Quantifying the Safety Effects of Access Management Using VISSIM and SSAM: A Case Study

By

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ABSTRACT

The purpose of this study is to determine the safety effects of different levels of access management strategies on vehicular traffic. The researchers concentrated the study on one of the major arterial located in Lawrence, Kansas.

This research used VISSIM 5.40 microsimulation software to model the existing conditions and three models with different levels of access management such as low, medium, and high. These models were based on the 23rd Street/ Kansas -10 located in Lawrence, Kansas in 2014. The two access management strategies that were implemented were driveway consolidation and median control. The three levels developed were: 1) low – driveway consolidation only, 2) medium – driveway consolidation along with raised median and 8 mid-block openings, 3) high – driveway consolidation along with raised median and 5 mid-block openings. Left turning movement into the driveways was only permitted at the mid-block openings. Simulated conflict were used to evaluate the safety of the access management strategies. The researchers used Safety Surrogate Assessment Model (SSAM) to identify the simulated conflicts generated by VISSIM.

The simulated conflicts and travel times of each model were compared with each other. There was an increase in the travel times for the low level and the high level of access management compared to existing conditions. The medium level of access management experienced a slight decrease in the travel time compared to the existing conditions. In case of total simulated conflicts, there was a significant decrease and a slight decrease in the low level and the medium level respectively when compared with the existing conditions. The total simulated conflicts increased significantly for the high level compared to the existing conditions. There was a significant decrease in the crossing conflicts in all the levels compared to the existing conditions.

In conclusion, the findings of this study indicated that the access management strategies do have a positive effect on the safety of the corridor.

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CHAPTER 1: INTRODUCTION

1.1. Background

According to the Access Management Manual (2003), access management is the systematic control of the location, spacing, design, and operation of driveways, median, openings, interchanges, and street connections to a roadway. All of the above create potential conflict points, where there is a possibility of a vehicle getting into a crash. Access management techniques are proven methods for improving traffic flow and safety.

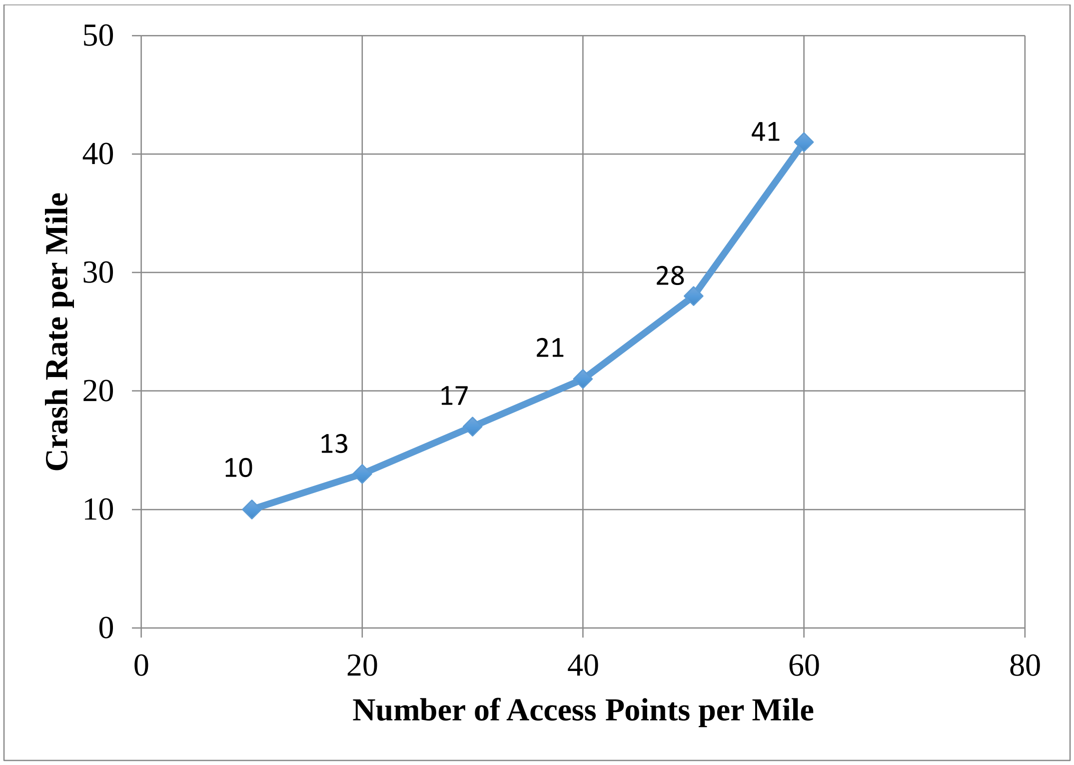


Figure 1: Composite Crash Rate Indices (Source: Gluck et. al., 1999)

Figure 1 shows the relationship between access density and vehicle crash rate per mile. The figure shows that if the access points per mile increase from 10 to 20 there will be an increase in crash rates by 30 percent. Thus, Figure 1 shows that an increase in access density results in the increase of vehicle crash rate per mile. Figure 1 was based on crash rates derived by analyzing 37,500 crashes and comparing that with the literature to get the suggested value (Gluck et. al., 1999).

National Cooperative Highway Research Program (NCHRP) Report 420: Impact of Access Management Techniques also compared 16 studies conducted between the years 1983 – 1995 and found a reduction in the number of crashes in 15 studies. All the studies compared the safety benefits of two-way left turn lane (TWLTL) and raised median. The crash rates varied between an increase of 15 percent (on Central Business District (CBD) of Atlanta, Georgia; Phoenix, Arizona; and Los Angeles, California) to a reduction of 57 percent (on 4-lane arterial streets of Michigan), with a median reduction percentage of 27 percent. This shows that the access management technique of raised median have a considerable safety benefit over TWLTL.

Table 1 shows the relation between access density and the crash rate depending on the median type. It can be seen the crash rates increase as the access density increases. The undivided median with 60 or more access points per mile has 10.6 crashes per million vehicle-miles traveled (million VMT) which was higher than 9.2 per million VMT for TWLTL and 8.2 per million VMT for non traversable median.

Table 1: Representative Accident Rates (Crashes per Million Vehicle-Miles Traveled) by Type of Median-Urban and Suburban Areas (Source: Gluck et. al., 1999)

Total Access Points Per Miles [1]	**Crashes per Million Vehicle-Miles Traveled**		
	Median Type		
	Undivided	**Two-Way Left Turn Lane**	**Non Traversable Median**
Less than or 20	3.8	3.4	2.9
20.01 - 40	7.3	5.9	5.1
40.01 - 60	9.4	7.9	6.8
60 or more	10.6	9.2	8.2
All	9	6.9	5.6

[1] Includes both signalized and unsignalized access points

Along with the safety effects, access management has considerable operational effects as well. Studies have indicated that access management reduces vehicle travel time and delay. NCHRP Report 3-33: Capacity and Level of Service Procedures for Rural and Suburban Highways suggested that a right turning movement reduced the speed by 0.005 mph with a maximum of 10 mph. Table 2 shows that increase in access density leads to the reduction in the free flow speed.

There would be a 10 mph reduction in the free flow speed if the access density were more than 40 access points per mile.

