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An examination of the safety of signalized intersections in consideration of nearby access points

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An examination of the safety of signalized intersections in consideration of nearby access points

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred

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DEDICATION

I dedicate this thesis to my parents who have never stop believing in me since the first time I came to this world. Without their endless support and prayers, I would not have been able to complete this thesis smoothly. I also dedicate this thesis to my sisters (Nusayba, Bushra, Al-Rumaisa', and Musfirah) and brother (Mus'ab) who are my biggest supporters in this journey and have always been there when I needed them.

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NOMENCLATURE

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AP	Access Points
DOT	Department of Transportation
FHWA	Federal Highway Administration
GIMS	Geographic Information Management System
GLM	Generalized Linear Model
HSM	Highway Safety Manual
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
PRT	Perception Reaction Time
QA/QC	Quality Assurance/Quality Control
SPF	Safety Performance Function
Std. Dev.	Standard Deviation
Std. Error	Standard Error

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ABSTRACT

Access management, or the management of vehicular access to adjacent land parcels, is critical to safe roadway operation, allowing state and local governments to control ingress and egress to freeways, arterials, collectors, and local roads. Access management is particularly important near signalized intersection, where nearby access points can increase the crash risks resulting from additional conflict points for vehicles traversing the primary intersection. The primary objective of this study was to examine the relationship between access point density and the frequency of crashes at signalized intersections located along state-maintained urban roadways in the state of Iowa. Information regarding adjacent access points (i.e., intersections and driveways) was collected at a total of 415 signalized intersections from 13 different municipalities. The information collected included the type of access (driveway, unsignalized intersection, alley, median opening, or field access), as well as any restrictions related to turning movements (e.g., prohibited left-turns, right-in/right-out). Access volumes were collected for public roadways and driveway volumes were estimated using trip generation models. Two subsets of crashes, total and driveway-related, were used to examine the safety-access relationship over a five-year analysis period. A series of concentric buffers were applied to investigate how the relationship between crashes and the number of access points varies spatially depending upon the buffer radius. These buffers varied from 50 ft. to 600 ft. in radius with increment of 50 ft. A series of crash prediction models were estimated to discern the impact of access spacing while controlling for other pertinent variables such as traffic volumes and roadway geometry. The results showed that the number of crashes increased consistently as the frequency of access points increased,

regardless of the size of the buffer radius. However, the rate of increase in crashes tended to decrease as the buffer radius increased. The findings from this study can be used to establish thresholds for the minimum distance that an access point should be located from an adjacent signalized intersection.

CHAPTER 1. INTRODUCTION

1.1 Background

Intersections are critical to transportation network operation and poorly designed intersections tend to introduce adverse impacts on both traffic safety and mobility. According to the Federal Highway Administration (FHWA), more than 50% of fatal and injury crashes between 2010 and 2014 occurred in the vicinity of intersections (USDOT, 2017). This has motivated substantive research to better understand how intersection design decisions influence both delay and the potential for traffic crashes. Recent research has spurred the development of novel intersection designs, including the modern roundabout, continuous flow intersections, and J-turn intersections. While several such designs have been shown to improve safety and operations as compared to conventional intersections. However, as these designs comprise a very small portion of all intersections across the U.S., there remains a strong need for additional research into various aspects of conventional intersection design.

According to Williams et al. (2014), access management can be defined as “the coordinated planning, regulation, and design of access between roadways and land development”. It consists of various methods (i.e., spacing between access points, median treatment, etc.) that can reduce the number of conflicts on the roadway network to increase the safe movement of people and goods. Throughout the years, there has been a significant amount of study conducted on access management, including traffic safety, traffic operations, and economic point of view. In terms of traffic safety, numerous studies have pointed out the relation between access management and the number of crashes related to the road network. Studies have shown that crash rate increase when number of access points or access point density increases (Dart & Mann 1970, Drummond, et al. 2002, Avelar, et al. 2013). Most of the crashes occurring at or near access point are usually associated with conflicts between two or more vehicles. The conflicts occurring between vehicles at this location are often due to a vehicle trying to make a left or right turn into the major road, or from vehicles attempting to enter the access point from the major road. Typically, location at or near to access point is exposed to two types of crashes; right-angle and rear-end crashes. These conflicts usually occur along the midblock portion of road segments; however, they are more likely to occur near intersections, more so when multiple access points are located near each other. Presence of access points within the vicinity of intersections will not provide enough clearance for vehicles to make a maneuver into or out of access points without potentially causing conflicts with vehicles attempting to go through the intersection. Most of the studies conducted on the safety performance of roadway related to access point density were based on segment-level. However, only few of them focused on intersection-level in consideration of nearby access points.

Previous studies on the safety performance of intersection with nearby access points used different variety of methods, geographical locations, sample size, type of intersection, and type of land development. These differences however produce the same result in general where less number of crashes will be observed if the access points are located further from the intersections. The majority of these studies used count models when estimating the number of crashes (Vogt & Bared, 1998, Oh, et al, 2004, Xu, et al. 2011, Xu, et al. 2014) whilst Shultz, et al. (2010), used multiple linear regression to predict the crash. There were two types of approaches shown from these studies when analyzing the effect of access points on crashes near intersections: (1) they used a specific distance from the center of intersection and analyzed effect of all crashes on access points within the distance (Vogt & Bared, 1998, Oh, et al 2004, Schultz, et al, 2010), (2) they used the distance between the first access point to the intersection (i.e., corner clearance) and analyzed the number of crashes (Xu, et al. 2011, Xu, et al. 2014, Le, et al. 2018). The two types of intersection controls being analyzed from the previous studies were signalized intersection and stop-controlled intersection. Ultimately, the findings from the previous studies showed that length of corner clearance is inversely proportional to the number of crashes and every additional access point within the study distance will result in increasing number of crashes.

The guideline on access management varies across the states particularly on minimum distance required for the first access point from the intersection. This distance usually differs in value within a state depending on the type of development adjacent to the intersection. Rural areas are usually associated with shorter allowable distance when compared to urban areas. Some states used multiple attributes (e.g. sight distance, various mode of distances travel, etc.) in order to determine the minimum distance to be established for a specific intersection. Others used only one distance for all types of intersections with different characteristics. The allowable distance of first access point from intersection varies from 50 ft. to 800 ft. for the average speed of 40 mile per hour. Essentially, no access points should be allowed within the functional area of the intersection (American Association of State Highway and Transportation Officials, 2001).

Further research on the safety impact of access points near intersections is required to help establish or improve guidelines for better access management strategies. The objectives of this study will be discussed in detail in the following section.

1.2 Research Objective

The primary objective of this study was to examine the relationship between access point density and crashes at urban signalized intersection approaches on the primary (i.e., state-maintained) roadway network in the state of Iowa. A total of 415 signalized intersections were considered from 13 different municipalities across Iowa. These intersections were purposely selected from urbanized area due to the prevalence of access points near intersections. A series of concentric buffers were used to investigate how the relationship between crashes and number of access points varies spatially depending upon the buffer radius. These buffers vary from 50 ft. to 600 ft. in radius with increment of 50 ft.

All access points along the primary roadway network were disaggregated into five types of accesses, including: various types of driveways, unsignalized intersections, alleys, median openings, and field access points. Some these access points were broken down into further categories. Driveway traffic volumes were estimated based on the type of access they provide in order to analyze the effect of access point traffic volumes (i.e., associated with type of development) on crashes. Moreover, allowable turning movements from and into the access points were collected in order to examine the safety effect of these access points in terms of the allowable turning movements.

Two subsets of crashes were analyzed in this study in order to distinguish how crashes vary based upon these datasets. The types of roadway junctions obtained from the police-reported crashes were used to differentiate two types of crashes; driveway-related crashes and total crashes.

Other than access point frequency and the characteristics of it, there are many other factors that can influence crashes since crash data are few and far in between. Information regarding other roadway characteristics was considered, including the traffic volumes for both major and minor approach, number of lanes, posted speed limit, presence of left-turn lane, and other variables. Ultimately, using all the listed information, series of safety performance functions were estimated to comprehend the relationship between crashes and nearby access points of signalized intersection while controlling other roadway characteristics.

1.3 Thesis Structure

This thesis consists of six main chapters, which include the background of the research problem of interest, presentation of the literature on prior studies related to this area, description of the data and the method used to carry out the data analyses, discussion on key findings from the results with respect to the objective of this study, and presentation on final conclusions and recommendations. Brief descriptions of each chapter are as follows:

- Chapter 1: Introduction – This chapter contains the background on general information related to the safety and operation of intersection in consideration of nearby access points, as well a brief outline on the current guidelines from various states. The following section in this chapter is presenting the detail information on the objectives of this study
- Chapter 2: Literature Review – This chapter is organized into four parts to summarize the extant literature review regarding the safety and operation of intersection with the adjacent access points. This chapter begin with the overview of access management, including the general benefits of having good access management in terms of safety, operation, and economic. The second section describes the intersection configuration. This is followed by a detail review of prior studies related to the access points near intersection. Last is a section that outlines the current guidelines on the minimum distance of access point from intersection that should be used

- Chapter 3: Data Description – This chapter provides brief information on types of data utilized in this study, including databases from Iowa Department of Transportation (Iowa DOT) and manually collected data. The next section is the summary of data integration process before obtaining the final data set. The chapter concludes with the summary statistics of all variables that were tested in this study, including the crash data and the roadway characteristics
- Chapter 4: Methodology – This chapter describes the statistical method used in this study, including the general formulations of the statistical method, as well as the justifications of why this method was utilized in this study.
- Chapter 5: Results and Discussion – This chapter consists of results based on the statistical regression model developed from different dependent variables, from type of crashes to different buffer radii. These results are supported by a brief discussion on the practical implications of the findings, as well as the justifications of the results obtained.
- Chapter 6: Conclusion – This chapter provides the conclusions of this research study and a concise summary of key findings. This chapter also discusses on how these findings can be utilized in the real-world problems, as well as recommendations for future research.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview of Access Management

Access management is one of the keys to a safe road. It is a process that both state and local governments use to control the access to freeways, arterials, collector roads, local roads and other roadways. This process can be achieved by applying several techniques or designs to the road segments such as applying adequate spacing between driveways, treatment of medians, providing turning lanes for both left- and right-turns, and right-of-way management which refer to the reservation for future construction such as location of new access points, and additional lanes. Good access management design can have positive impacts on traffic safety and operations. These include reducing number of crashes and increasing the capacity of these roads thereby reducing traffic delay (U.S. Department of Transportation Federal Highway Administration, 2017). The lack of proper access management such as high density of access points will not only impede on traffic flow by creating unnecessary congestion, but it will also increase the chance of possible conflicts between vehicular and non-vehicular traffic.

Studies related to access management were shown to have positive impacts on highway safety including the ability to maintain the traffic flow and travel speed without having an impact on the businesses outcome of the abutting land (Plazak, et al. 2005). Plazak et al (2005) also stated that, well-managed arterial roadways in urban area were 40 to 50 percent safer than poorly managed urban arterials on a per-vehicle-mile basis. On the operation side of the roadways, the mean travel speed as well as traffic service levels are significantly greater on well-managed urban streets (Plazak, et al. 2005). On the economic level, studies have found that the impact on business sales, business turnover, new business development, or customer satisfaction on well-managed roadways is little or no impact at all (Maze & Plazak 1997, Riffkin, et al. 2015, Benz, et al. 2015, Shiri, et al. 2018).

Most states have their own guidance on managing their roadways. These manuals and guidelines consist of several aspects including planning, regulation, and design of access between roadways and land development (Williams, et al. 2014). They encompass a wide range of methods to ensure efficiency and safety of the roadway system. One of the methods that required attention to is the roadway functional hierarchy (U.S. Department of Transpiration Federal Highway Administration, 2017). Roadways are ranked by their functionality based on the priority given access to abutting lands or through movement as shown in Figure 1. Freeway, expressway and other primary roads require high levels of access control in considering the safety and efficiency of the roadway over longer distances at the appropriate speed limit (i.e., high speed roadway system). In contrast, local streets, cul-de-sac and other minor road provide direct access to abutting properties (Williams, et al. 2014).

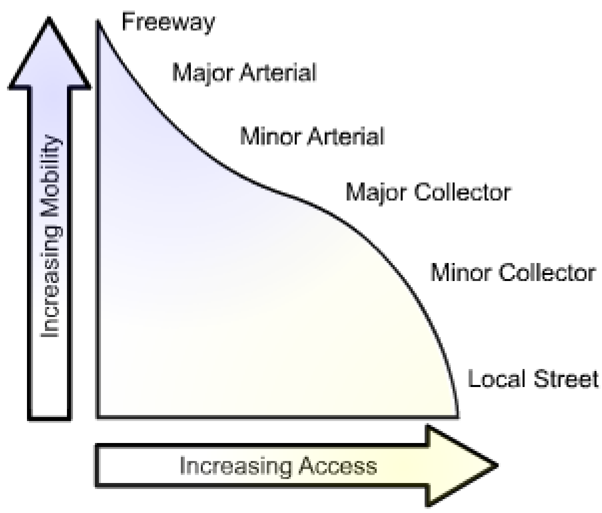


Figure 1: Conceptual roadway functional hierarchy (U.S. Department of Transportation Federal Highway Administration, 2017)

As mentioned before, good access management will result in positive impact on both safety and operation of the roadway. Williams et al. (2014) mentioned that well-managed access points can reduce crashes by 50 percent, increase capacity by 23 percent to 40 percent, and it can reduce travel time and delay by 40 percent to 60 percent. The consequences of failure to manage the access points are; increase the number of crashes involving vehicles and vulnerable road users, increase travel time and delay for both private and public transportation, increase fuel consumption due to congestion resulting in higher vehicular emissions, and increase the possibility of having to reconstruct the roadway. That is why access management is no longer an option but is a requirement to the transportation network (William, et al. 2014).

2.2 Intersection Configuration

Designing intersections within urban areas can be complex and unique. The process of designing intersections can be affected by many conflicts that can happen within and near the intersection. As a result, several aspects must be considered within the vicinity of intersection such as geometrics designs (i.e., presence of raised median, turn lanes, etc.), operational impacts, human factors (i.e., perception-reaction time, etc.), presence of pedestrian and bicyclist, and types of land developments adjacent to the intersection (William, et al. 2014).

