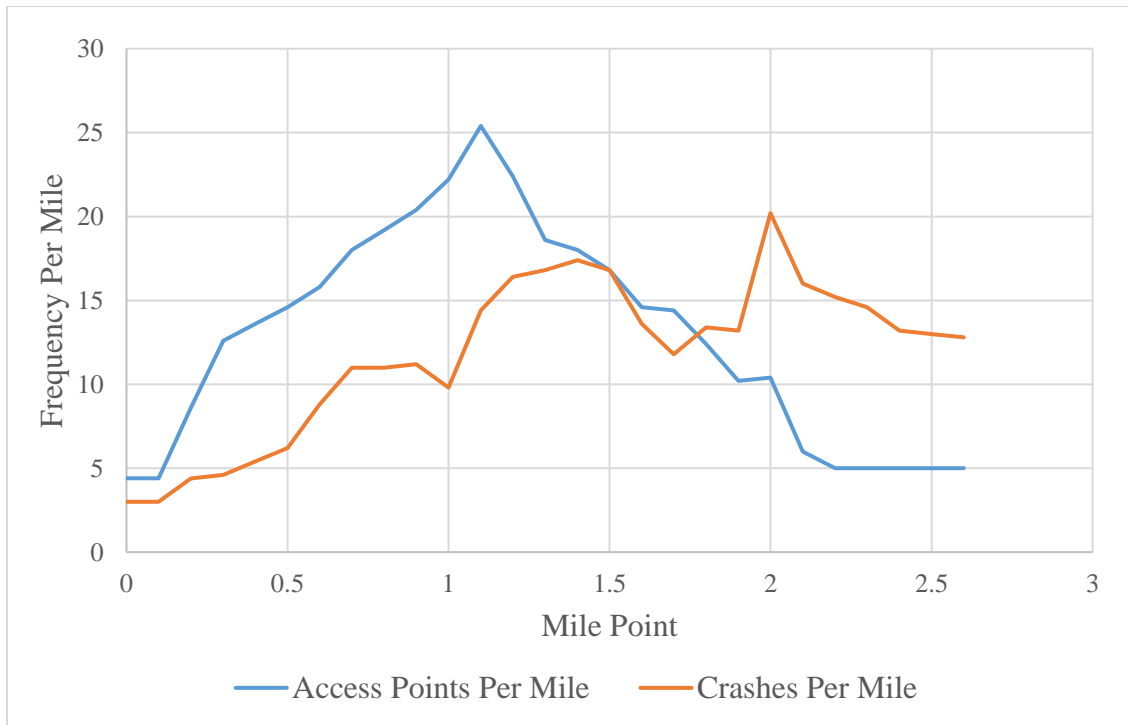


Figure A36: Mason City/Clear Lake- IA 122 West of I-35 Interchange

- IA 28 North of High Road: Located in the city of Norwalk and Warren County, Iowa. The AADT along this corridor is 15,780 and the length of the corridor is 1.97 miles. The corridor currently includes 3 driveways and 11 intersections.

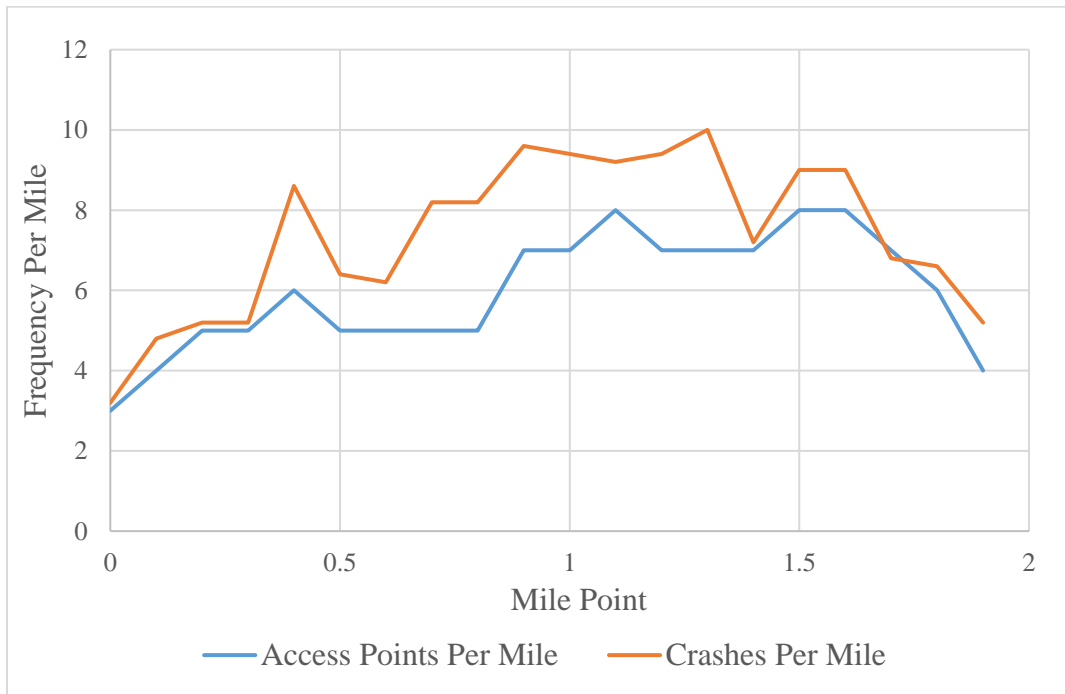


Figure A37: Norwalk- IA 28 North of High Road