Table 2: Access Point Adjustment Factors (Source: Table 7-5 of 1994 HCM)

Access Points Per Mile	**Reduction in Free-flow Speed (mph)**
0	0
10	2.5
20	5
30	7.5
40 or more	10

The most important result of properly implemented access management in an urban corridor is increasing safety for vehicles and pedestrians. Bowman and Vecellio (1993) reported that the vehicle-pedestrian crash rate for raised median was lower than the TWLTL and undivided sections of the CBD of Atlanta, Georgia; Phoenix, Arizona; and Los Angeles, California.

There are a number of access management strategies that can be implemented, which include the following:

- Access spacing: Access spacing is the distance between the centerlines of two adjacent access points. Access points such as driveways increase conflict points and slows down the through traffic. Controlling access spacing reduces the conflict points and smoothens the traffic flow. Figure 2 shows the spacing between the driveways.

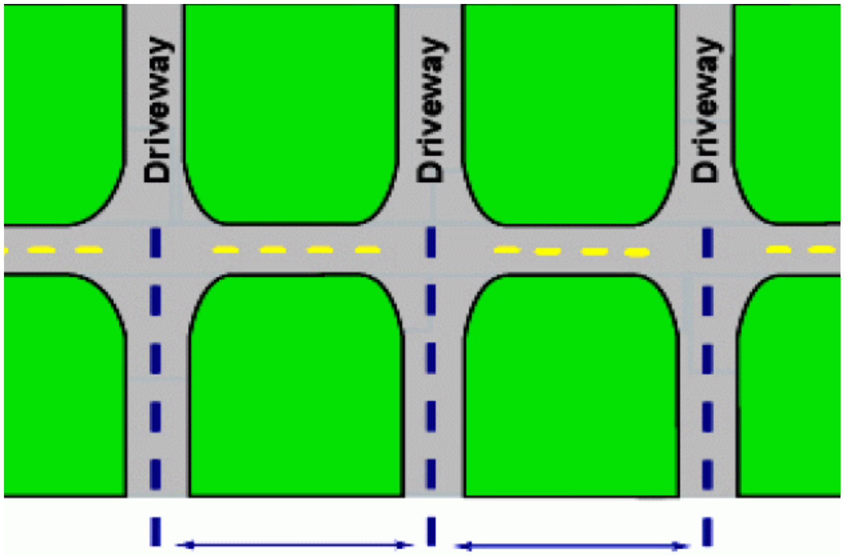


Figure 2: Access Spacing (Source: Missouri Department of Transportation, 2014)

- Cross access: Cross access allows the adjacent property to share a single access. In this case the vehicles can move between properties without entering the roadway. This helps in maintaining the access spacing. Figure 3 shows a sample of cross access. In Figure 3 vehicles can move between properties A, B, C, and D and there is a single access point along the front street.

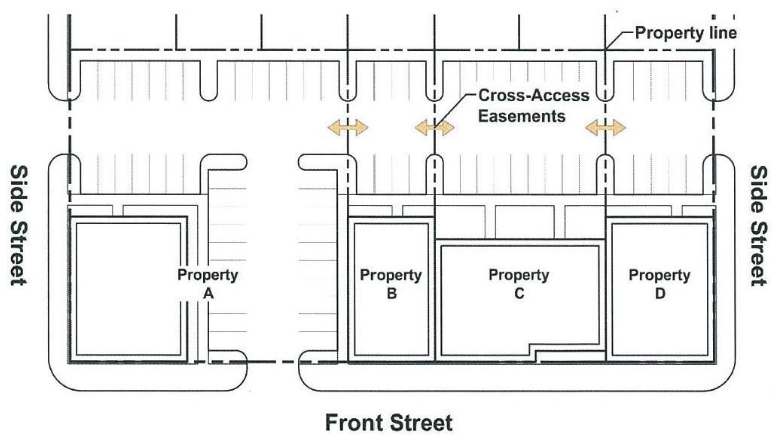


Figure 3: Cross Access (Source:City of Yorker, 2014)

- Driveway channelizing islands: Channelizing islands help prevent the prohibited movements. Figure 4 shows a sample driveway channelizing island. In this case left turning movement out of the driveway is prohibited.

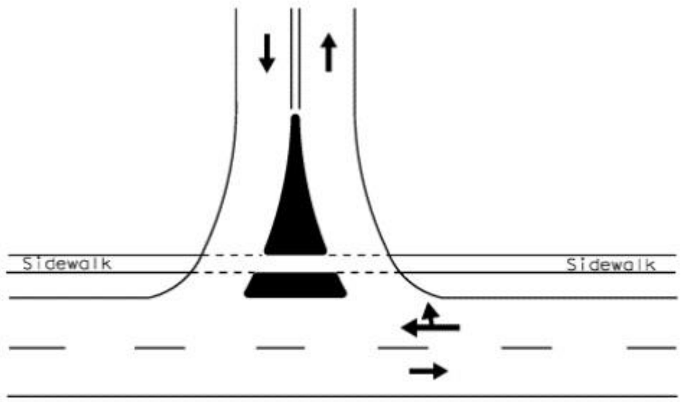


Figure 4: Driveway Channelizing Island (Source:Texas Department of Transportation, 2014)

- Indirect left turn: In this strategy left turns are prohibited at the signalized intersections along the intersection, instead U-turns are permitted at locations upstream or downstream of intersections. This strategy reduces the conflict points at the intersections. Figure 5 shows an indirect left turn at an intersection with capability of U-turn downstream of the intersection.

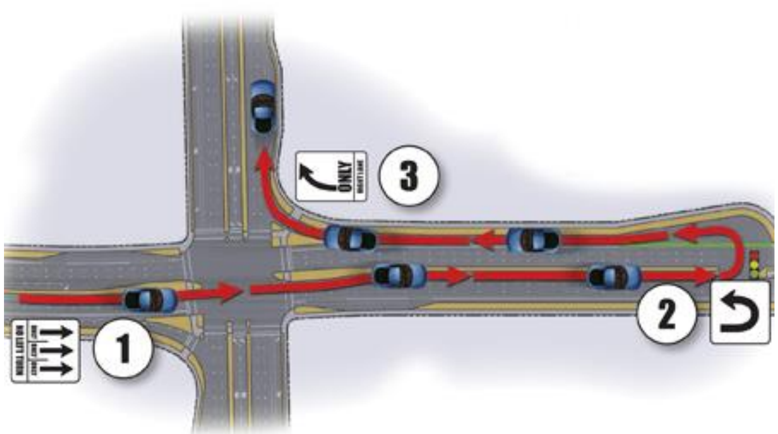


Figure 5: Indirect Left Turn (Source: Pima County, Arizona, 2014)

- Non-traversable median: Non-traversable median physically separates the opposing traffic. It also limits access and conflicts. Figure 6 shows a raised median laid along a roadway.