Conflicts within the vicinity of intersection can be managed by determining the functional area of the intersection. The functional areas of intersection can be divided by two areas, upstream and downstream of an intersection as shown in Figure 2. The upstream functional area varies based on three variables which are: (1) distance travelled during perception-reaction time, (2) distance travelled during deceleration to a complete stop, and (3) the length of queue storage and the intersection (William, et al. 2014). While for downstream functional area, William, et al. (2014) stated that this area can be calculated using the sight distance of drivers to see and avoid conflicts or distance of acceleration (i.e., vehicles required sufficient distance to accelerate from a stopping position to match with the normal roadway speed).

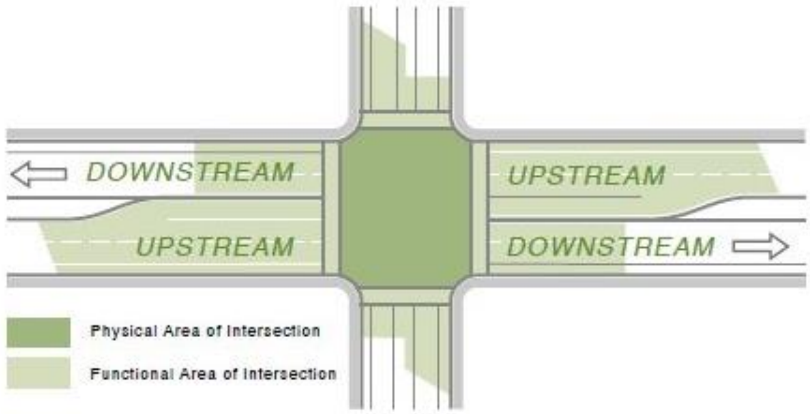
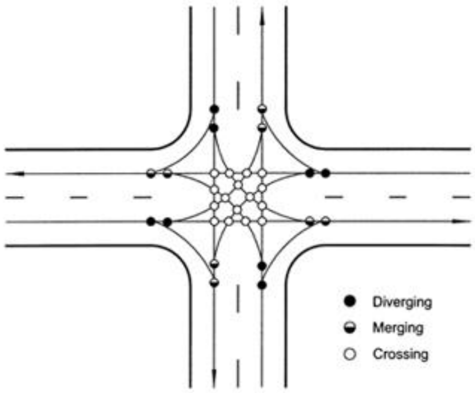
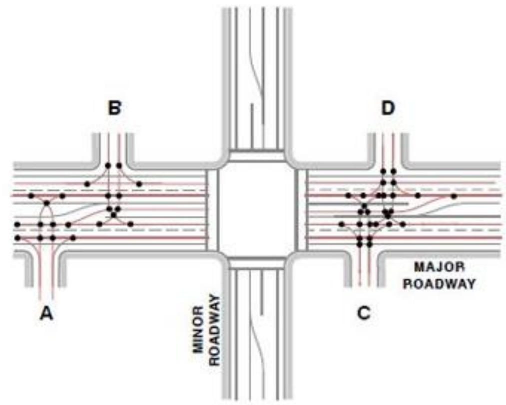


Figure 2: Functional and physical areas on an intersection (U.S. Department of Transportation Federal Highway Administration, 2010)

Ideally, no access point should be placed within these functional area of an intersection (American Association of State Highway and Transportation Officials, 2001). Typically, at a conventional four-legged intersection, 32 conflict points will be observed which consists of three types, merging, diverging and crossing conflict points as shown in Figure 3a. If access points are located within the functional areas, it will create additional conflict points within the vicinity of intersection as shown in Figure 3b.



(a)



(b)

Figure 3: (a) Conflict points at conventional 4-legged intersection, (b) Additional conflict points with the presence of access points within functional areas (U.S. Department of Transport Federal Highway Administration (a), 2016, (b), 2010)

Corner clearance is defined as the minimum distance required from an intersection to the first access point along a roadway as shown in Figure 4. This distance is usually associated with the functional distance of upstream and downstream of an intersection. Some states with access management guidance (i.e., Texas, Massachusetts, Oregon, etc.) use the functional distance as their corner clearance. According to Gluck, et al. (1999), insufficient corner clearance can affect traffic flow and also create safety problem at intersection which include; traffic being block by vehicles waiting to enter driveways, and increase the probability of rear-end and right-angle crashes.

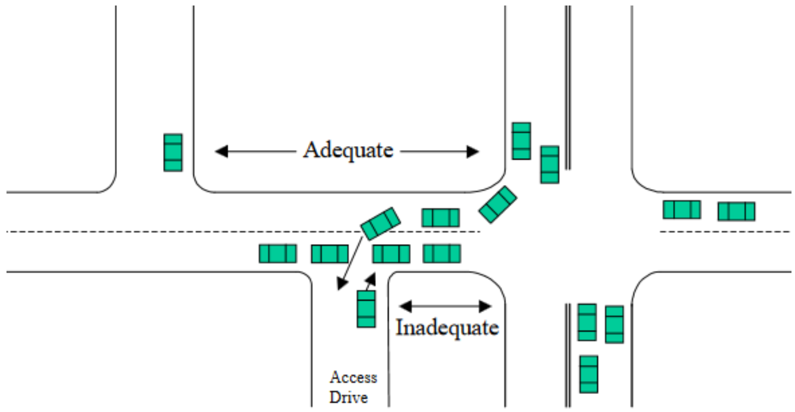


Figure 4: Example of access points near intersection (Institute for Transportation, Iowa State University, 2007)

2.3 Access Points near Intersection

Studies on safety performance for intersection have widely been conducted. However, only few of these studies examined the effect of access point distance near signalized intersection. A study from the State of Nevada evaluated the effect of corner clearance on signalized intersection. A random effect negative binomial model was used to develop the safety performance model using crash data from 300 signalized intersections in Las Vegas Metropolitan area. Crash data from 2003 was utilized in this study. From this study, it was found that the average length of corner clearance was inversely related to the number of crashes. In other words, the further the access points from the intersection, the fewer the number of crashes predicted for these intersections. This study also found that the distance between access points and signalized intersection varies with the type of land development. Residential areas usually have longer corner clearance compared to commercial areas. As a result, it showed that residential areas were associated to low number of crashes when compared to commercial areas (Xu, et al. 2011).

Another study by Oh et al. (2004) examined the safety performance of intersections. In this study, three types of rural intersections were analyzed; stop-controlled intersection with three-legged (major road: four lanes and minor road: two lanes), stop-controlled intersection with four-legged (major road: four lanes and minor road: two lanes), and signalized intersection (both major and minor road are two lanes). This study developed crash prediction models for the purpose of identifying the countermeasures that can be used to improve signalized and multilane stop-controlled intersections in rural areas. Two types of regression models were used to predict the number of crashes on these intersections; Poisson and negative binomial regression models. Oh et al. (2004) used crash data and intersection data from 3 different states; Georgia, California, and Michigan. The number of years for crash data used in this study varies from state to state, from the year 1991 to year 1998. The models were predicted based on total crashes and injury crashes within 250 ft. from the center of intersection. From the study, it was found that the number of commercial driveways within 250 ft. has positive correlation with the number of crashes for three-legged and signalized intersections based on total crash model. The same estimate was obtained for injury crash model on three-legged intersection.

Results from Oh et al. (2004) study revealed that every addition of commercial driveway within 250 ft. would result in 6 to 7 percent increase in number of crashes (depending on type of intersections and crashes). This shows that as the number of commercial driveways increases, the average distance between intersection and the first commercial driveway decreases, which contributes to the reduction in the safety of the intersection.

Le et al. (2018) evaluated the safety performance of four-legged signalized intersection in consideration of corner clearance on mainline road in the state of California and North Carolina. They used cross-sectional analysis to estimate the effect of corner clearance on crashes by types. In their study, they found that less clearance from signalized intersection to the first access point associated with increasing in total crashes. Other than fatal and injury crashes, Le et al. (2018) also found that, rear-end crashes will be reduced for limited corner clearance on main road. Similar study related to corner clearance by Xu et al. (2014) found that corner clearance has negative correlation with crash frequency. This study investigated the effects of corner clearance on number of crashes using 275 signalized intersections in southern part of Nevada State. It was found that random effect negative binomial model was the best-suited regression model to be used in predicting the number of crashes. They used 200 ft. and 400 ft. buffer distance to count the number of crashes occurred from the center of the intersection. It was found that crashes will be reduced by three with every 100 ft. of additional corner clearance. They also found that, commercial areas are associated with more crashes when compared to residential area.

In addition, Schultz et al. (2010) used different method from the previous literatures on determining the effects of access points on crashes within the functional area of signalized intersections. Instead of using count models, they used multiple linear regression model to predict the number of crashes occurred within the intersection functional area. The functional area of each intersection from this study was determined based on Access Management Manual (2003). In this study, 144 signalized intersections in the state of Utah were utilized to determine the safety effects of signalized intersections. Three years of crash data from 2002 to 2004 were used as the dependent variables (i.e., the crash data were classified into five different dependent variables; crash total, crash rate, crash severity, right angle, and rear end). Based on the results from this research, at least one predictor variable related to access points was significantly correlated with the dependent variable as shown in Figure 5. The positive sign from this figure indicates a positive estimate coefficient from the models. The commercial access density is the number of commercial driveway within the functional distance area and the corner clearance score is the number of corner clearances that violate the Utah Department of Transportation (DOT) corner clearance guidelines. The results from this study also found that intersections meeting the guidelines by Utah DOT had less right-angle related crashes and lower crash severity cost.

TABLE 4 Summary of Significant Access-Related Variables (9)

	Dependent Crash Variable (natural log transformed)				
Access-Related Variable	Crash Totals	Crash Rate	Crash Severity	Right Angle	Rear End
Commercial access density	+	+			+
Corner clearance score			+	+	
Median score					+

NOTE: "+" denotes positive relationship.

Figure 5: The results related to access points on different dependent variables (Schultz, et al. 2010)

Furthermore, Vogt and Bared (1998) examined the safety effect of rural intersections in Minnesota using databases from Highway Safety Information System (HSIS). Two types of intersections were examined in this study; three- and four-legged intersections with stop sign control on minor road. In this study, distance of 250-ft. from intersection was used to analyze crashes that occurred within this distance. 389 three-legged intersections were used while for four-legged intersection, 327 sample of intersections were utilized in this study. Eight predictor variables were examined (i.e., traffic volume, horizontal and vertical alignment, land and shoulder widths, roadside hazard rating, channelization, and number of driveways within 250-ft.) in both model using negative binomial regression model. It was found that only four-legged intersection model showed significant result for number of driveways. The model showed that every additional driveway within 250-ft distance form intersection, crashes were expected to increase by 11.6 percent.

Another study related to corner clearance on traffic operation of signalized intersection in Beijing, China was conducted by Qu et al. (2015). They used simulation models to predict the average delay per vehicle on functional areas of signalized intersection based on several criteria. Different traffic volumes on major road and driveway were used as well as the distance from the intersection to the first driveway while holding other variables constant. Figure 6 to Figure 8 show the results of average delay per vehicle in this study. It was found that average delay per vehicle had negative correlation with corner clearance for both upstream and downstream of signalized intersection. As the distance from signalized intersection to the first driveway increases, the average delay per vehicle decreases. They also discovered that the average delay per vehicle was directly proportional to the traffic volume on major road. However, upstream of signalized intersection had greater impact on traffic volume when compared to downstream of signalized intersection.

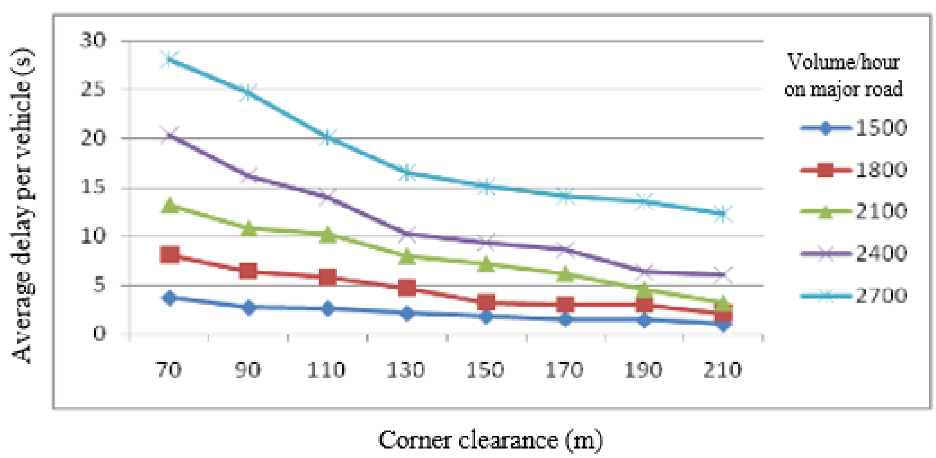


Figure 6: Average delay per vehicle at upstream of signalized intersection based on different traffic volume on major road (Qu, et al. 2015)

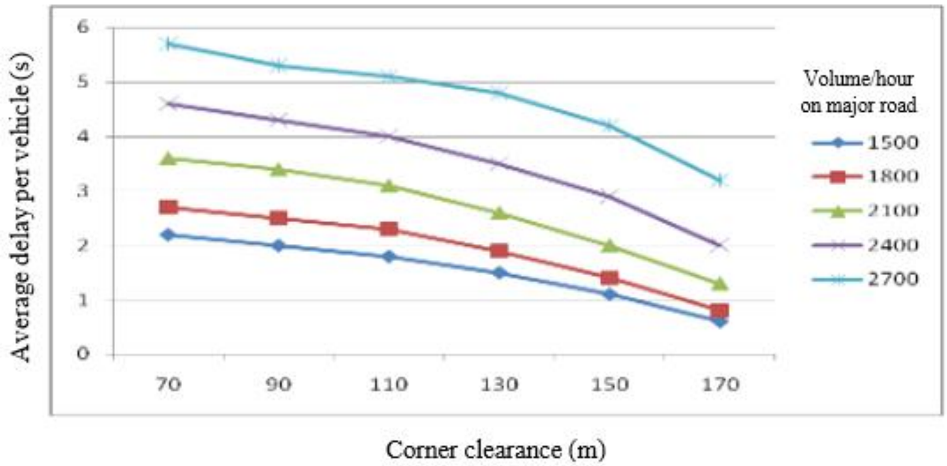


Figure 7: Average delay per vehicle at downstream of signalized intersection based on different traffic volume on major road (Qu, et al. 2015)