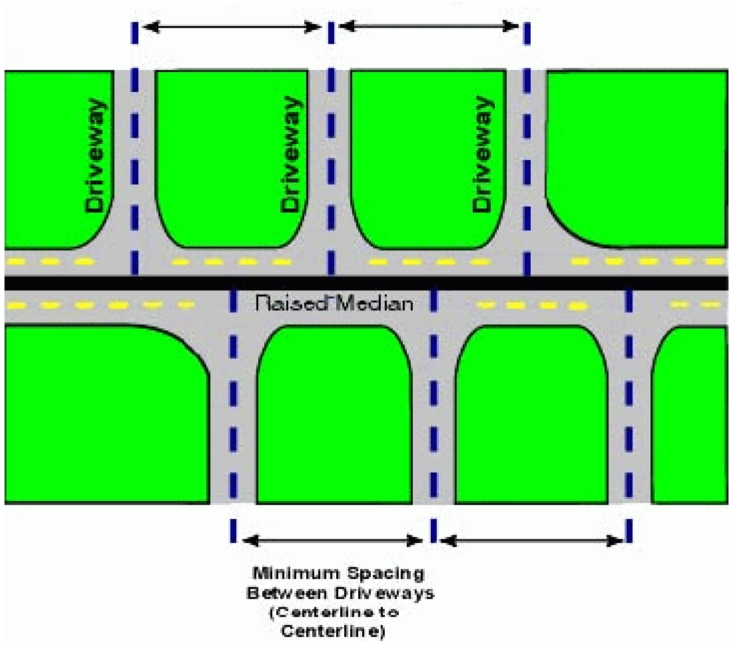


Figure 6: Non-traversable Median (Source: Missouri Department of Transportation, 2014)

- TWLTL: TWLTL helps vehicles make left turns in either direction. This improves the safety by removing the left turning vehicles from the through lanes. Figure 7 shows a typical TWLTL.

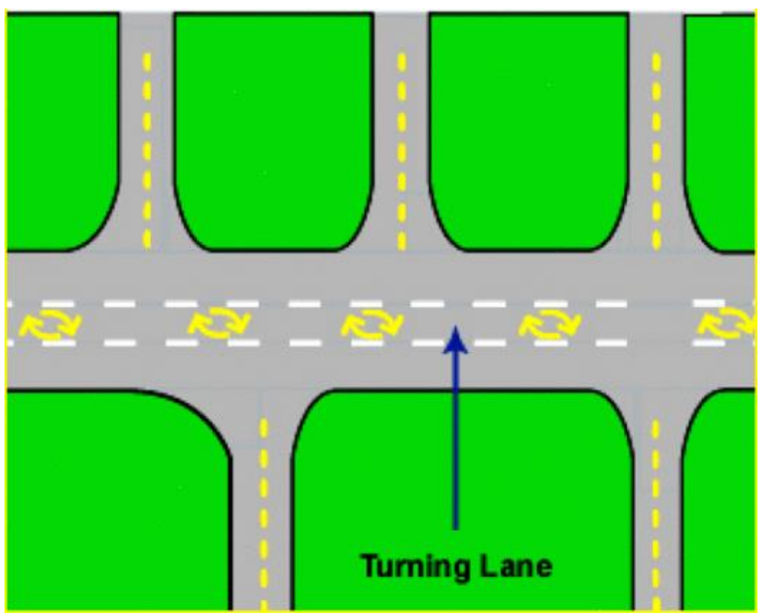


Figure 7: TWLTL (Source: Missouri Department of Transportation, 2014)

- Uniform signal spacing: Signal spacing helps maintain efficient traffic flow and progression along urban roadways. A quarter mile or half-mile signal spacing allows traffic signals to be interconnected and synchronized. Figure 8 shows a corridor with uniformly spaced traffic signals.

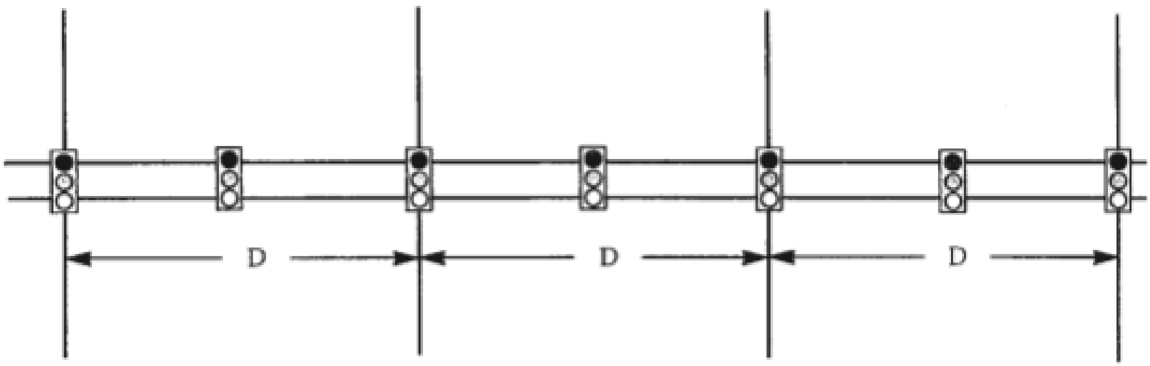


Figure 8: Uniform Signal Spacing (Source: NCHRP 420, 1999)

- Upstream/downstream corner clearance: Corner clearance is the distance between the corner of the intersection of two public roadways and the next private driveway. Distance between the intersection and the first driveway should be sufficient so that it efficiently separate conflict points and allows drivers to make safe movement into driveway. Figure 9 shows a adequate and inadequate corner clearance.

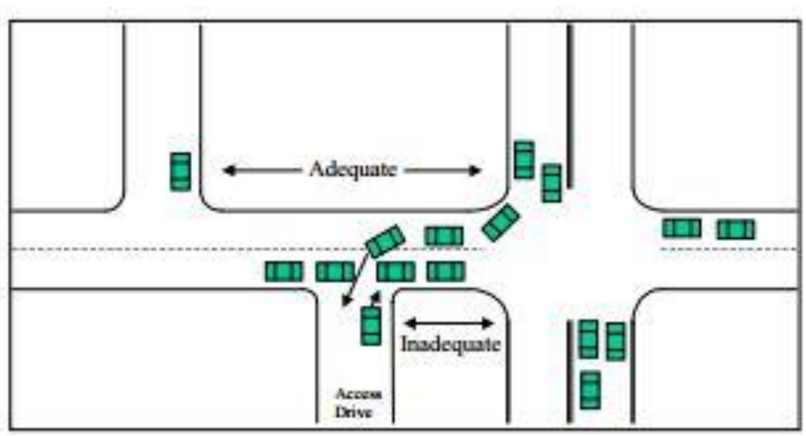


Figure 9: Corner Clearance (Source: CTRE, Iowa State University, 2014)

These access management strategies have been implemented across the country and their effectiveness has been reported by previous research studies (Gluck et. al., 1999; Bowman and Vecellio 1993; Eisele and Frawley 2004).

Currently, there is no inexpensive way to measure the impacts of access management strategies over a corridor, let alone different levels of access strategies or combination of access management strategies. It is important to study the impacts of the strategies so as to provide better guidelines when it comes to implementation of various strategies. The implementation of access management strategies is relatively expensive; hence, it is essential to be sure that access management will have a positive impact on the corridor.

Retrofitting corridors with access management strategies is difficult compared to implementing it in new corridors. Businesses along existing corridor perceive that the impact of access changes on their business will be adverse. However a study by Eisele and Frawley (2000) suggests that raised median allowed for efficient traffic flow and resulted more customers for the business. The researchers conducted interviewes of business owners along the corridor in College Station, Texas before, during a construction project with a raised median, and after completion of the project. Even with the study showing increased business, the businesses are apprehensive about implementation of access management strategies.

A low-cost way to quantify the safety effects of access management that has been found to have limited research is the use of microsimulation and the Federal Highway Administration (FHWA) Safety Surrogate Assessment Model (SSAM). This combination of programs has had limited research published with respect to access management.

1.2. Research Objective

The objective of this research study was to quantify the safety and operational effects of implementing access management strategies along the 23rd Street corridor in Lawrence, Kansas.

Generally the safety of intersections and roadways can be assessed by performing a crash analysis over a specified period of time. This method can sometimes be cumbersome to identify the need to make changes in the roadway geometry or operation, given the infrequent and random nature of crashes. Access management is aimed at increasing the safety in the corridor where it is implemented. The FHWA SSAM is a model that combines microsimulation and an automated conflict analysis. The SSAM analyzes the frequency of averted vehicle-to-vehicle collisions in traffic, and to evaluate the safety of the facilities without waiting for the crashes and injuries to actually occur. FHWA studied the inclusion of SSAM as a microsimulation tool. Pu and Joshi (2008) define surrogate safety measures as time-to-collision (TTC) and post enchroachment time (PET). The TTC value is defined as the time that remains until a collision between two vehicles will occur if the collision course and the relative speed difference remains unchanged. The FHWA SSAM analysis TTC value for each vehicle-to-vehicle interaction and records a conflict if the TTC value is less than the threshold value of TTC. The PET value is defined as the time between when the first vehicle's last occupied position and the the time when the second vehicle occupies or encroaches on the same position. A PET value of zero indicates a collision, as two vehicles try to occupy the same position at the same time.

1.3. Thesis Organization

This thesis is divided into seven chapters. Chapter 1, Introduction, presents a brief background of access management and discusses the effects it has on the corridor. The research objective is presented in this chapter. Chapter 2 summarizes the literature from past and current studies on access management, microsimulation, SSAM and traffic conflicts. Chapter 3 introduces the problem statement and explains why a low-cost way is needed to quantify the effects of access management strategies. Chapter 4 explains the methodology of microsimulation model creation and field data collection. Chapter 5 includes the results of the research and the statistical analysis of the research. Finally, Chapter 6 has the summary of findings, and the scope for future studies.

CHAPTER 2: LITERATURE REVIEW

2.1. Access Management

FHWA defines access management as a set of techniques that state and local governments can use to control access to highways, major arterials, and other roadways. There are various techniques in which access management can be implemented, such as increased spacing between intersections, driveway spacing and driveway design.

Squires and Parsonson (1989) found that crashes increased by 40 percent when the as the number signalized intersection density increased from two to four per mile. Reilly (1990) found that doubling the number of driveways from 10 to 20 access points per mile increased the crashes by almost 30 percent.

Noyce et. al. (2006) evaluated the safety and operational characteristics of TWLTL compared to four-lane undivided roadways at nine different sites in Minnesota. An analysis of operational and crash data was performed before and after the conversion of a four-lane undivided to a three-lane roadway with TWLTL. They observed that the crashes were reduced by 37 percent, 46 percent, and 24 percent, respectively, for total crashes, property damage only (PDO) and left turning crashes.

Gattis (1996) compared three four-lane divided roadway segments, which had similar volumes, and similar land use in Arkansas. The roadways differed in the level of access control. Segment A has an older type of development with individual access points, segment B has some individual accesses with some combined/shared access points, and segment C has mostly combined/shared access points. After analyzing the crash data for all three roadway segments, it was found that segments A and B had similar crash frequency and PDO frequency while segment C's PDO frequency was almost reduced by half and the crash frequency lower. The travel times of segment C were 30 percent lower than segment A and slightly lower than segment B.

Stuecheli (2000) reviewed the 135th Street corridor in Overland Park, Kansas, in order to assess the access management strategies to determine whether the traffic operations along the intersecting streets and collector streets could be improved by providing more access to adjacent properties. Alternative access management strategies were evaluated based on the traffic operations for projected 2020 p.m. peak hour traffic conditions. Assumptions were made for type, location and intensity of development and the street network available to serve it. The study area included 135th Street, 133rd Street and 137th Street, from Blackbob Road in Olathe on the west to State Line Road in Leawood to the east. The researcher used Overland Park's traffic model, which was a travel demand model distributing the p.m. peak hour traffic over the street network. To make the model accurate, the street network extends to the cities of Prairie Village, Kansas, Kansas City, Missouri, Lenexa, Kansas, Olathe, Kansas, Leawood, Kansas, and Johnson County on the south. A level of service (LOS) assessment was done at all the proposed intersections along 135th Street. The corridor was modeled for future conditions in CORSIM. After considering several alternatives, the researcher concluded that the current access management strategy was acceptable. They also noted that adding access at one-eighth mile intervals wherever feasible would have a minimal effect on the operations. They also suggested a full access signalized intersection between US 69 and Antioch Road.

Brown and Tarko (1999) studied the effects of access control on safety of an urban arterial by developing three regression models. The researchers developed models with similar structures, to predict the number of total crashes, number of PDOs and the number of fatal and injury crashes. Risk variables used were segment length, number of years and average annual daily traffic (AADT). Factors that were considered included density of access points, proportion of signalized access points, outside shoulder presence, TWLTL presence and a raised median presence. The researchers selected 155 segments with various levels of access control, but similar cross sections and traffic. Crash data for a five-year period (1991 to 1995) was used. Exceptions where the segments underwent improvements, three-year crash data were used. The researchers concluded that increase in the access density and the number of signals increased the crash rates, while the presence of a median with no openings and an outside shoulder reduced the crash rate.

A demonstration project conducted by the Colorado Department of Highways (1985) analyzed and compared three-year crash data for two access-managed highways (Arapahoe Avenue and Parker Drive in Denver, Colorado) with that of five arterials with no access control. The two access managed arterials had crash rate 40 percent less than the crash rate for the arterials with no access control (the range was 27 to 69 percent).

Bowman and Vecellio (1993) performed a study to investigate the safety impacts of raised curb medians, TWLTL and undivided cross sections. The researchers analyzed a total of 32,894 vehicle crashes and 1,012 pedestrian crashes, from 145.9 miles of unlimited access arterials in central business districts and suburban environments of Atlanta, Georgia; Phoenix, Arizona; and Los Angeles, California. The researchers collected average daily traffic (ADT), segment length, land use, geometric, crash data, and conflict data for the selected arterial roadways. A relationship between crash and conflict data was developed using a paired t-test. The researchers developed 12 models to estimate vehicle crashes, mid-block vehicle crashes, pedestrian crashes, and mid-block pedestrian crashes for raised, TWLTL, and undivided arterials, respectively. The researchers, after running the predictive models concluded that crash rates were significantly reduced with raised medians in the CBD, but there were no significant differences between crash rates for raised medians and TWLTL in suburban areas.