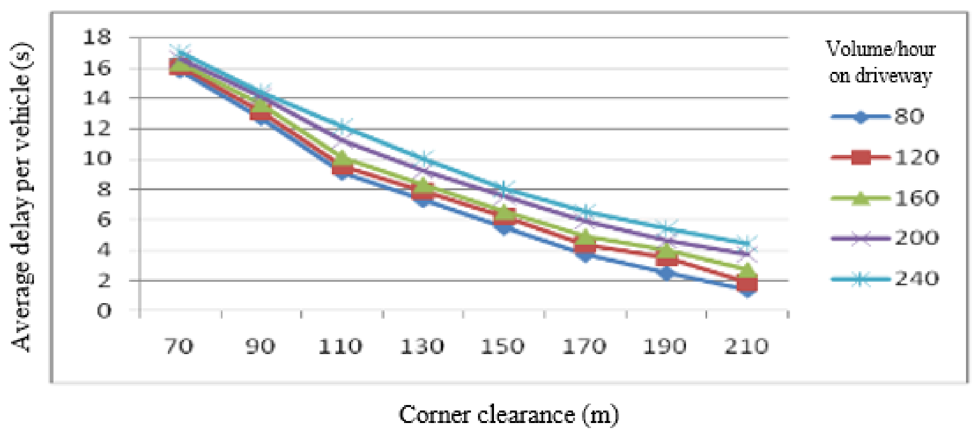


Figure 8: Average delay per vehicle at upstream of signalized intersection based on different traffic volume of driveway (Qu, et al. 2015)

Moreover, some of the studies that examined the safety effects of intersection did not find significant results on some of the characteristics of the intersections. A study by Jafari, et al. (2013) on 108 signalized intersections in North Carolina found that, corner clearance did not shows significant effect on access points related crashes. In this study, only 3 out of 15 predictor variables were significantly correlated with crash frequency; traffic volume, width of driveway, and through movement queue at the intersection near the access point.

The results from this study found that the longer the queue of through movement at the intersection, the more likely for access-related crashes to occur. Addition to that, narrower driveway was associated with fewer crashes.

2.4 Access Management Policy on Access Spacing from Intersection

There are many guidelines or policies on access management that have been developed across the time. These guidelines or policies include from American Association of State Highway and Transportation Officials (AASHTO), National Cooperative Highway Research Program (NCHRP), states policies, and many more. Such guidelines contain information regarding the requirements of access spacing for intersection, driveways, and median opening. For the purpose of this research, only guidelines from these agencies on locating the access points near intersections will be discussed.

In the second edition of the Access Management Manual (Williams, et al. 2014), both upstream and downstream functional areas depend on various factors. For upstream functional distance, the variables that are used to determine this distance include the distance traveled during the perception-reaction time, the deceleration distance travelled (this variable can be determine by two parameters; deceleration distance and impact distance), and the present of queue storage. However, for downstream functional distance, there are additional factors that can affect this distance which are geometric feature, operational effects, and human factors. For downstream functional distance, Williams et al. (2014) suggest that for a road segment with speed limit of 35 mph (average posted speed limit for major road in this research is 37 mph) located in urban area, no driveways or any access points should be located within 590 ft. from the intersection. Table 1 shows the ideal downstream functional distance (Williams, et al. 2014).

Table 1: Ideal downstream functional distance based on decision sight Distance to stop and for change in speed, path, or direction (Williams, et al. 2014)

Speed (mph)	Decision Sight Distance to Stop (ft.)			Decision Sight Distance (ft.) for Change in Speed, Path, or Direction		
	Rural[a]	Suburban[b]	Urban[c]	Rural[d]	Suburban[e]	Urban[f]
20	130	215	305	305	340	430
25	180	280	400	375	400	525
30	220	350	490	450	535	620
35	275	425	590	525	625	720
40	330	505	690	600	715	825
45	395	590	800	675	800	930
50	465	680	910	750	890	1,030
55	535	775	1,030	865	980	1,135
60	610	875	1,150	990	1,125	1,280
65	695	980	1,275	1,050	1,220	1,365
70	780	1,090	1,410	1,105	1,365	1,445
75	875	1,200	1,545	1,180	1,365	1,545

[a]Stop on rural road with perception reaction time (PRT) = 3.0s.
[b]Stop on a suburban road with PRT = 6.0s.
[c]Stop on a urban road with PRT = 9.1s
[d]Change in speed, path, or direction on rural road, PRT = 10.2 to 11.2s.
[e]Change in speed, path, or direction on a suburban road, PRT = 12.1 to 12.9s.
[f]Change in speed, path, or direction on an urban road, PRT = 14.0 to 14.5s.

According to AASHOTO’s *A Policy on Geometric Design of Highways and Streets*, “ideally, driveway should not be located within the functional area of an intersection or in the influence area of an adjacent driveway”. Access to the commercial driveways or private facilities adjacent to the intersections should be located where through traffic movement will be disturbed as little as possible. It is suggested that the distance from intersections to the access points should be at least 300 ft., and the sight distance for vehicles to maneuver into or out of the driveways should be sufficient. In other words, driveways should not be located on top of vertical curves (American Association of State Highway and Transportation Officials, 2001).

Many states have their own guidelines or policies on managing the access points along the roadway. The level of details for each policy or guideline depends on each state. Some states have detail manuals or guidebooks on access management and some only have the standards or regulations that must be followed. As previously mentioned, since this research focuses on access points adjacent to the intersections, such guidelines from several states will be discussed. According to Iowa Department of Transportation's *Iowa Primary Highway Access Management Policy*, access points on the primary road network may be allowed if the distance from the center of primary intersection to the facility access is greater than 300 feet. Additionally, Florida Department of Transportation provides a guideline on access spacing from intersection based on the types of facilities and the posted speed limit. Table 2 shows the minimum distance from the intersection should be for the access point to be located (Florida Department of Transportation, 2008). The roadway facilities are divided into 7 categories based on the access controlled with Class 1 to be the most restrictive and Class 7 the least restrictive based on land development.

Table 2: Connection spacing and corner clearance (Florida Department of Transportation, 2008)

Access Class Rule 14-97	Connection Spacing (feet)	
	>45mph	= or <45mph
1	N/A – Freeways	N/A – Freeways
2	1,320	660
3	660	440
4	660	440
5	440	245
6	440	245
7	125	

In addition to this, the guidelines provided by Texas Transportation Institute (The Texas A&M University System) suggested that roadway with the posted speed limit of 40 mph should have minimum spacing between intersection and the driveways by 305 ft. (William F. & William E., 2005). Further guidance provided by Kansas Department of Transportation mentioned that, to determine the access windows (allowable location for driveways) between intersections or access points, both upstream and downstream functional area have to determine first. The steps in determining the upstream functional distance for this guidelines is similar to Access Management Manual (Williams, et al. 2014) which consist of three criteria; distance traveled during perception-reaction time (d1), deceleration distance when coming to stop (d2), and the length of queue storage (d3). For downstream functional area, the stopping sight distance (d4) is used to determine the functional distance by using the posted speed limit of the roadway. Table 3 shows the distance traveled based on three criteria for upstream functional distance and the stopping sight distance for downstream functional distance (Kansas Department of Transportation, 2013).

Moreover, Mississippi Department of Transportation (2012) mentioned in their access management manual that the minimum corner clearance for both signalized and unsignalized intersection should be 125 ft. or the length of intersection queue, whichever is larger. Other than that, guidance from Alabama Department of Transportation (2014) on corner clearance depends on the turning movement into and out of the driveways. It is suggested that in urban areas with posted speed limit less than 45 mph, the distance between intersection and the immediate driveway should be greater than 660 ft. with allowable right- and left-turn into and out of the driveway. South Carolina Department of Transportation (2015) suggested that for both signalized and unsignalized intersection, the minimum corner clearance to the first access point should be greater than 275 ft. on the roadway with speed limit equal to 40 mph.

Table 3: Distance traveled during driver's perception-reaction (d1), lateral movement and deceleration (d2), and downstream functional distance (d4) (Kansa Department of Transportation, 2013)

Speed (mph)	d1- Undeveloped [1] (feet)	d1- Developed/CBD [1] (feet)	d2- Deceleration [2] (feet)	d4- Undeveloped [3] (feet)	d4- developed/CBD [3] (feet)
20	75	45	70	155	85
25	95	55	115	155	120
30	110	65	160	200	155
35	130	80	220	250	195
40	145	90	275	305	245
45	165	100	350	360	295
50	185	110	425	425	355
55	205	125	515	495	415
60	220	135	605	570	480
65	240	145	715	645	550
70	255	155	820	730	625

[1] Source d1: Modified version of TRB, Access Management Manual, 2003, Table 8-3, p. 133
[2] Source d2: Modified version of TRB, Access Management Manual, 2003, Table 10-2, p. 172
[3] Source d4: Modified version of AASHTO's A Policy on Geometric Design of Highways and Streets, Table 3-2 (2011)

Ultimately, Table 4 shows the summary of minimum corner clearance based on different access management policies across the states. The states that are not shown in this table either do not have guidelines on minimum corner clearance or guidance on the access management is not available online. Based on this table, the method used to calculate or measure the minimum corner clearance varies across the states, and this value ranged from 50 ft. to 800 ft. for roadways with average speed limit of 40 mph.

Table 4: Guidelines on minimum corner clearance based on state policy

State	Minimum Corner Clearance (ft.)	Year Published/ Revised	Remarks
Alabama	660	2014	Full access unsignalized for urban area under 45 mph road segments
Florida	245	2008	Speed limit less than 45 mph
Indiana	200	2009	n/a
Iowa	300	2012	n/a
Kansas	660	2013	Upstream functional area (40 mph)
Kentucky	450	2004	Urban area (minor arterial)
Louisiana	660	2013	Upstream functional area (40 mph)
Massachusetts	610	2006	Based on Access Management Manual (Speed limit = 40 mph, PRT = 2.5 s, Queue length = 225 ft.
Michigan	460	2001	Signalized intersection (40 mph)
Minnesota	435	2008	Upstream corner clearance (≤40 mph)
Mississippi	125	2012	n/a
Missouri	440	2006	Urban area on major road
New Hampshire	100	2000	n/a
New Mexico	402	2001	Full access on principle arterial (40 mph)
New York	100	2003	n/a
North Carolina	50	2003	Corner clearance is measured from radius point of intersection to the first radius point of driveway
Ohio	305	2001	Driveway spacing (40 mph)
Oregon	800	2012	Under limiting conditions (speed limit = 40 mph, queue length = 250 ft.)
Pennsylvania	600	2006	Corner clearance on principle arterial
South Carolina	275	2015	Full access with AADT greater than 2000 veh/day (40 mph)
South Dakota	250	-	Upstream corner clearance (40 mph)
Texas	305	2011	Roadway with 40 mph speed limit
Utah	300	2013	Based on minimum driveway spacing
Vermont	230	2005	Corner clearance for full access driveway
Virginia	475	2014	Upstream minor road corner clearance (queue length = 250)
Washington	230	2002	Corner clearance for full access driveway
West Virginia	185	2004	Based on driveway spacing (40 mph)
Wyoming	330	2005	Roadway with 40 mph speed limit

Most the results found on previous studies show that access management is important in facilitating safe and efficient roadway operation near signalized intersection. Locating access point further from intersection will result in reducing intersection related crashes. However, most of the study focused on the effects of corner clearance near intersection on crashes. Some of the study used only one buffer distance to examine the effects of access point density on crashes. Based on the summary table of different manuals, majority used at least three difference factors to calculate minimum corner clearance. Thus, this study aims to examine the safety effects of access points adjacent to signalized intersection using different buffer radii on primary roadway network in urban area. The results of this study will help to provide Iowa DOT with information regarding the appropriate distance to be established near intersection.

CHAPTER 3. DATA DESCRIPTION

3.1 Overview of Data Description

The main focus of this research is to evaluate the safety effects of access point density adjacent to urban signalized intersection on the primary road network. To accomplish this study, two types of data were utilized; databases from Iowa Department of Transportation (Iowa DOT) and also manually collected data. Iowa DOT provides a great numbers of databases from open source databases to confidential databases. These databases include traffic information and roadway characteristics from the Iowa DOT Geographic Information Management System (GIMS) database, detail information of intersections in Iowa (i.e., types of traffic controls, number of legs, etc.), and crash data, which contain information about each crash reported. As previously mentioned, manually collected data was also used in this study. The number of access points as well as detail information of each access points was collected along the primary road network. Ultimately, due to the georeferenced nature of these data sources, most of the works from data collection to data integration were done using ArcGIS software.

The utilization of each database in this study will be discussed in detail in the following section. The process of data integration using ArcGIS and Microsoft Excel will be discussed later on under the Data Integration Process section. Lastly, the summary of final dataset used in the analyses will be talked through under the Data Summary section.

3.2 Iowa DOT Geographic Information Management System

Iowa DOT Geographic Information Management System (GIMS) is a set of georeferenced datasets maintained by Iowa DOT that contains statewide information on roadway characteristics and traffic information. Every year, Iowa DOT updates the datasets based on new construction of highways or changes in roadway characteristics of existing facilities. Iowa DOT GIMS database consists of more than 10 different datasets that contain certain information pertaining to a specific roadway segment. In this study, three of those datasets used to obtain roadway characteristics and traffic information were Traffic, Road Info, and Direct Lane.