2.2. Access Management using Microsimulation and the Surrogate Safety Assessment Model

Generally, safety of the access management strategy is evaluated by comparing the before and after crash rates for the corridor. In this method it is not possible to evaluate the safety effects of access management strategy before it is implementation. Microsimulation tools used in combination with SSAM help evaluate the impacts of access management strategies before they are actually implemented. The engineers can compare number of alternative design for different access management strategies and select the with most safety benefit.

Eisele and Frawley (2004) investigated the operational impacts (travel time, speed, and delay) of access management techniques raised medians and driveway consolidation using VISSIM. The researchers considered Bryan, Temple, and Tyler in Texas for the study. All the corridors had a TWLTL before the raised medians were implemented, and traffic performances before and after implementation were studied. Three scenarios were investigated with varying driveway spacing, number of lanes, and median types. The researchers were required to run the VISSIM model at least three times to get the results to converge on an acceptable average value for the performance measures. It was reported that implementation of raised median increased travel times from 2 to 57 percent in two corridors, while a reduction of 11 to 38 percent on one corridor compared to TWLTL. They also reported a reduction in the number of conflicts after implementation of a raised median and reduction in the number of driveways. TTC was used as a surrogate measure in SSAM. It was noted that the vehicles in the simulation did not suffer from inattentiveness, misjudgments and errors, thus they assumed a slightly higher TTC. They observed that the harmonic mean of the TTC was higher for the TWLTL corridor than that of the raised median for higher AADTs.

Eisele and Frawley (2004) investigated the relationship of crash rates and access point density, as well as raised medians and TWLTLs. The researchers selected three corridors in Texas, Texas Ave. (Bryan), 31st Street (Temple), and Broadway Ave. (Tyler) to develop a crash rate and access point density relationship. Crash rates were calculated for each corridor in crashes per million vehicle miles traveled. They observed that the presence of raised medians reduced the crash rate by an average of 36 percent. Theoretical corridors were developed for further analysis. Theoretical corridors were divided into three scenarios with varying median treatment, lane configuration, and number of driveways, which in turn decreased the conflict points along the corridor. Decreased conflict points would most likely result in a reduced number of crashes. The analysis results for the theoretical corridors revealed a small difference between travel time and delay between the existing (TWLTL) and proposed (raised median) conditions. Researchers observed that there was a slight increase in the travel time with raised medians compared to the future TWLTL condition. This increase was attributed to the U-turn traffic and circuitous travel. The increase was considered to be offset by the reduction in the conflict points. The crash analysis indicated that the crash rate and access point density shared a linear relationship, thus a higher access point density resulted in higher crash rates.

2.3. Microsimulation and Surrogate Safety Assessment Model

Surrogate measures are observable non-crash events that are physically related in predictable and reliable way to crashes. The surrogate measure should also have a practical way to convert the non-crash events into crashes. These measures can be used in microsimulation models to assess the safety of proposed and experimental roadway designs or operational strategies before they are built.

Sayed and Zein (1999) developed regression prediction models to find relationship between traffic conflicts defined by TTC and traffic volumes and crash rates. Both conflicts and crashes were assumed to follow a Poisson relationship. A statistically significant relationship was found between crashes and conflicts, with an R-square value ranging between 0.70 and 0.77 for signalized intersections. No significant relationship was found at unsignalized intersections.

The FHWA approach is to record all conflict events between any two vehicles during the entire simulation run. There are two criteria for a conflict: a vehicle in the simulation must engage in an evasive action, and the resulting surrogate measure must be below a predefined threshold. A number of surrogate measures were proposed: TTC, PET, maximum speed of the two vehicles, the maximum difference in speed between the two vehicles during the conflict event, initial deceleration rate (DR) of the reacting vehicle, and the location of the start and end points of the conflict event. The report included algorithms to calculate the surrogate measures for different conflict types. In order for surrogates to be extracted and computed from microsimulation, the major microsimulation suites need to be able to output data that can be input into a post-processor. The format proposed for these data was an "event file" that would contain a time history of the speed, acceleration, and location of vehicles that are participants in a conflict during the simulation run. The event file would be created as a plug-in to simulation software and then separately post-processed (Gettman and Head, 2003).

Huang et. al. (2013) conducted a study to identify whether VISSIM simulation models and SSAM provided reasonable estimates of conflicts at signalized intersections. The researchers collected conflict data at 10 signalized intersections in the Nanjing area of China. They compared the observed conflicts with those produced by the simulation model and SSAM. They also studied the effect of calibrating the simulation model on the consistency between the observed and simulated conflicts. They proposed a two-stage calibration procedure and found that the consistency between the observed and simulated conflicts improved considerably. A linear regression model was developed to study the relationship between the observed and simulated conflicts. The model showed that the relationship was statistically significant. The researchers also studied the transferability of the calibrated model with the data that were not used to calibrate and validate the models. The researchers concluded that the models provided reasonable estimates for rear-end and total conflicts, but didn't provide good enough estimates for unexpected driving maneuvers like sudden lane change.

Zhou et. al. (2010) proposed a method to calibrate and validate a microsimulation model, used to study the intersection safety using VISSIM and SSAM. The researchers proposed a two-stage calibration method by combining an experimental optimization and a feasibility test. The researchers analyzed the traffic safety by acquiring the vehicle trajectories from the simulation model and then computing conflict indices. The researchers collected volumes, signal control, geometric design, conflict number (CN), conflict velocity (CV) and delays. They divided CN, CV and delays into two groups, one each for experimental design and validation. After building the base model in VISSIM, delay and vehicle trajectories were acquired. If the delay was within acceptable limits, SSAM was used to identify CV and CN. The model was redesigned if the delay was not within the acceptable limits. The CV and CN values from simulation were then compared with the observed values. A statistical analysis was done, if CV and CN values were within the acceptable range. For the experimental optimization, the parameters were carefully selected, uniform test was designed and the model adjusted to pass the feasibility test. Interval estimations are then performed for the delay, CV, and CN, for an unknown variance and a 95 percent confidence interval. To validate the model, it was again simulated and run using the second data group. A t-test was performed to validate the results; if the results were reliable, then safety was evaluated using the SSAM and VISSIM outputs. To show the application of the proposed procedure the researchers selected three intersections in Shanghai City, China and Hangzhou City, China each. The researchers concluded that safety can be evaluated directly using the experimental optimization.

Fan et. al. (2013) performed safety assessment of seven freeway merge areas in the Nanjing area of China using VISSIM and SSAM. The researchers collected ramp geometric characteristics, speeds, and video for traffic flow and conflicts. The researchers separated the traffic conflicts by identifying the evasive actions such as braking, swerving and sudden deceleration of vehicles. The researchers prepared a base model in VISSIM. In order to replicate the exact behavior of the drivers merging the freeway, a reduced speed zone was established near the entrance of the ramp. The researchers used a two-stage calibration procedure with a travel time based calibration as the first and an adjustment of crucial VISSIM and SSAM parameters in the second. The researchers used a genetic algorithm in order to automatically optimize the calibration parameters. Validation of the simulated model was done using the data that were not used in the calibration procedure. The researchers concluded that VISSIM and SSAM provided good estimates of traffic conflicts, which could be improved by calibrating the simulation models and adjusting the threshold values in SSAM.

Zhou and Huang (2013) developed a traffic safety evaluation method with the use of VISSIM microsimulation and SSAM. The site selection criteria was little or no pedestrians, no on-street parking, and good sight distances, which led to the selection of a two phase signalized intersection in Nanjing, China. All the field data required for calibration and validation of the VISSIM model, like geometrics along with traffic conflicts, were collected in the field. The researchers used a two-stage calibration to improve the goodness-of fit between the simulated data and the field data. The vehicle trajectories from VISSIM were inputted in the SSAM, which then identified the conflicts. The researchers also performed an evaluation of a speed limit reduction as another treatment. The researchers concluded that a safety evaluation of a signalized intersection can be done using the VISSIM and SSAM and speed limit reduction does improve the safety of the intersection.

2.4. Identification of Research Gaps

Several important considerations were found through this literature review. Most of these relate to ways to develop a VISSIM model and analyzing the conflicts.

- According to Squires and Parsonson (1989), Reilly (1990), and Noyce et. al. (2006), access management has a considerable safety effect on corridor.
- Eisele and Frawley studied the effects of access management using microsimulation and SSAM. They also compared the simulated conflicts with those observed in field. It shows the advantages of using microsimulation and SSAM such as comparison of various alternative design can be done, operational and safety effects of access management strategies can be evaluated effectively.
- Research on the use of microsimulation and SSAM to study the safety of intersections and freeway merge areas provided a guide for the threshold values of TTC and PET to be used in this research.

CHAPTER 3: PROBLEM STATEMENT

Traffic engineers are always faced with difficulty when wanting to compare multiple design alternatives. Microsimulation has made this easier and VISSIM is one of the many microsimulation packages available. VISSIM was used for this study as it can model almost all the elements of a roadway, including a TWLTL. It is possible to change the driver behavior in VISSIM, so that a driver can safely turn from the TWLTL and replicate the real world conditions.

Traditionally, a safety assessment of a corridor is done by analyzing the crash data over a period of time. This method is not only cumbersome, but also unreliable due to the limited availability of crash data. It is also difficult to assess the safety effects of treatments before their implementation.

The objective of this study was to evaluate the safety and operational effects of various levels of access management strategies in an urban corridor. The microsimulation package, VISSIM and SSAM, were used to evaluate the safety and operational effects of access management strategies. There have been a number of studies reporting the operating effects of access management strategies in the United States. However, there has been limited research on the use of VISSIM in conjunction with SSAM to evaluate the safety effects of access management strategies. The 23rd Street (K-10) corridor in Lawrence, Kansas was selected for evaluation.

Levels of access management were evaluated for safety and operational effects by compering the levels with each other. To assess the safety effects, the change in the number of conflicts was used as a surrogate for the potential changes in crashes. The number of potential conflicts was obtained from the SSAM, which had input from the vehicle trajectories from VISSIM.

The null hypothesis for this study was, there was no difference in the simulated conflicts with the alternative hypothesis being there was a difference in the simulated conflicts.

CHAPTER 4: RESEARCH APPROACH

This section describes the procedures used to conduct the access management study for the selected corridor in the city of Lawrence. This corridor was modeled in VISSIM using the GIS imagery obtained from the City of Lawrence. The travel time data were collected using the "floating car runs" method.

4.1. Study Development

To evaluate the operational and safety effects of access management strategies, it is necessary to conduct before and after implementation studies. Access management strategies affect operations and safety of the corridor considerably (Eisele and Frawley, 2004). Conflicts were considered as a surrogate measure to evaluate the effectiveness of access management when it comes to safety. 23^{rd} Street/ Kansas-10 (K-10) corridor is one of the busiest roadways in Lawrence, Kansas. The corridor has a high access density and a high crash rate compared to other arterials in Lawrence. A corridor study was also conducted by the city in 1999 to evaluate the existing conditions and analyze traffic operations. These reasons led to the selection of 23^{rd} Street/K-10 for this study.

4.2. Background

The City of Lawrence, Kansas is located in Douglas County, 40 miles southwest of Kansas City, Kansas. The city has a population of over 87,000 residents and is the location of the University of Kansas. Interstate 70 (I-70) also borders Lawrence on the north. K-10 runs east west and connects the City to the Kansas City Metropolitan area. West 23^{rd} Street/ K-10 is a major arterial and is signal controlled through the city, with many retail and commercial establishments located along the route.

4.3. Study Area

Figure 10 shows the study corridor along with all the signalized intersections as black dots. The focus area for the study was the section of K-10 (West 23^{rd} Street) bounded by Iowa Street (US 59) on the west and Massachusetts Street on the east. The length of the section was approximately 1.32 miles. The majority of the corridor had commercial establishments with some exceptions near the east end where some residences were located. K-10 for its entire study length was a four-lane undivided paved roadway with curb and gutter. The corridor had commercial and residential driveways, and collector streets intersecting the roadway. Sidewalk was present for almost the entire corridor on both sides.

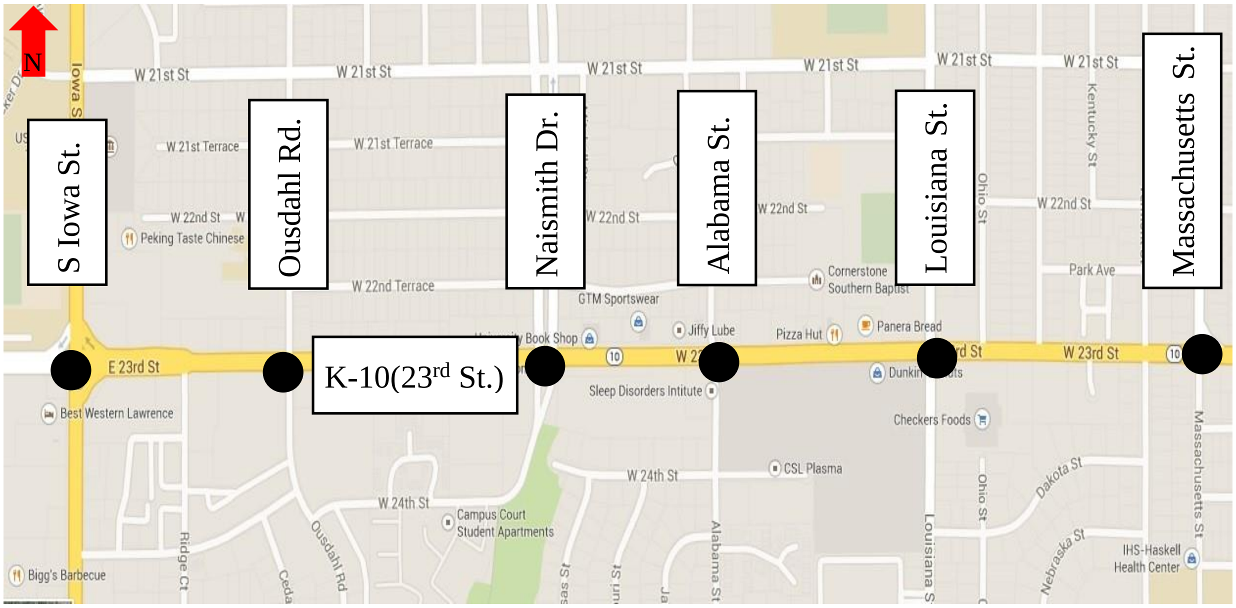
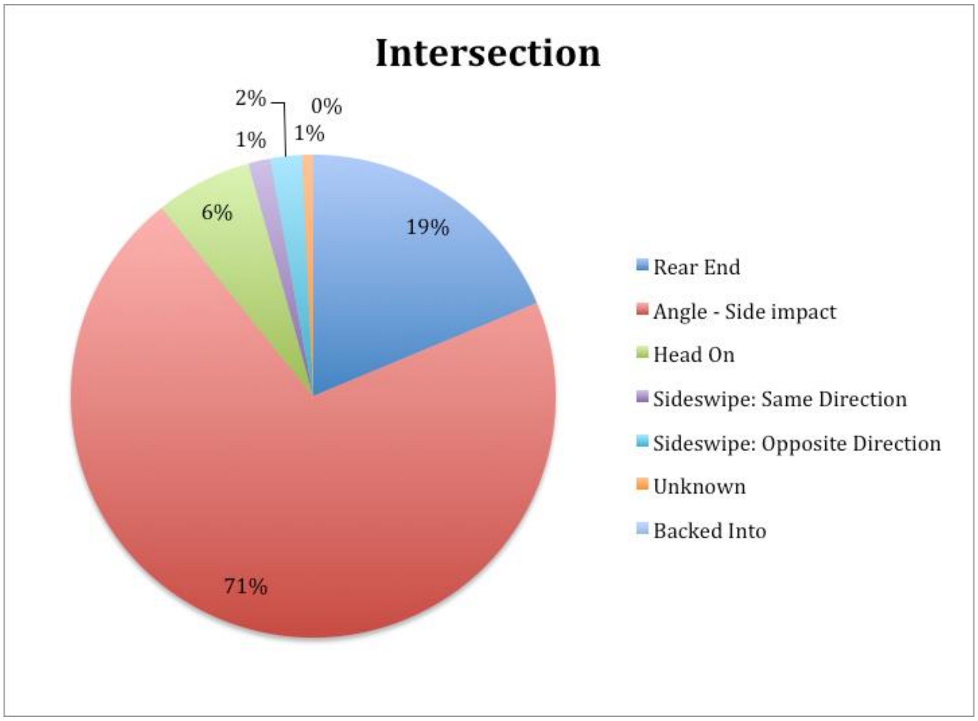