The Traffic dataset provides specific information on traffic parameters, which include annual average daily traffic (AADT) and percentage of various types of vehicles (i.e., motorcycle, pickup, bus, and other large vehicles) on each roadway segment. The Road Info dataset gives information regarding the geometric design of the roadway, which includes; number of lanes and the purpose of each lane (i.e., though lane, right-turn lane, two-way left turn lane, etc.) lane width, and median characteristics. Whilst the Direct Lane dataset outlines various characteristics pertaining to the countermeasures and infrastructure of the road segment such as presence of both edge line and centerline rumble strips, posted speed limit, shoulder width, and presence of roadside curb, among others. Figure 9 shows an example of signalized intersection on primary roadway in Ames, Iowa. This figure shows a layer of shapefile from GIMS database overlay a satellite imagery. Each line represents different segment pertaining to the underlay road segment. Ultimately, the three datasets were used to identify the major and minor roads at signalized intersections using traffic volumes as well as other roadway geometries.

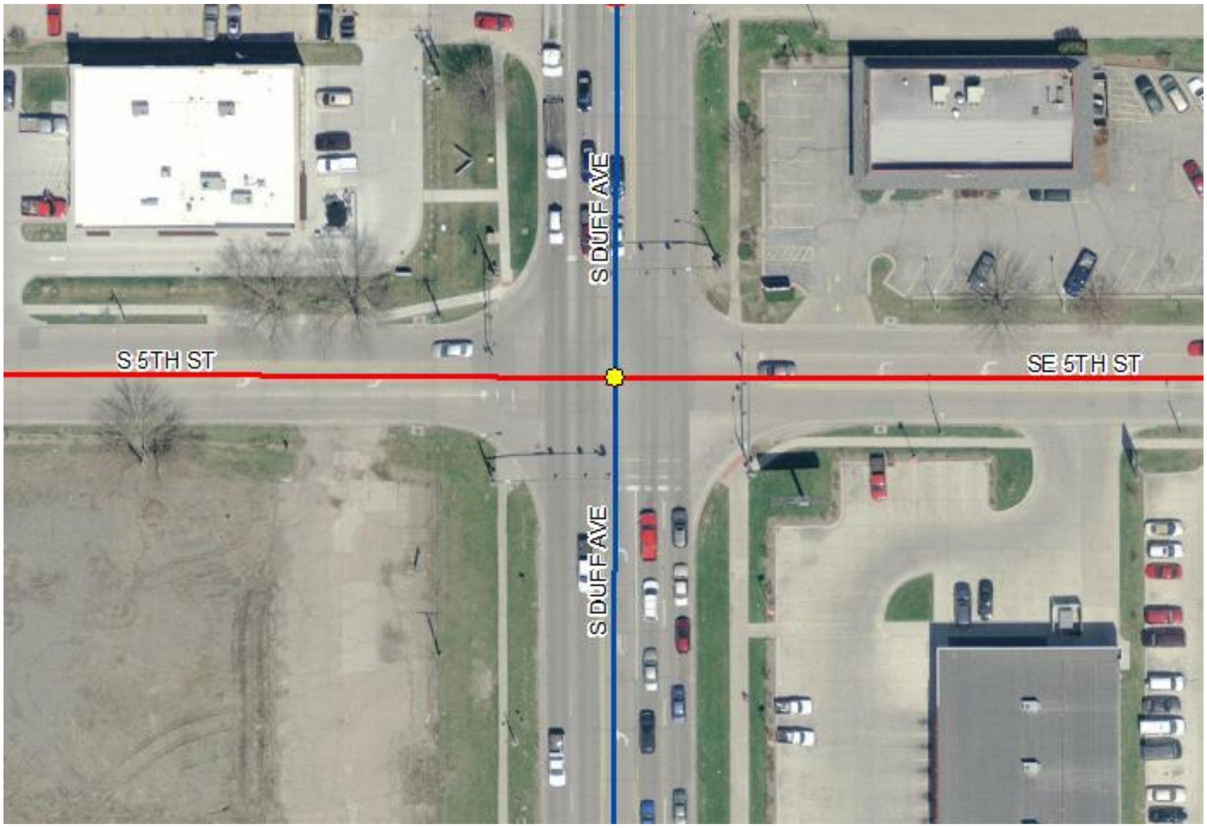


Figure 9: Iowa DOT GIMS shapefile overlay satellite imagery from ArcGIS

3.3 Iowa DOT Intersection Database

The characteristics of intersections utilized in this study were derived from a database developed by the Iowa DOT. The information available from this database comprises of broad categorical information, including types of traffic controls (i.e., signalized, all-way stops control, yield, etc.), number of legs, intersection angle, number of approach lanes, median types, and general shape of intersection (i.e., T- and Y-intersections, roundabout, etc.). The type of feature class for this database used in ArcGIS is a point feature. From Figure 9, the yellow dot represents the intersection shown in the figure. This dot contains all information pertaining to this specific intersection. In this study, due to the possible difference in the performance of each intersection, the sample used specifically focuses on non-ramp and at-grade intersections, determined from the largest population of all Iowa intersections. Moreover, two groups of intersection were utilized in this study: four-legged signalized intersections and three-legged signalized intersection.

3.4 Iowa DOT Crash Database

The Iowa DOT crash database contains detailed information regarding all reported crashes occurred in the state of Iowa. This database includes three aggregated level of datasets, including person-level, vehicle-level, and crash-level. Some of these information are open data which can be obtained from Iowa DOT website as georeferenced format or in spreadsheet format. However, only crash-level information are available to the public, comprising time of the crash, manner of the collision, drug or alcohol related, weather condition during the crash, crash severity, number of vehicles involved and many more. In this study, only crash-level dataset was used to estimate the safety performance of signalized intersection in consideration of adjacent access points on primary road network in Iowa.

Five years of crash data from 2011 to 2015 were integrated using ArcGIS and used in the analysis. The number of crashes on each intersection for a given year was identified based on various radii distances. These radii ranged from 50 ft. to 600 ft. with increment of 50 ft. interval. The analysis in this study is based on two subsets of crashes within the respective radii along the primary roadway. These subsets of crashes include total crashes and driveway-related crashes. The driveway-related crashes were based upon the types of roadway junctions' field in the crash data. Figure 10 shows a signalized intersection in Ames, Iowa with all five years of crashes within 300 ft. from the center of the intersection. The green square in this figure represents the driveway-related crashes that were coded in Iowa police crash report form and the grey triangle represents other types of crashes associated to other roadway junctions.

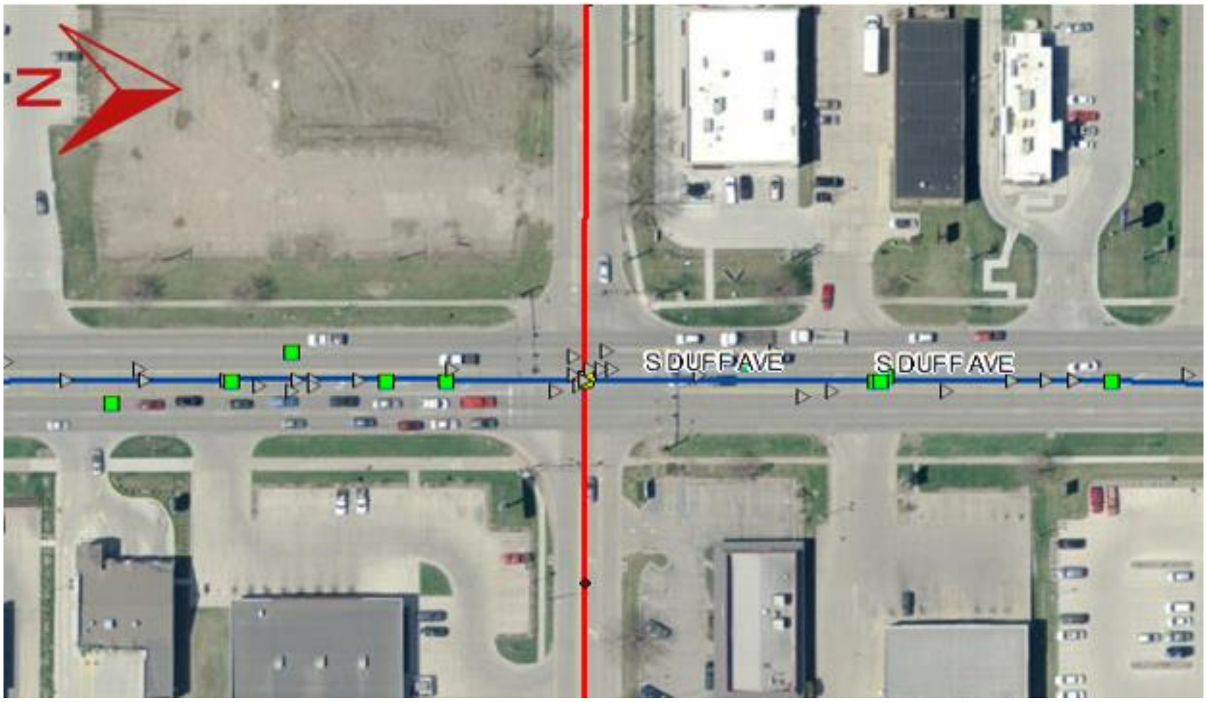


Figure 10: Crashes related to driveway near signalized intersection in Ames, Iowa

3.5 Manual Data Collection

Manual data collection was required to achieve the objectives of this study. There are two categories of data that were collected in this study; access point related information, and the type of land development adjacent to each intersection (intersection-level). The frequency of access points were determined first on the primary road network within the study limit area where the selected intersections are present. Each access point was recorded using a process called heads-up digitizing, where in this study, the ArcGIS software was used. A georeferenced of point feature was used to record all access points. Figure 11 shows an example of a corridor between two signalized intersections on Lincoln Way in Ames, Iowa. The star symbol in this figure represents the access points (in this case it was driveways) that were manually collected along this corridor for both sides of the roadway.

Figure 11: Access points between two signalized intersections on Lincoln Way in Ames, Iowa

While collecting the access points along the selected primary roadway network, detail information of each access point were also recorded. In this study, five different types of access points were observed, comprising driveways, field access locations, median openings (i.e., sometimes used for U-turn purposes), alleys (access to residential or commercial alley), and unsignalized intersections. However, only two types of access points fall within the studied buffers; driveways and unsignalized intersections. In this study, driveways were disaggregated into three categories, including commercial, residential and industrial driveways. Each of these categories can be broken down into further categories focused on type of adjacent development. For example, commercial driveways can include restaurants, hotels, shopping centers, small stores, and office buildings among others. While for residential driveway, it can be for single unit house, apartment, and many more.

The purpose of collecting specific information on type of development for each driveway type was to estimate the traffic volume generated from these driveways. Trip rate from Institute of Transportation Engineers (ITE) Trip Generation Manual (Institute of Transportation Engineers, 2008) was used to estimate the traffic volumes. The predictor variable used to estimate the traffic volumes varies based on the type of land use. For example, some of the access points have land area as the predictor variable and some depends on the number of dwelling units as predictor. Most of the land uses consist of three different categories of traffic volumes, which are volumes on weekday, Saturday, and Sunday. Consequently, the average daily value of the 7 days was used in the analysis. Table 5 shows different category of driveways observed on primary road network within the study areas with the estimated traffic volumes.

Table 5: Driveway AADT Estimate from ITE Trip Generation Manual

Classification	**AADT**	**References Page**	**Classification**	**AADT**	**References Page**
Apartments	1310	326	Hardware Store	1729	1415
Apparel Store	19	1700	Home Store	3654	1654
Art Shop	123	1704	Hospital	5100	1133
Auto Parts Sales	500	1533	Hotel	2054	570
Auto Service	41	1880	Industrial	1127	89
Bank	372	1746	Motel	1128	620
Building Material Store	377	1356	Nursery	8	1471
Car Wash	77	1919	Office Building	1490	1194
Cemetery	582	1095	Oil Service	15	1876
Church	259	1043	Restaurant	1031	1794
Coffee Shop	3500	1183	Salon	25	1768
Clinic	1195	1850	Shopping Mall	15486	1497
Convenience Market	95	1593	Single House	10	289
Department Store	2477	1692	Single Restaurant	833	1794
Discount Store	5219	1396	Sport Store	140	1651
Drug Store	977	1707	Storage	1328	188
Electrical Store	1660	1664	Supermarket	4188	1572
Fast Food	1606	1820	Tire Store	120	1540
Field Access	10	289	Toy Store	230	1670
Furniture Store	367	1721	Vehicle Dealership	936	1519
Gas Station	1865	1896	Veterinary Clinic	57	1191

Other detail information on each driveway used in this study is the permissibility of turning movements of vehicles into and out of driveways. There are six possible movements related to driveway that a vehicle can complete, including right- and left-turn into a driveway, right- and left-turn out of a driveway, and through movement into and out of a driveway. Figure 12 shows two driveways located in front of each other. This figure is an example of driveways that allow all the movements listed above.

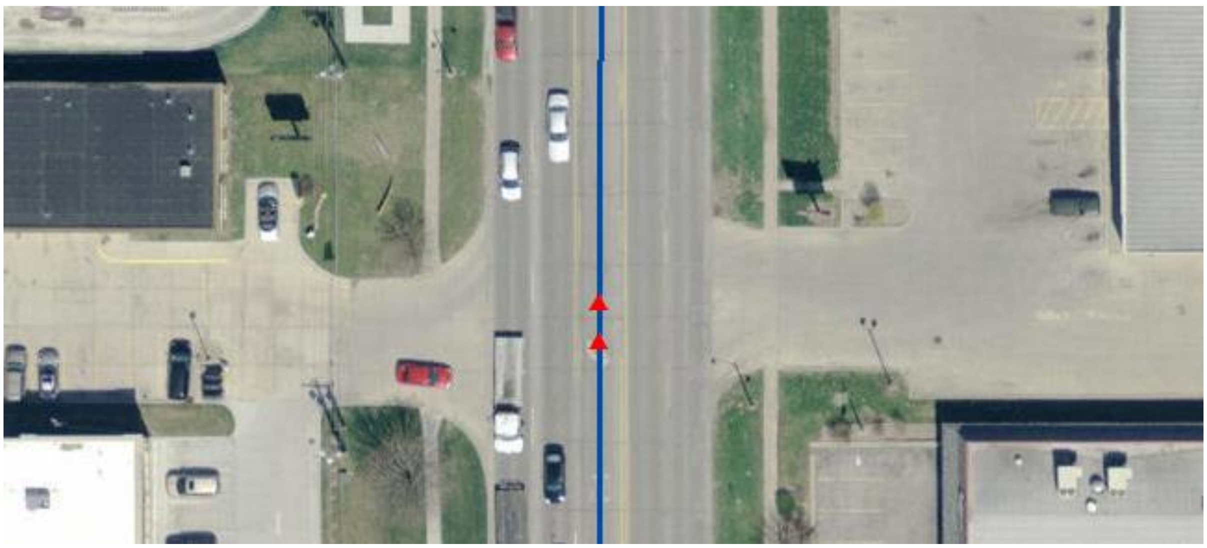


Figure 12: Driveways with permissible turning movements

The second category of manual data collected was the type of land development adjacent to the signalized intersections (intersection-level). Each of the intersection was categorized into the type of development that represents majority portion at the site location. For example, if a four-legged signalized intersection had a residential development on the north-east of the intersection and the rest was commercial development, this intersection will be categorized as commercial development. In this study, two types of developments observed during the process of data collection were commercial and residential developments.