Figure 10: 23rd Street Study Corridor

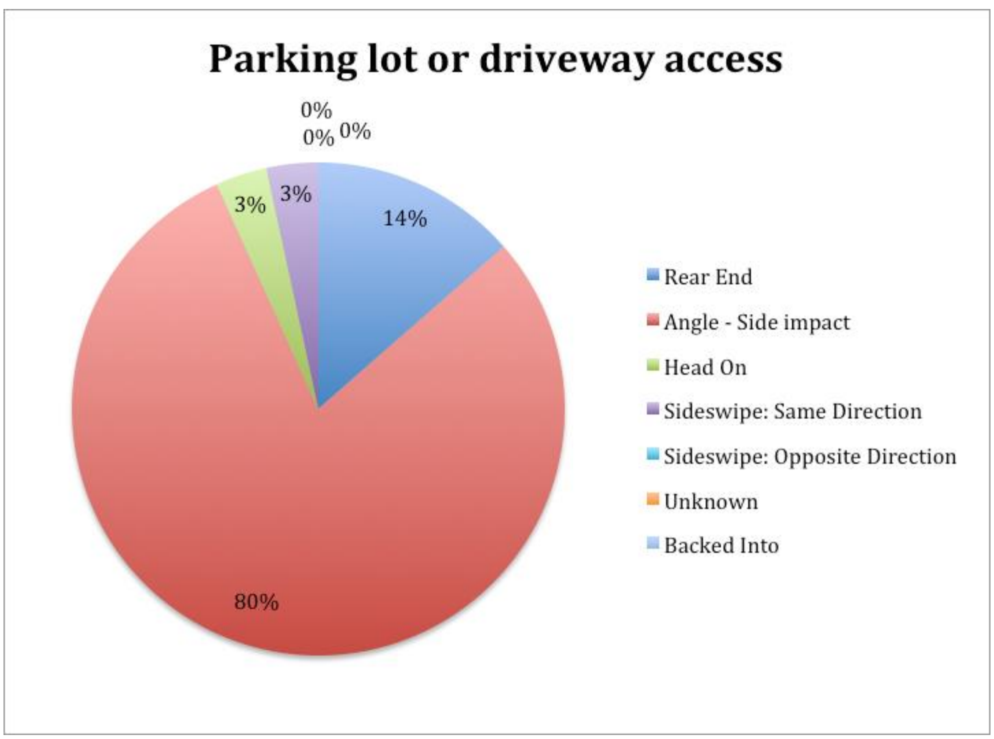
Turning volumes and signal timings at each intersection 2011 were obtained from the City of Lawrence. To reduce the complexity and make the process streamlined, 2011 volumes and signal timings were used for this study.

4.4. Crash Analysis

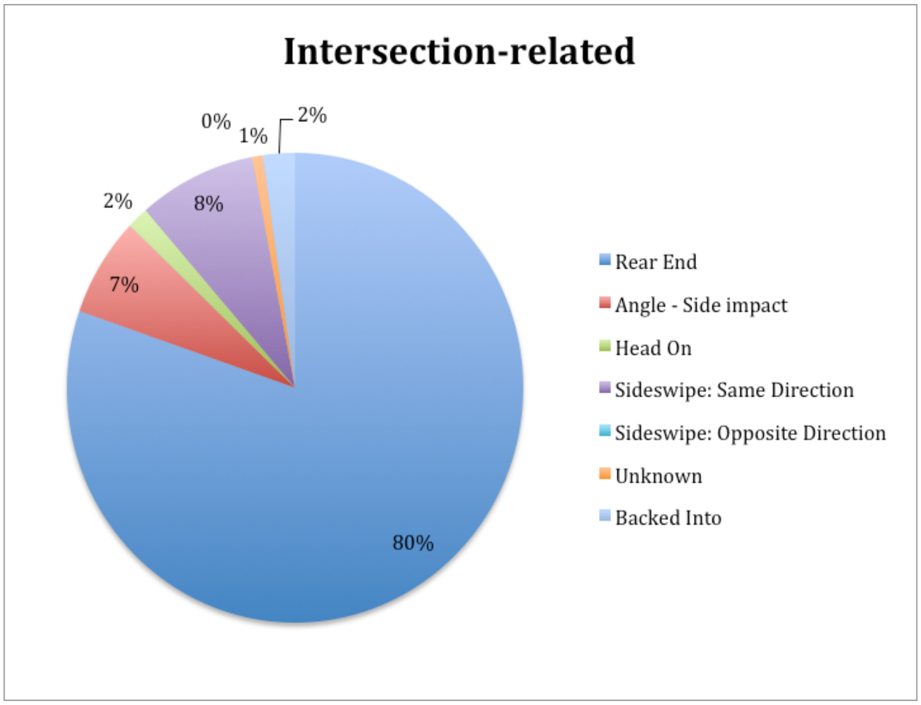
Three years of crash data were plotted for the study corridor and were obtained from Kansas DOT. The crash data included crash type, location, type of impact, number of injuries, fatalities, and the coordinates of each crash. Figure 11 shows the distribution of crashes, according to their type and location.