3.6 Data Integration Process

This section consists of four general aspects of data integration processes; intersection selection, linking the crash data to the nearest intersection, joining the roadway information from Iowa DOT GIMS database to the selected intersection, and merging access point information from manually collected data to the selected intersections.

The primary roadway network was determined first by using Iowa DOT GIMS database. A field in this database allows researchers to filter the roadways that are maintained by Iowa DOT. Hence, any roadway network that falls within Iowa DOT jurisdiction is considered as primary roadway. However, this process includes all segments regardless of type of land development. Since the focus of this study was within the urban limit, a database from U.S. Department of Commerce was used to obtain the boundary of all cities (urban area) in the state of Iowa. The selected roadway segment that falls within the city's boundary were then considered. Next, signalized intersections along the primary roadway within the study limit that meet all the requirements were selected. As a result, 415 signalized intersections that meet the criteria were selected from 13 different cities across Iowa.

After obtaining the final sample size of signalized intersection, five years of crashes within the studied buffers on primary roadway network were linked to the selected intersections. In this study, a crash may associate to more than one intersection depending on the distance between two signalized intersections. If the distance between two signalized intersections is less than 600 ft., crashes that occurred between these two intersections might be attached to both intersections depending on the buffer analysis.

The process of joining roadway information to the selected intersections was meticulous, however the detail step by step in joining these two files will not be discussed in detail in this research. The general process of this data integration will be explained briefly.

Each intersection will have at least three approach segments, at most, four. All segments have to be linked with the nearest intersection. For example, Figure 9 shows an intersection with four different approach segments. All four segments (S 5th Street, SE 5th Street, upper part of S Duff Avenue and lower part of S Duff Avenue) have to be joined with the yellow dot, which represents the intersection. In order to accomplish this, a geoprocessing tool called 'Generate Near Table' from ArcGIS was utilized. After obtaining the output table from this process, the approach segments were then combined to produce major and minor roadways based on the name of the roadway using Microsoft Excel. Arithmetic average between two approach segments was used to obtain the variables from the GIMS database. For example, the two blue segments in Figure 9 have the same name, S Duff Avenue (assume this is major roadway), hence the traffic volume on this major roadway will be the average between these two segments. However, two approach segments sometime do not have the same road name. Thus, segments with this problem were manually checked and fixed. In determining the major and minor roadways, annual average daily traffic (AADT) was used as predictor. Roadways with higher average AADT were considered as major roadway and roadway with lower AADT were considered as minor roadway.

In combining access point information with the selected intersections, various buffer distances were used to spatially connect these two data sets. Twelve different sizes of buffers, ranging from 50 to 600 ft. with increment of 50 ft. were used to count the number of access points and obtain relevant information related to it.

3.7 Data Summary

To obtain suitable crash prediction model for each buffer, 15 different predictor variables were tested to examine the relationship between crash frequency and nearby access points. The roadway characteristics and traffic volumes were examined for both major and minor roadway approaches to the intersections. The descriptive statistics of some of the predictor variables are shown in Table 6. These data outline the number of driveways and unsignalized intersections present within the studied buffers; 50 ft. to 600 ft. from the center of intersections. The maximum number of driveways observed within 600 ft. is 29 driveways. Note that these driveways were counted for 600 ft. upstream and downstream of the intersection for both directions of the roadway. Traffic volumes for these roadways ranged from 853 vehicles per day (vpd) to around 37,000 vpd for the major roadway, with a mean of 17,083. The intersecting minor roadway had traffic volumes between 13 vpd to more than 23,000 vpd, with a mean of 4,982. The minimum traffic volume observed in this study is due to the location of intersections within small residential areas. Based on Table 6, about 20 percent of the intersections in this study are located in residential areas, while the rest are located in commercial areas. Other roadway characteristics of interest in this study were the posted speed limit, the number of lanes, the presence of left-turn lanes, and the presence of medians on both major and minor roadways.

Crash data is one of the primary factors of interest in this study. Summary of types of crashes with different buffer radii are provided in Table 7. These crashes were total crashes and target crashes. Location of the crash was used to identify the target crashes. Crashes that occurred near or at the driveway were considered as target crashes. These crash locations were determined based on the police-reported crash data. One of the objectives of this study was to distinguish how crashes vary based upon the subsets of crashes that were considered. Previous studies have suggested issues in regards to the accuracy of the police-reported crash data, explicitly when trying to identify the point location of those crashes, which may have been intersection- or driveway-related.

Table 6: Descriptive statistics for predictor variables

Variable	Min.	Max.	Mean	Std. Dev.
Number of driveways within 600 ft.	0	29	4.72	5.45
Number of driveways within 550 ft.	0	26	4.23	4.97
Number of driveways within 500 ft.	0	23	3.76	4.43
Number of driveways within 450 ft.	0	21	3.33	3.98
Number of driveways within 400 ft.	0	20	3.00	3.63
Number of driveways within 350 ft.	0	16	2.66	3.25
Number of driveways within 300 ft.	0	15	2.26	2.83
Number of driveways within 250 ft.	0	13	1.80	2.33
Number of driveways within 200 ft.	0	10	1.21	1.68
Number of driveways within 150 ft.	0	7	0.70	1.11
Number of driveways within 100 ft.	0	4	0.29	0.60
Number of driveways within 50 ft.	0	2	0.10	0.32
Number of unsignalized intersections within 600 ft.	0	5	0.59	0.88
Number of unsignalized intersections within 550 ft.	0	4	0.54	0.84
Number of unsignalized intersections within 500 ft.	0	4	0.50	0.80
Number of unsignalized intersections within 450 ft.	0	4	0.43	0.75
Number of unsignalized intersections within 400 ft.	0	4	0.29	0.61
Number of unsignalized intersections within 350 ft.	0	2	0.16	0.45
Number of unsignalized intersections within 300 ft.	0	2	0.06	0.28
Number of unsignalized intersections within 250 ft.	0	2	0.03	0.20
Number of unsignalized intersections within 200 ft.	0	1	0.02	0.14
Number of unsignalized intersections within 150 ft.	0	1	0.01	0.11
Number of unsignalized intersections within 100 ft.	0	1	0.00	0.07
AADT for major road	853	37300	17083	6804
AADT for minor road	13	23800	4982	4192
Speed limit (mph) for major road	25	55	37.04	7.14
Speed limit (mph) for minor road	25	55	31.18	8.59
Number of lanes on major road	2	9	4.61	1.16
Number of lanes on minor road	2	7	2.91	1.16
Presence of median on major road (1 if yes; 0 otherwise)	0	1	0.57	0.50
Presence of median on minor road (1 if yes; 0 otherwise)	0	1	0.16	0.37
Land development (1 if commercial; 0 if	0	1	0.81	0.39
Presence of left-turn lane on major road (1 if yes; 0 otherwise)	0	1	0.57	0.50
Presence of left-turn lane on minor road (1 if yes; 0 otherwise)	0	1	0.16	0.37
Number of legs (1 if four-legged; 0 if three-legged)	0	1	0.80	0.40

The summary statistics from Table 7 also shows that most of the intersections in the studied sample experienced zero or a few driveway-related crashes (this include 600 ft. radius), as evidenced by the mean value. Some of the studied buffers experienced a total number of driveway-related crashes adjacent to all intersections collectively less than 100 crashes per year. According to Bahar and Hauer (2014), to have a reliable SPF, the minimum number of crashes that the sample should have is more than 100 crashes per year.

Table 7: Descriptive statistics for dependent variables

Variable	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Total crashes, 600-ft. radius	0	152	35.61	29.14
Total crashes, 550 ft. radius	0	151	33.67	27.91
Total crashes, 500 ft. radius	0	135	32.24	26.98
Total crashes, 450 ft. radius	0	129	30.50	25.91
Total crashes, 400 ft. radius	0	124	27.60	24.05
Total crashes, 350 ft. radius	0	113	24.91	22.30
Total crashes, 300-ft. radius	0	108	23.15	21.14
Total crashes, 250-ft. radius	0	103	21.59	20.09
Total crashes, 200-ft. radius	0	101	20.12	19.21
Total crashes, 150-ft. radius	0	96	18.19	17.97
Total crashes, 100-ft. radius	0	93	16.60	17.13
Total crashes, 50-ft. radius	0	88	14.60	15.91
Target crashes (driveway), 600-ft. radius	0	39	1.60	3.80
Target crashes (driveway), 550-ft. radius	0	39	1.48	3.69
Target crashes (driveway), 500-ft. radius	0	39	1.35	3.41
Target crashes (driveway), 450-ft. radius	0	38	1.23	3.13
Target crashes (driveway), 400-ft. radius	0	37	1.06	2.87
Target crashes (driveway), 350-ft. radius	0	37	0.97	2.71
Target crashes (driveway), 300-ft. radius	0	36	0.85	2.46
Target crashes (driveway), 250-ft. radius	0	35	0.69	2.14
Target crashes (driveway), 200-ft. radius	0	27	0.55	1.71
Target crashes (driveway), 150-ft. radius	0	20	0.37	1.27
Target crashes (driveway), 100-ft. radius	0	12	0.26	0.85
Target crashes (driveway), 50-ft. radius	0	4	0.16	0.52

The traffic volumes of each driveway were estimated using ITE Trip Generation Manual. Table 8 shows the summary statistics of different categories of traffic volumes for driveway within each buffer distance. Three types of traffic volumes were tested in this study; the minimum, and the maximum traffic volumes generated from one of the driveways within the buffer radii, and the average traffic volumes from all driveways within the studied buffers.

Based on Table 8, the maximum traffic volumes estimated for driveway in this study was 15,486 vpd with minimum of zero vpd (i.e., some intersections do not have driveway or unsignalized intersection within 600 ft. distance). All three different types of traffic volumes used in this study for 50 ft. buffer distance had the same maximum estimate of vehicles entering and exiting the driveway (15,486 vpd). The reason that this distance had a maximum traffic volume is due to presence of a shopping mall at one of the intersections in the study sample. Based on the Iowa GIMS database, entrance to this shopping mall was not considered as the leg of intersection, instead it was considered as a driveway. Moreover, the minimum traffic volumes estimated for all three types of traffic volumes within the studied buffers was 0 vpd. Based on the sample of signalized intersections used in this study, some of the intersections do not have any access points within the 12 buffer distances.

Table 8: Summary statistics for driveway traffic volumes within each buffer

Variable	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Driveway with maximum AADT within 600 ft.	0	15486	1547	2023
Driveway with maximum AADT within 550 ft.	0	15486	1455	1978
Driveway with maximum AADT within 500 ft.	0	15486	1361	1836
Driveway with maximum AADT within 450 ft.	0	15486	1294	1800
Driveway with maximum AADT within 400 ft.	0	15486	1216	1746
Driveway with maximum AADT within 350 ft.	0	15486	1121	1684
Driveway with maximum AADT within 300 ft.	0	15486	1029	1620
Driveway with maximum AADT within 250 ft.	0	15486	905	1571
Driveway with maximum AADT within 200 ft.	0	15486	785	1536
Driveway with maximum AADT within 150 ft.	0	15486	594	1398
Driveway with maximum AADT within 100 ft.	0	15486	369	1291
Driveway with maximum AADT within 50 ft.	0	15486	255	1245
Driveway with minimum AADT within 600 ft.	0	9100	322	794
Driveway with minimum AADT within 550 ft.	0	9100	317	780
Driveway with minimum AADT within 500 ft.	0	9100	323	797
Driveway with minimum AADT within 450 ft.	0	9100	361	897
Driveway with minimum AADT within 400 ft.	0	9100	385	993
Driveway with minimum AADT within 350 ft.	0	9100	365	937
Driveway with minimum AADT within 300 ft.	0	9100	372	1003
Driveway with minimum AADT within 250 ft.	0	9100	357	985
Driveway with minimum AADT within 200 ft.	0	9100	386	1001
Driveway with minimum AADT within 150 ft.	0	9100	402	1050
Driveway with minimum AADT within 100 ft.	0	9100	291	1003
Driveway with minimum AADT within 50 ft.	0	15486	237	1216
Average AADT of Driveways within 600 ft.	0	9100	765	975
Average AADT of Driveways within 550 ft.	0	9100	731	955
Average AADT of Driveways within 500 ft.	0	9100	717	971
Average AADT of Driveways within 450 ft.	0	9100	719	1028
Average AADT of Driveways within 400 ft.	0	9100	714	1085
Average AADT of Driveways within 350 ft.	0	9100	673	1048
Average AADT of Driveways within 300 ft.	0	9100	649	1089
Average AADT of Driveways within 250 ft.	0	9100	605	1093
Average AADT of Driveways within 200 ft.	0	9100	576	1132
Average AADT of Driveways within 150 ft.	0	9100	499	1156
Average AADT of Driveways within 100 ft.	0	9100	329	1090
Average AADT of Driveways within 50 ft.	0	15486	246	1223

The allowable turning movements for each driveway were determined based on satellite imagery. Three different configuration of turning movements were tested in the SPFs to see if they affect the number of crashes significantly or not. The first type of configuration was the percentage of driveways with prohibited left-turn movements (either from the access point to the main street or from main street into the access point) within each buffer. This percentage was calculated based on the number of driveways that do not allow left-turn movement over the total number of driveways within each buffer. The second configuration was the percentage of driveways with full movements within the buffer radii. This variable was calculated based on the number of driveways that allowed all turning movements (left-turn, right-turn, or access points with thru movement) over the total number of driveways in each buffer. These first two configurations were treated as both categorical variable and also continuous variable. For categorical variable, intersection without any driveway within 600 ft. will have undefined value of the percentages (i.e., if the percentage of driveways with prohibited left-turn movement was calculated for these intersections, it will give undefined value due to the division of zero). This category will be treated as intersection without any access points and other categories will be in between 0 to 100 percent of driveways with prohibited left-turn or full movements. For continuous variable, the undefined intersection will be assumed to have 100 percent prohibited left-turn or zero percent of full movements, depending on the types of configurations. The last type of turning movement configuration tested was the density of driveways that prohibit left-turn movement; which was calculated by diving the number of driveways that prohibit left-turn by the distance of the buffers.

CHAPTER 4. METHODOLOGY

Safety performance function (SPF) is an equation developed based on crash history, roadway geometry characteristics, and traffic volume (exposure variable), used to predict the average number of crashes per year at a given location. For SPFs using intersection-level, exposure variable is represented by the AADT for major and minor intersecting roads. In this study, the safety performance functions were estimated based on intersection-level in order to determine the safety effects of access points on crashes adjacent to signalized intersection while considering other variables. The statistical examination in this study was carried out using R Studio with 'MASS' package to obtain the SPFs.

Linear regression is a method for estimating the relationship between a dependent variable and predictor variable/s. For this method, the dependent variable is continuous, which can include negative value. The distribution of the dependent variable follows the normal distribution. However, crashes are random, non-negative, and discrete in nature. Most of the intersections will have minimal or zero crashes, which will result in a skewed distribution of the crashes. Because of this, if crashes were predicted using a linear regression model, negative estimates might be obtained. The better way to estimate the number of crashes is by using count models from generalized linear models (GLMs). The models allow the predictor variables to have error distribution other than a normal distribution. They are fitted by maximizing the likelihood or log-likelihood of the observed parameters.

There are two types of commonly used count models from GLMs in developing SPFs, which are Poisson and negative binomial (also known as Poisson-gamma models) regression models. Typically, the Poisson regression model is considered first when modeling crash data. The probability of the number of crashes occurring at a given intersection during a specific time period is given by:

$$P(y_i) = \frac{e^{-\lambda} . \lambda_i^{y_i}}{y_i!} \tag{1}$$

where y_i is the number of crashes at a given intersection, *i* and λ_i is the Poisson parameter for intersection *i*. Based on this study, λ_i will be the expected number of crashes at intersection *i* for a given time period based on the 12 different buffer distances. The expected number of crashes can be expressed as:

$$\lambda_i = EXP(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n) \tag{2}$$

where X_1 through X_n are explanatory variables which represents site characteristics such as traffic volumes, roadway geometry, and types of land developments among others; β_1 through β_n are the estimate coefficients obtained from the regression analysis. When using Poisson regression model, one of the assumptions of using this model is that the mean number of crashes is equal to the variance. However, crash data in nature will have variance greater than the mean, known as overdispersion. Overdispersion of crash data can be overcome generally by using negative binomial model. This model is a generalized version of the Poisson model and the expected number of crashes can be expressed as:

$$\lambda_i = EXP(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon_i) \tag{3}$$

where $EXP(\varepsilon_i)$ is a gamma-distributed error term with a mean equal to one and variance α (also known as overdispersion parameter). The inclusion of the overdispersion parameter allows the variance to differ from the mean, as demonstrated in the equation below:

$$Var(y_i) = E(y_i) + \alpha E(y_i)^2 \tag{4}$$

The estimate coefficients obtained from the model represents impact of the variables on total and target crashes. The positive sign of the estimate coefficient represents increase in the number of crashes; while negative sign is associated with decrease in the number of crashes. The estimate coefficient can be used, by using equation 5, to obtain the percentage increase or decrease (marginal effect) in the number of crashes. This equation provides the percentage change in the number of crashes when the value of the independent variable changed. The equation can be expressed as:

$$\Delta\lambda = 100(e^{\beta_n X_n} - 1) \tag{5}$$

where $\Delta\lambda$ is the percentage change in the number of crashes.

CHAPTER 5. RESULTS AND DISCUSSION

5.1 Overview

After integrating all the data into one coherent format, the effects of access points on safety near signalized intersection in considering other aspect of roadway characteristics were determined. One of the objectives of this study was to discern on how crashes vary based on two subsets of crashes; driveway related crashes and total crashes. The following sections of this chapter are based on the two subsets of crashes. Note that the models from the two subsets of crashes may vary from each other on the use of predictor variables due to the extreme p-value or the estimate coefficients of the variables were unable to justify.

The effects of each variable related to access point on crashes (access point density, traffic volumes of access points, and turning movements) as well as other roadway characteristics will be discussed in detail for each subset of crashes. This discussion will include the marginal effect of each predictor variable and the possible explanation on the findings. The differences in estimate coefficients between the two crash data subsets will be discussed in the following sections.

5.2 Driveway Related Crashes

Table 9 through Table 11 represent the safety performance functions (SPFs) when using driveway-related crashes as dependent variable. The first three buffer radii (50 ft., 100 ft., and 150 ft.) were removed from the result due to the extreme p-value for some of the predictor variables in the models. As mentioned in the previous section, to have a reliable SPF, the minimum number of crashes a sample should have is at least 100 crashes per year. One possible reason why the first three buffer radii had poor results was that the observed number of crash for the study period did not meet the minimum value of 100 crashes per year.

Notice from these models, the only roadway characteristics from GIMS that were included in the models were the annual average daily traffic (AADT) for major and minor road. To be consistent between all SPFs, the same variables were used even though some of the roadway characteristics in some SPFs (buffer radii) were significant. Likewise for the base case (dummy variable) of categorical variable, same dummy variable was used for all buffer radii.

Table 9: Safety performance function for driveway-related crashes within 600 ft.

Parameter	**Estimate**	**Std. Error**	**Pr(>|z|)**
Intercept	-11.767	2.015	<0.001
Natural log of major AADT	0.810	0.206	<0.001
Natural log of minor AADT	0.250	0.086	0.003
Natural log of average driveway AADT	0.133	0.033	<0.001
Number of driveways	0.089	0.016	<0.001
Percentage of driveways with prohibited left-turn	-0.647	0.184	0.005
Commercial land development (base = residential)	1.285	0.285	<0.001
Overdispersion	1.248	0.190	<0.001

Table 9 represents the SPF for 600 ft. buffer distance. Five of the predictor variables had a positive sign of estimate coefficient, associated with increasing in the number of crashes and only one variable had a negative sign, which indicates a reduction in the number of crashes. As expected, traffic volumes positively affect the predicted number of crashes on both major and minor road. A one percent increase in traffic volumes on major roadway would be expected to increase the number of crashes by 0.81 percent while holding other variables constant. As for minor roadway, a one percent increase in traffic volumes would result in 0.25 percent increase in the number of crashes. Likewise for driveway traffic volumes, crashes would be expected to increase by 0.13 percent as the average number vehicle entering and exiting the driveways within 600 ft. from the intersection increase by one percent. Based on Table 5, the number of vehicles entering and exiting the driveways is associated with the types of developments. Consequently, this SPF can be used to predict the number of crashes based on the different purpose of driveways (i.e., single unit house, office building, restaurant, shopping mall etc.).

The frequency of driveways within 600 ft. buffers is also associated with increase in the number of predicted crashes. Every additional driveway within 600 ft. from signalized intersection would be expected to increase the number of crashes by 9.31 percent. Based on some of the states' guidelines from Table 4, the minimum corner clearance that should be established is 600 ft. and above. Having a driveway within 600 ft. will create additional conflict points within the intersection area as shown in Figure 3(b). According to Gluck, et al. (1999), inadequate corner clearance will increase the probability of rear-end and angle crashes at this location. Analysis on the crash data used to develop the model in Table 9, revealed that approximately 79 percent of the crashes were associated to rear-end and angle crashes (i.e., 15 percent of the crashes were rear-end crashes and 64 percent were angle crashes).

The number of turning movements at driveways is also correlated with the number of crashes. Any driveways with restriction on turning movements (i.e., prohibited left-turn into and out of the driveway, right turn into the driveway only, etc.) will reduce the probability of a crash occurring. Based on Table 9, the percentage of driveways with prohibited left-turn movements was used to represent the availability of turning movements of the driveways. Crashes would be expected to decrease by 28 percent when 50 percent of the driveways within 600 ft. prohibit vehicles to make a left-turn into or out of a driveway in comparison to an intersection that allow the same number of driveways to have left-turn movements. Note that this variable is a continuous variable (better estimate than the categorical variable), which indicates the percentage change in the number of crashes varied based on the number of driveways that prohibited left-turn movements. Figure 13 shows the percentage of driveways with prohibited left-turn movements from 0 to 100 percent (in 10 percent increments) within a 600 ft. buffer at a variety of driveway counts. From this result, it shows that if the turning movements of a driveway adjacent to a signalized intersection were restricted, the number of conflict points can be reduced. This will result in reducing the probability of getting involved in a driveway-related crash.

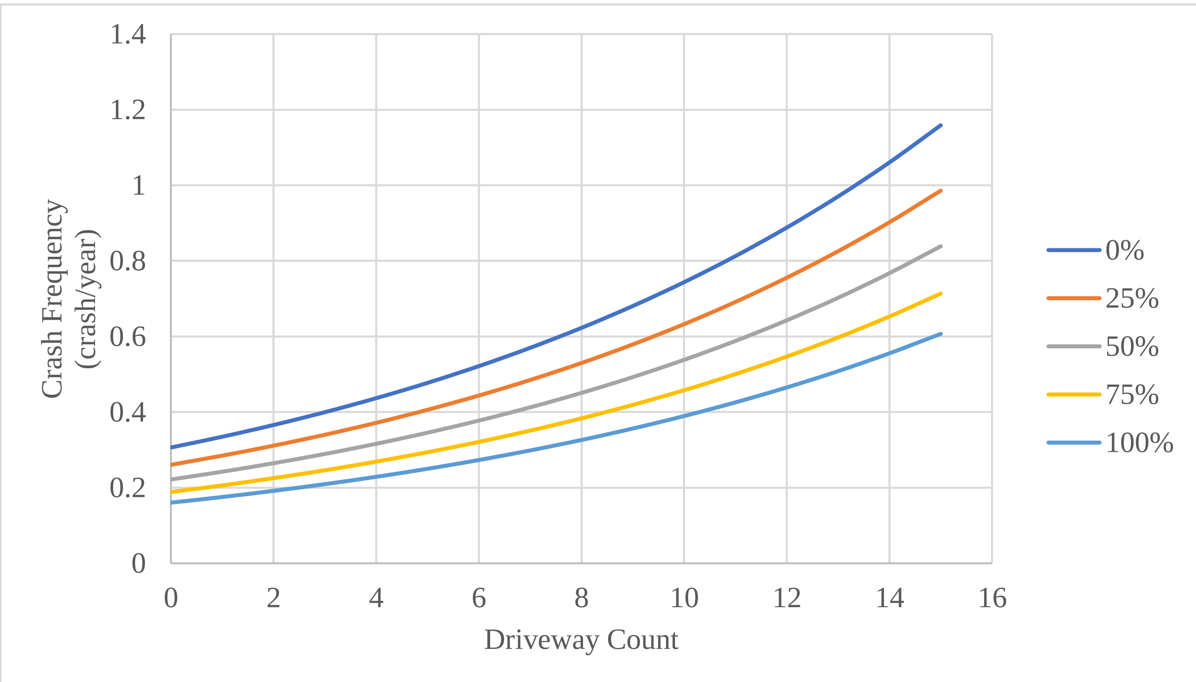


Figure 13: Driveway counts with different percentage of driveways with prohibited left-turn movements on crash frequency within 600 ft. radius

Intersections located in areas with majority of the developments are commercial, experienced about 261 percent more crashes on average than those with residential developments. This result suggests that driveway volumes are higher in commercial areas when compared to residential areas. Table 5 demonstrates the traffic volumes of driveway based on the types of developments with most of the commercial developments have higher estimated AADT than single unit house.

Some of the predictor variables were not shown to have a significant correlation with the number of crashes, including the other types of access points, unsignalized intersection. One possible reason why this variable did not have a significant correlation was because of the sample size itself. There were only a few intersections categorized as unsignalized intersection within the buffers based on the mean value as shown in Table 6. Since only crashes that occurred within the vicinity of driveways were utilized in the analyses, it is not suitable to sum up the number of driveways and unsignalized intersections to a single predictor variable since it may create a bias in the estimate coefficient. Moreover, the posted speed limit for both major and minor roads also did not show any significant correlation with the safety performance of the intersections. Some of the intersections with lower speed limit experienced more crashes when compared to the intersections with higher speed limit. This shows that speed limit was not important in estimating the number of driveway-related crashes in this study. Similarly for the number of legs, a small sample size would affect the performance of the model. Based on Table 6, about 20 percent of the intersections were three-legged, whilst the rest were four-legged intersections.

Table 10 and Table 11 contain the results for the models with 9 different buffer distances from 200 ft. to 600 ft. buffer. Similar trends were shown for all predictor variables with different magnitude. The effect of spatial proximity of access points near signalized intersection based on different buffer distances can be considered effectively. The parameter estimates for driveway count outline an increase in the magnitude as the buffer size decreases (i.e., the rate of crashes tend to increase more rapidly). The percentage increase in the number of predicted crashes based on the parameter estimates of driveway count increased from 9.31 percent (600 ft. buffer) to 31.40 percent (200 ft.) with every additional driveway. The findings demonstrate that crashes are more prone when a driveway is close to an intersection. The increase in the number of crashes as a driveway gets closer to an intersection is intuitive; a limited space available for drivers to maneuver through intersection and change lanes as desired, may result in risky behavior from driver that will increase the probability of getting involved in crashes.

The percentage of driveways with prohibited left-turn movements showed a trend for some range of buffers. The estimate coefficient of this variable increases (in a negative form) as the distance from the signalized intersection increase from 400 ft. to 600 ft. in radius. This indicates that the effect of prohibiting left-turn movements of driveways on crashes increases as the buffer distance increases, which means less crashes would be observed for larger buffers in this range. However, for radius below 400 ft., no trend was shown for this variable with respect to the buffer radii.

Figure 14 graphically shows the estimated number of crashes based on different driveway counts, while holding other predictor variables constant. The crashes on all buffers were estimated using the average AADT for major and minor roadways, the mean value of average driveway AADT at the 600 ft. radius (765 vpd), 50 percent of the driveways within the buffers were assumed to have prohibited left-turn movements, and the location of the intersections was assumed to be in commercial areas.

Each line in this figure represents different SPFs as shown in Table 10 and Table 11. The safety performance of each buffer shows an increase in the number of crashes as the number of driveways increase, regardless of the size of the buffer. Interestingly, all buffers seem to estimate approximately the same number of crashes with four driveways within the buffers. As the number of driveways increase from four, the number of crashes tended to increase exponentially for all buffer distances. The slope of the line becomes steeper as the buffer distance decreases; which indicates the higher the expected impact on crash risk.

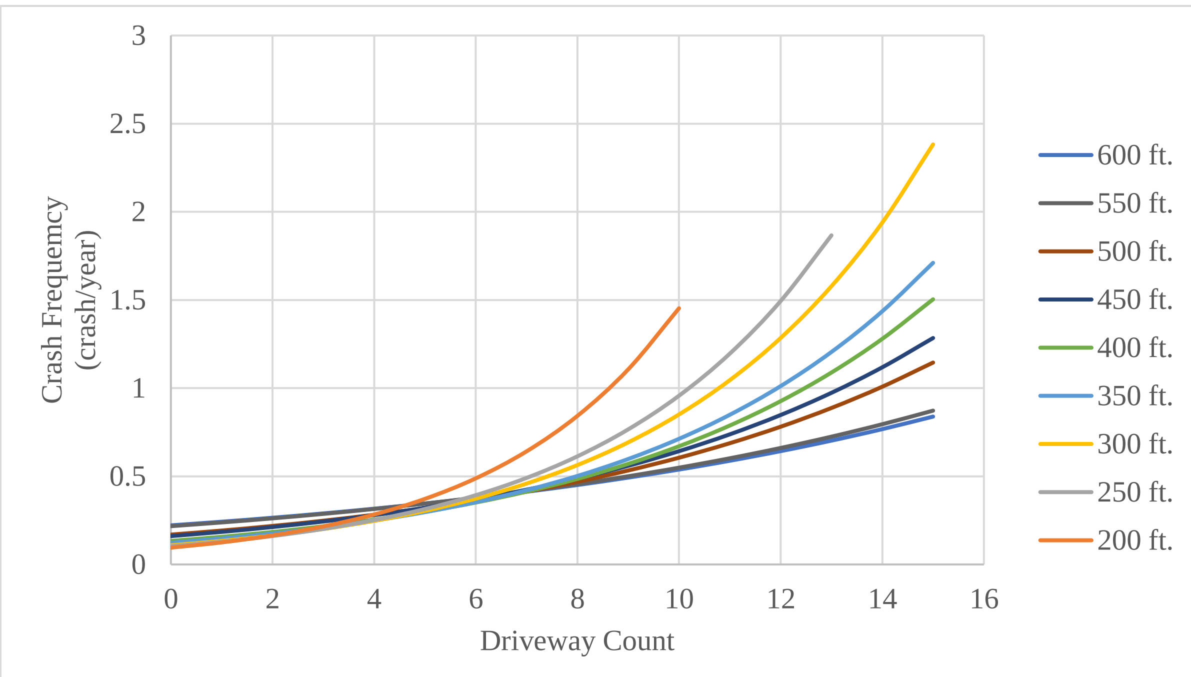


Figure 14: Expected number of crashes with different driveway count using driveway-related crashes

Table 10: Buffer performance based on driveway-related crashes (200 ft. to 450 ft.)

Parameter	**200-ft radius**			**250-ft radius**			**300-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-9.245	2.542	<0.001	-8.103	2.345	0.001	-8.962	2.253	<0.001
Natural log of major AADT	0.459	0.260	0.078	0.429	0.241	0.075	0.513	0.231	0.026
Natural log of minor AADT	0.330	0.118	0.005	0.226	0.109	0.038	0.240	0.104	0.021
Natural log of average driveway AADT	0.077	0.047	0.100	0.070	0.044	0.107	0.050	0.040	0.220
Number of driveways	0.273	0.072	<0.001	0.223	0.050	<0.001	0.206	0.039	0.000
Percentage of driveways with prohibited left-turn	-0.542	0.279	0.052	-0.424	0.268	0.114	-0.458	0.259	0.077
Commercial area (base = residential)	0.979	0.363	0.007	1.086	0.338	0.001	1.214	0.332	<0.001
Overdispersion	1.393	0.314	<0.001	1.414	0.284	<0.001	1.376	0.263	<0.001

Parameter	**350-ft radius**			**400-ft radius**			**450-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-9.427	2.225	<0.001	-10.219	2.213	<0.001	-10.166	2.111	<0.001
Natural log of major AADT	0.556	0.228	0.015	0.624	0.226	0.006	0.640	0.216	0.003
Natural log of minor AADT	0.241	0.101	0.017	0.238	0.098	0.015	0.222	0.092	0.016
Natural log of average driveway AADT	0.066	0.039	0.090	0.085	0.038	0.025	0.121	0.036	0.001
Number of driveways	0.175	0.032	<0.001	0.162	0.028	<0.001	0.139	0.023	<0.001
Percentage of driveways with prohibited left-turn	-0.466	0.250	0.063	-0.421	0.239	0.078	-0.351	0.230	0.127
Commercial area (base = residential)	1.267	0.327	<0.001	1.347	0.324	<0.001	1.194	0.299	<0.001
Overdispersion	1.385	0.249	<0.001	1.346	0.235	<0.001	1.238	0.210	<0.001

Table 11: Buffer performance based on driveway-related crashes (500 ft. to 600 ft.)

Parameter	**500-ft radius**			**550-ft radius**			**600-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-10.833	2.081	<0.001	-11.828	2.078	<0.001	-11.767	2.008	<0.001
Natural log of major AADT	0.712	0.213	0.001	0.797	0.212	<0.001	0.810	0.205	<0.001
Natural log of minor AADT	0.214	0.090	0.017	0.256	0.090	0.004	0.250	0.085	0.003
Natural log of average driveway AADT	0.127	0.036	<0.001	0.176	0.038	<0.001	0.133	0.036	<0.001
Number of driveways	0.127	0.021	<0.001	0.093	0.018	<0.001	0.089	0.016	<0.001
Percentage of driveways with prohibited left-turn	-0.365	0.231	0.114	-0.511	0.233	0.028	-0.647	0.228	0.005
Commercial area (base = residential)	1.246	0.298	<0.001	1.054	0.287	<0.001	1.285	0.283	<0.001
Overdispersion	1.250	0.205	<0.001	1.290	0.196	<0.001	1.248	0.185	<0.001

The average AADT of driveways within each buffer showed positive correlation with the expected number of crashes. Figure 15 shows the safety performance of all buffers with different traffic volumes. Each line have similar trends in which the expected number of crashes increase rapidly when the average AADT of driveways is in between zero to 500 vpd. This observation may be due to the small sample size of intersections with average AADT of driveways less than 500 vpd for all buffers. Moreover, this figure shows that on average, bigger buffers had higher number of crashes when using the same traffic volumes. This finding reveals that bigger buffers would yield more driveways, which will associate with high average of traffic volumes entering and exiting the driveways, and eventually will increase the expected number of crashes. However, despite the increase in the expected number of crashes, the slope of each line decrease exponentially as the average traffic volumes increase.

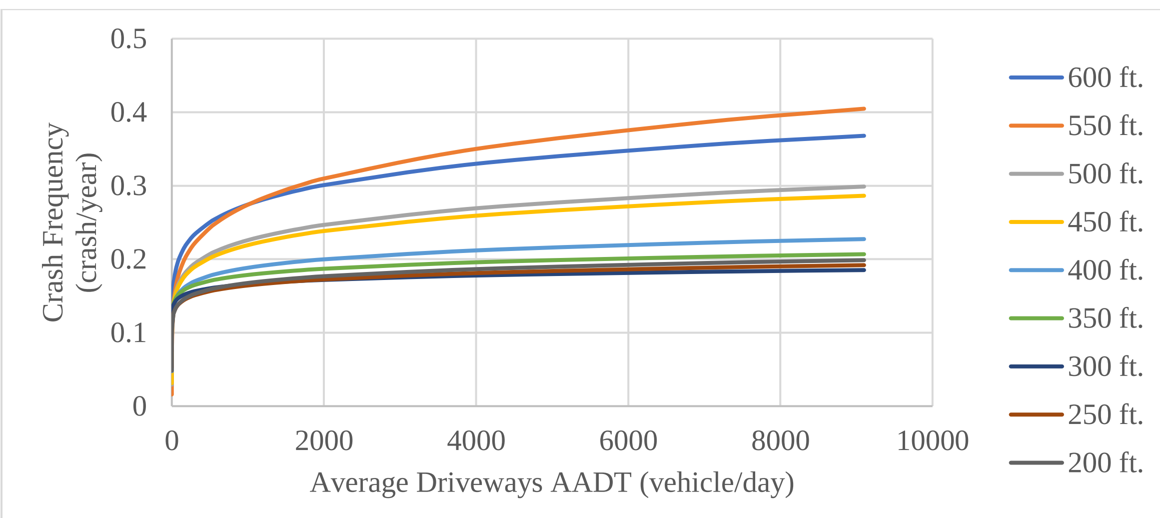


Figure 15: Expected number of crashes with different driveway AADT

5.3 Total Crashes

In this research, the total crashes will include all crashes that occurred on primary road network within the studied buffers. Table 12 to Table 14 represents the SPFs for all 12 buffers. For total crashes models, the only variable related to driveway that was significant was the driveway frequency. Some of the bigger buffers (400 ft. and above) were shown to have significant results on other variables related to driveway (turning movement and driveway volumes). However, as mentioned previously in section 5.2, similar predictor variables were used for all buffers to ensure the consistency between the buffers when predicting the total crashes (similar for the base case of categorical variable). Thus, those variables were removed from the models. Moreover, compared to driveway-related crashes models, number of lanes was shown to be significant for total crashes models. For the analyses of total crashes within the intersection area, the total number of access points was used as a predictor, which includes the count of both unsignalized intersections and driveways within each buffer.

Table 12: Safety performance function for total crashes within 600 ft.

Parameter	**Estimate**	**Std. Error**	**Pr(>|z|)**
Intercept	-4.113	0.796	<0.001
Natural log of major AADT	0.492	0.087	<0.001
Natural log of minor AADT	0.221	0.036	<0.001
Number of access points within 600 ft.	0.039	0.006	<0.001
Residential land development	-	-	-
Commercial land development	0.378	0.091	<0.001
Major road – 2 lanes (base)	-	-	-
Major road – 3 lanes	0.726	0.209	0.001
Major road – 4 lanes or more	0.520	0.172	0.003
Overdispersion	0.451	0.033	<0.001

Table 12 shows the SPF for total crashes using 600 ft. buffer, which includes the estimate coefficients, standard errors, and p-values for the intercept and predictor variables. All variables in this table have positive correlation with the expected number of crashes. Increase in the traffic volumes for both major and minor roadways will result in 0.49 percent and 0.22 percent increase in the expected number of crashes, respectively. As expected, the percentage increase in the number of crashes based on traffic volumes when using total crashes is lower than the one in the driveway-related model. One of the reasons to this finding may be due to the non-inclusion of other predictor variables in the model that influenced those crashes as this model includes all types of crashes.

The number of access points in a close vicinity of a signalized intersection can create safety issues for the intersection based on previous study. Table 12 shows that the number of access points within 600 ft. from the center of intersection has an estimate coefficient of 0.039. By using Equation 5, the marginal effect of this variable can be determined. With every access point within 600 ft. distance, crashes would be expected to increase by 3.98 percent. Moreover, commercial areas are expected to experience 46 percent more crashes when compared to residential areas.

From previous studies, number of lanes is shown to have a directly proportional relationship between crashes. Noland and Oh (2004) mentioned that increase in the number of lanes would be expected to increase the number crashes as well as the number of fatalities. Table 12 shows two categories of number of lanes and a dummy variable (lanes equal to two). The result shows that with an increase in the number of lanes on major roadway, crashes would be expected to increase as well. Intersections where the major roadway has three lanes experienced twice as many crashes when compared to intersections where the major road has only two lanes. Intersections with more than three lanes on the major roadway experienced 68 percent more crashes (compared to locations where the major roadway has two lanes).

The findings on number of lanes initially seem counterintuitive, since crashes would be expected to consistently increase as the number of lanes increase. This result suggested that intersections with four lanes or more on major roadway would have turning movement channelization features for vehicles to decelerate safely adjacent to the through moving traffic (which is likely to reduce the possibility to involve in rear-end collision). For three lanes roads, one possibility for this finding was the sharing of lanes between through movement and turning movement. Abdel-Aty and Wang (2006) presented in their research that intersections with no exclusive right-turn lane or protected left-turn lane would have higher number of crashes when compared to intersections with exclusive right-turn lane or protected left-turn lane. Consequently, crashes would increase as the number as the number of lanes increased. Drivers requiring to change lanes more often and prepare their movements further ahead when high number of access point are present adjacent to the signalized intersection, will increase the likelihood of motorists to be involved in crashes.

Similar to the models from driveway-related crashes, there are some predictor variables that did not show any significant effect on the safety performance of the intersections. Except for the number of lanes, other variables were not significantly correlated with expected number of crashes including the traffic volume of the driveways as well as the turning movement's availability.

Table 13 and Table 14 show the SPFs created from all 12 buffers for total crashes on primary roadway segments. The effect of access point frequency within proximity of each buffer radius to signalized intersection can be determined from these two tables. The findings demonstrate that the estimate coefficients of number of access points increased as the buffer radius decreased which indicates that crashes would be higher within the smaller buffer.

Table 13: Buffer performance based on total crashes (50 ft. to 300 ft.)

Parameter	**50-ft radius**			**100-ft radius**			**150-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-5.887	1.125	<0.001	-6.138	1.016	<0.001	-6.126	0.957	<0.001
Natural log of major AADT	0.528	0.124	<0.001	0.566	0.112	<0.001	0.581	0.105	<0.001
Natural log of minor AADT	0.322	0.053	<0.001	0.317	0.047	<0.001	0.306	0.044	<0.001
Number of access points	0.135	0.158	0.390	0.120	0.072	0.093	0.077	0.037	0.037
Residential land development (base)	-	-	-	-	-	-	-	-	-
Commercial area (base = residential)	0.187	0.127	0.141	0.187	0.115	0.104	0.209	0.108	0.053
Major road – 2 lanes (base)	-	-	-	-	-	-	-	-	-
Major road – 3 lanes	0.572	0.296	0.053	0.639	0.268	0.017	0.655	0.252	0.009
Major road – 4 lanes or more	0.598	0.244	0.014	0.628	0.221	0.005	0.602	0.208	0.004
Overdispersion	0.872	0.065	<0.001	0.700	0.053	<0.001	0.616	0.047	<0.001
Parameter	**200-ft radius**			**250-ft radius**			**300-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-6.143	0.913	<0.001	-5.834	0.890	<0.001	-5.852	0.866	<0.001
Natural log of major AADT	0.602	0.100	<0.001	0.577	0.097	<0.001	0.577	0.095	<0.001
Natural log of minor AADT	0.292	0.041	<0.001	0.286	0.040	<0.001	0.281	0.039	<0.001
Number of access points	0.072	0.023	0.002	0.057	0.016	<0.001	0.053	0.013	<0.001
Residential land development (base)	-	-	-	-	-	-	-	-	-
Commercial area (base = residential)	0.174	0.102	0.089	0.217	0.100	0.030	0.232	0.097	0.017
Major road – 2 lanes (base)	-	-	-	-	-	-	-	-	-
Major road – 3 lanes	0.738	0.240	0.002	0.776	0.233	0.001	0.863	0.228	<0.001
Major road – 4 lanes or more	0.617	0.198	0.002	0.631	0.193	0.001	0.713	0.189	<0.001
Overdispersion	0.557	0.043	<0.001	0.532	0.041	<0.001	0.504	0.039	<0.001

Table 14: Buffer performance based on total crashes (350 ft. to 600 ft.)

Parameter	**350-ft radius**			**400-ft radius**			**450-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-5.337	0.850	<0.001	-4.890	0.845	<0.001	-4.249	0.836	<0.001
Natural log of major AADT	0.551	0.093	<0.001	0.526	0.092	<0.001	0.475	0.092	<0.001
Natural log of minor AADT	0.270	0.039	<0.001	0.247	0.038	<0.001	0.243	0.038	<0.001
Number of access points	0.050	0.011	<0.001	0.051	0.010	<0.001	0.049	0.008	<0.001
Residential land development (base)	-	-	-	-	-	-	-	-	-
Commercial land development	0.236	0.096	0.014	0.260	0.096	0.007	0.310	0.095	0.001
Major road – 2 lanes (base)	-	-	-	-	-	-	-	-	-
Major road – 3 lanes	0.757	0.223	0.001	0.840	0.222	<0.001	0.776	0.220	<0.001
Major road – 4 lanes or more	0.599	0.184	0.001	0.640	0.184	<0.001	0.568	0.181	0.002
Overdispersion	0.494	0.038	<0.001	0.496	0.038	<0.001	0.495	0.037	<0.001

Parameter	**500-ft radius**			**550-ft radius**			**600-ft radius**		
	Estimate	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
Intercept	-4.134	0.817	<0.001	-4.148	0.809	<0.001	-4.113	0.796	<0.001
Natural log of major AADT	0.479	0.090	<0.001	0.493	0.089	<0.001	0.492	0.087	<0.001
Natural log of minor AADT	0.238	0.037	<0.001	0.226	0.037	<0.001	0.221	0.036	<0.001
Number of access points	0.044	0.007	<0.001	0.041	0.007	<0.001	0.039	0.006	<0.001
Residential land development (base)	-	-	-	-	-	-	-	-	-
Commercial area (base = residential)	0.331	0.093	<0.001	0.339	0.092	<0.001	0.378	0.091	<0.001
Major road – 2 lanes (base)	-	-	-	-	-	-	-	-	-
Major road – 3 lanes	0.712	0.214	0.001	0.716	0.212	0.001	0.726	0.209	0.001
Major road – 4 lanes or more	0.492	0.176	0.005	0.495	0.174	0.005	0.520	0.172	0.003
Overdispersion	0.473	0.035	<0.001	0.464	0.034	<0.001	0.451	0.033	<0.001

Figure 16 shows the expected number of total crashes with respect to the number of access points while keeping other predictor variables constant. This figure illustrates how the annual number of crashes within the vicinity of the intersection varies based upon the size of the buffer radius. Similar to Figure 14, each line in this figure represents the SPF from Table 13 and Table 14. Regardless of the size of the buffers, crashes increase as the number of access points increase. However, the rate of increase in crashes generally decreases with each 50-ft increase in radius. Note that the first four buffer distances are characterized by both a solid and dashed line. The solid portion represents the range of access point values for which data were available within the sample, while the dashed portion is extrapolation beyond these limits. For example, the 50-ft buffer radius includes either zero, one, or two access points at each of the study intersections. Likewise, radii of 100 ft., 150 ft., and 200 ft. also include some gaps and, therefore, require extrapolation. At 250 ft. and beyond, there is full coverage with respect to access density and no extrapolation is necessary.

Based on this figure, general trends emerge with respect to buffer radii from 50 ft. to 300 ft. and from 350 ft. to 600 ft. As the buffer radius increases from 50 ft. to 300 ft., the impact of an increase in access density becomes less pronounced. This suggests that access points within the first 300 ft. of a signalized intersection should be of particular concern. This is evident by the declining rates (i.e., less steep slopes) as the buffer radius is increased. Beyond 300 ft., the crash rate with respect to the number of access points remains approximately constant, which provides support for locating the first access beyond 300 ft. from the center of the intersection.

From a practical point of view, it is difficult to differentiate if the crashes occurred within the vicinity of intersection are due to the presence of driveway or not. By utilizing the total crashes, it would reduce the potential problem regarding the accuracy of the police-reported crash codes that appoint whether the crash was intersection- or driveway-related. Since driveway-related crashes are a small subset of total crashes, and there might be some difficulty in determining crashes that are actually related to driveway, the effect of driveway (and unsignalized intersection) on total crashes is also important in form of a research and policy standpoint.

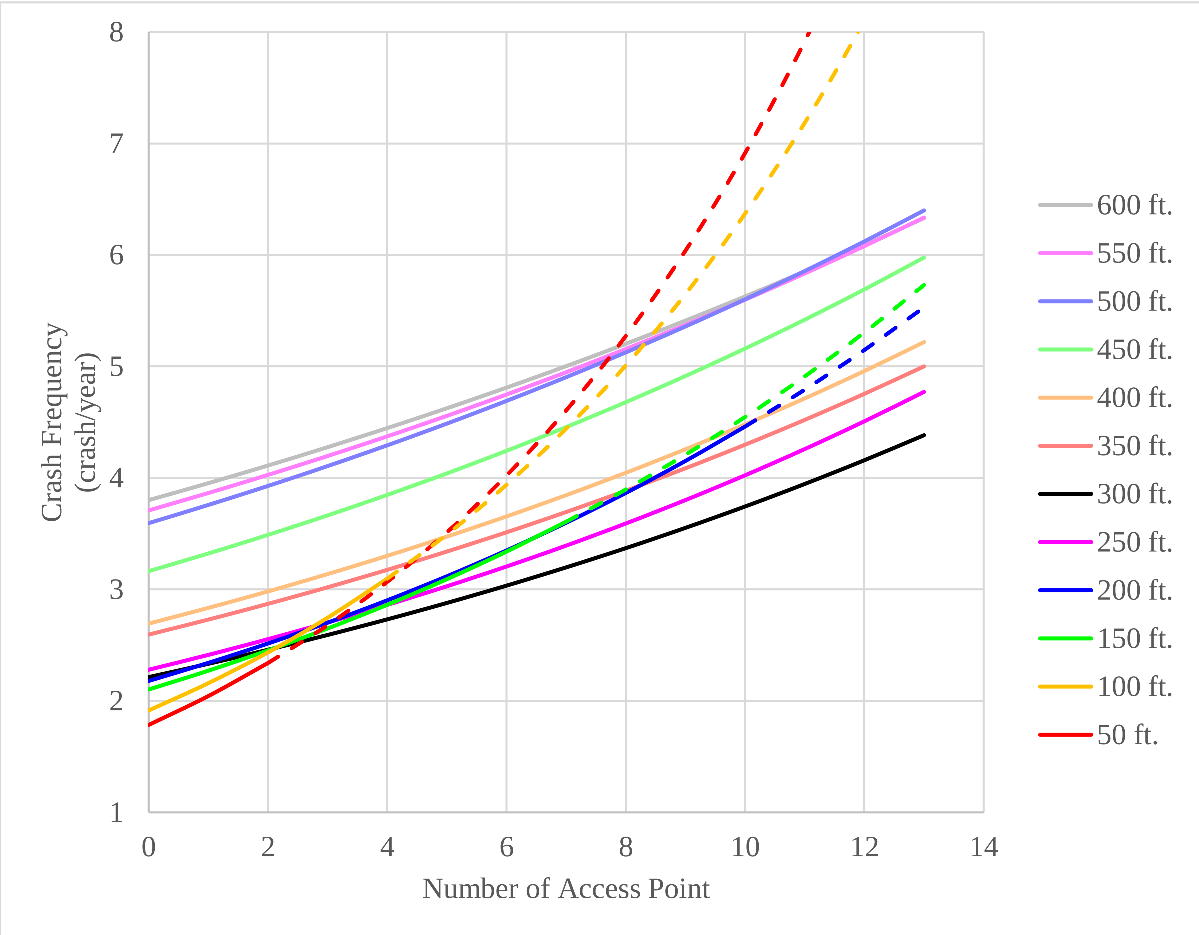


Figure 16: Expected number of crashes with different driveway count using total crashes

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Findings

This study examined the relationship between access point spacing/density on crashes adjacent to signalized intersection on the state-maintained roadway network within urban areas of Iowa. Separate analyses were conducted to discern how both total and driveway-related crashes varied with respect to access control. For each crash type, the sensitivity of crashes with respect to access point frequency was compared across 12 different sizes of buffers, which ranged from 50 ft. to 600 ft. in 50-ft. intervals. These analyses also considered the effects of roadway geometric characteristics, as well as information regarding the access points (e.g., driveway volumes, restrictions on turning movements).

Two types of access points were observed within the studied buffers, which included driveways and unsignalized intersections. Based on the models provided in the previous sections, access point related variables have been shown to have a significant effect on both subsets of crashes when approaching an intersection. The number of crashes was shown to increase consistently with the frequency of access points located along the primary roadway adjacent to signalized intersection regardless the types of crashes. From these results, it was presented that the location of an access point relative to a signalized intersection is an important element to ensure the intersection can operate safely and efficiently.

Additionally, restricting left-turn movements for those driveways located near signalized intersections was shown to reduce the expected number of driveway-related crashes. By limiting the movements of vehicles entering and exiting the driveways, the number of conflict points for traffic utilizing the adjacent signalized intersection can be reduced. These reductions were most pronounced for driveway-related crashes (rear-end and right-angle collisions).

The results of this analysis provide empirical support for a minimum corner clearance at signalized intersections, as well as for access policies that restrict left-turn movements into or out of driveways. As noted in the literature review, there are several guidelines from various jurisdictions as to the minimum corner clearance adjacent to intersections. However, these guidelines vary from one transportation agency to the other as shown in Table 4. Most of these guidelines used several factors (e.g., sight distance of drivers, distance of acceleration, distance travelled during perception-reaction time) to determine the minimum corner clearance that should be established near an intersection. The range of minimum corner clearance from the existing guidelines are from as low as 50 ft. to the maximum of 800 ft. for roadways with average speed limit of 40 mph (average speed for major roadway in this study is 37 mph).

Ultimately, the findings from this study showed that when access points are within close proximity to an intersection, crash rates tend to increase significantly, especially within the first 100 ft. radius (as shown in Figure 14 and Figure 16). The effects of each additional access point decreased as the radius from the center of the intersection increased. In general, the further an access point is located from the intersection, the fewer crashes would be expected. The results from this study showed that crash rates decreased consistently as the buffer radius (from the center of the adjacent intersection) was increased from 50 ft. to 300 ft. Beyond this distance, the crash rates remain almost constant. The findings from this study can be used by road agencies to establish thresholds for the minimum distance that an access point should be located adjacent to a signalized intersection. The results of this analysis suggest a 300-ft minimum distance as a reasonable policy/guideline for the primary road network with posted speed limits of 35 mph and 40 mph (the average posted speed limit on major road from the data was 37 mph).

6.2 Limitations and Future Research

There are several limitations that should be stated with respect to the study results. First, all roadway and crash data were integrated using the Geographic Information Management System (GIMS) maintained by the Iowa Department of Transportation (DOT). The GIMS database does not allow for a directional analysis. Consequently, these results consider crashes in both directions. As a result, the impacts of access points may be somewhat understated as compared to a directional analysis. The study also did not distinguish among intersections with different curb-to-curb widths. Intersections with widths greater than 100 ft. would obviously not include any access points within the smallest (50-ft) buffer distance. Additional research is warranted to examine the sensitivity of these results with respect to various intersection configurations.

Moving forward, there are several additional pieces of information that would provide further insight as to the safety of signalized intersection. For example, the analysis could be extended to consider various types of crashes (i.e., rear-end crashes, right-angle crashes, etc.). The sample was also somewhat limited in terms of the diversity of access control strategies, with limited numbers of intersections that prohibited left-turns into and out of driveways. Consequently, research is also warranted that considers how these results transfer to denser urban environments.

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