Intersection
2%
0%
1%
1%
6%
19%
71%
Rear End
Angle - Side impact
Head On
Sideswipe: Same Direction
Sideswipe: Opposite Direction
Unknown
Backed Into

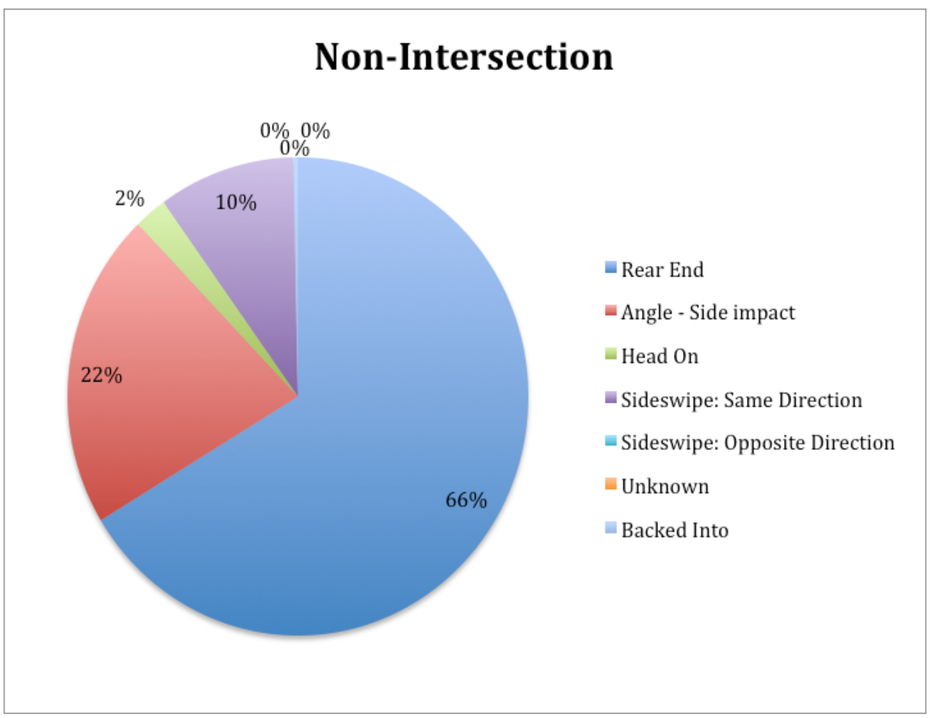
(a)


Parking lot or driveway access
0%
0%
0%
3%
3%
14%
80%
Rear End
Angle - Side impact
Head On
Sideswipe: Same Direction
Sideswipe: Opposite Direction
Unknown
Backed Into

(b)



(c)



(d)

Figure 11: Classification of Crashes According to Their Type and Location

As shown in Figure 11, the highest number of recorded crashes did not occur at intersections. Also shown, of the 362 non-intersection and parking/lot driveway crashes, 321 crashes were angled or rear-end. These were understandable as drivers may not be able to judge the gap time while turning onto 23rd Street. A high number of mid-block and unsignalized intersection rear-end crashes were found and may be due to the drivers making left turns out of driveways without the aid of a TWLTL, or sudden right turns out of the driveways.

Each impact has a particular color, which is shown in Table 3. Figures 12, 13, and 14 show the exact location of the non-intersection and parking lot/driveway access injury crashes according to their impact type.

Table 3: Color Coding

Color	**Impact Type**
Green	Head On
Pink	Rear-end
Blue	Angle Side-Impact
White	Sideswipe Opposite
Orange	Backed Into

Figure 12: Iowa to Naismith

Figure 13: Naismith to Louisiana

Figure 14: Louisiana to Massachusetts

Among the non-intersection and parking lot/driveway 73 injury crashes, there were 24 that were right angle impacts, which may be due to drivers not being able to judge the gap while turning left into driveways or onto West 23rd Street.

4.5. Signalized Intersections

4.5.1. 23rd Street & Iowa Street

The intersection of Iowa Street (US-59) and 23rd Street (K-10) is located at the west end of the study corridor. This signal operates as a split phase signal timing due to geometric constraints for the southbound and northbound left turning movement traffic. The intersection was fully actuated controlled and coordinated, and the signal timings were as shown in Table 4. Three quadrants of the intersection had commercial establishments while the northeast quadrant was an open field, as shown in Figure 15. The intersection had driveways close to the intersection.

Table 4: W 23rd Street & S Iowa Street Existing Signal Timing

	Northbound			Southbound			Eastbound			Westbound		
Phasing	3	8	8	7	4	4	5	2	2	1	6	6
Movement	L	T	R	L	T	R	L	T	R	L	T	R
No. of Lanes	2	2	1	2	2	1	1	2	1	1	2	1
Volume (veh./hr.)	55	907	95	268	473	28	340	911	81	118	494	239
Cycle Length (sec)	120	120	120	120	120	120	120	120	120	120	120	120
Offset (sec)	0	0	0	0	0	0	0	0	0	0	0	0
All-red clearance (sec)	1	2	2	1	2	2	1	2	2	1	2	2
Yellow (sec)	4	4	4	4	4	4	4	4	4	4	4	4
Min. green (sec)	6	6	6	6	6	6	6	6	6	6	6	6
Max. green (sec)	6	35	35	11	40	40	24	43	43	9	28	28
Total Splits (sec)	11	41	41	16	46	46	29	49	49	14	34	34

Figure 15: Aerial view of 23rd Street & Iowa Street

4.5.2. 23rd Street & Ousdahl Road

The intersection of Ousdahl Road and 23rd Street (K-10) is located east of Iowa Street and is the second signalized intersection in the study area. All approaches to the intersection operate as a protected and permitted left-turn signal. Between 11 p.m. and 4 a.m., Ousdahl Road signals flashed yellow and red due to low traffic volumes in the middle of the night. The intersection was actuated controlled and coordinated, and the signal timings were as shown in Table 5. The intersection had commercial establishment on all four quadrants, as shown in Figure 16. It also shows that the westbound approach had a driveway close to the intersection. Driveways were also located close to the intersection, downstream of the westbound and northbound approaches.

Table 5: 23rd Street & Ousdahl Road Existing Signal Timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
Phasing	8	8	8	4	4	4	5	2	2	1	6	6
Movement	L	T	R	L	T	R	L	T	R	L	T	R
No. of Lanes	-	1	-	-	1	-	1	2	-	1	2	-
Volume (veh./hr.)	42	80	34	48	57	70	134	1109	31	27	822	39
Cycle Length (sec)	120	120	120	120	120	120	120	120	120	120	120	120
Offset (sec)	100	100	100	100	100	100	100	100	100	100	100	100
All-red clearance (sec)	2	2	2	2	2	2	0.5	2	2	0.5	2	2
Yellow (sec)	4	4	4	4	4	4	3.5	4	4	3.5	4	4
Min. green (sec)	6	6	6	6	6	6	4	6	6	4	6	6
Max. green (sec)	43	43	43	43	43	43	20	50	50	11	42	42
Total Splits (sec)	49	49	49	49	49	49	24	56	56	15	48	48

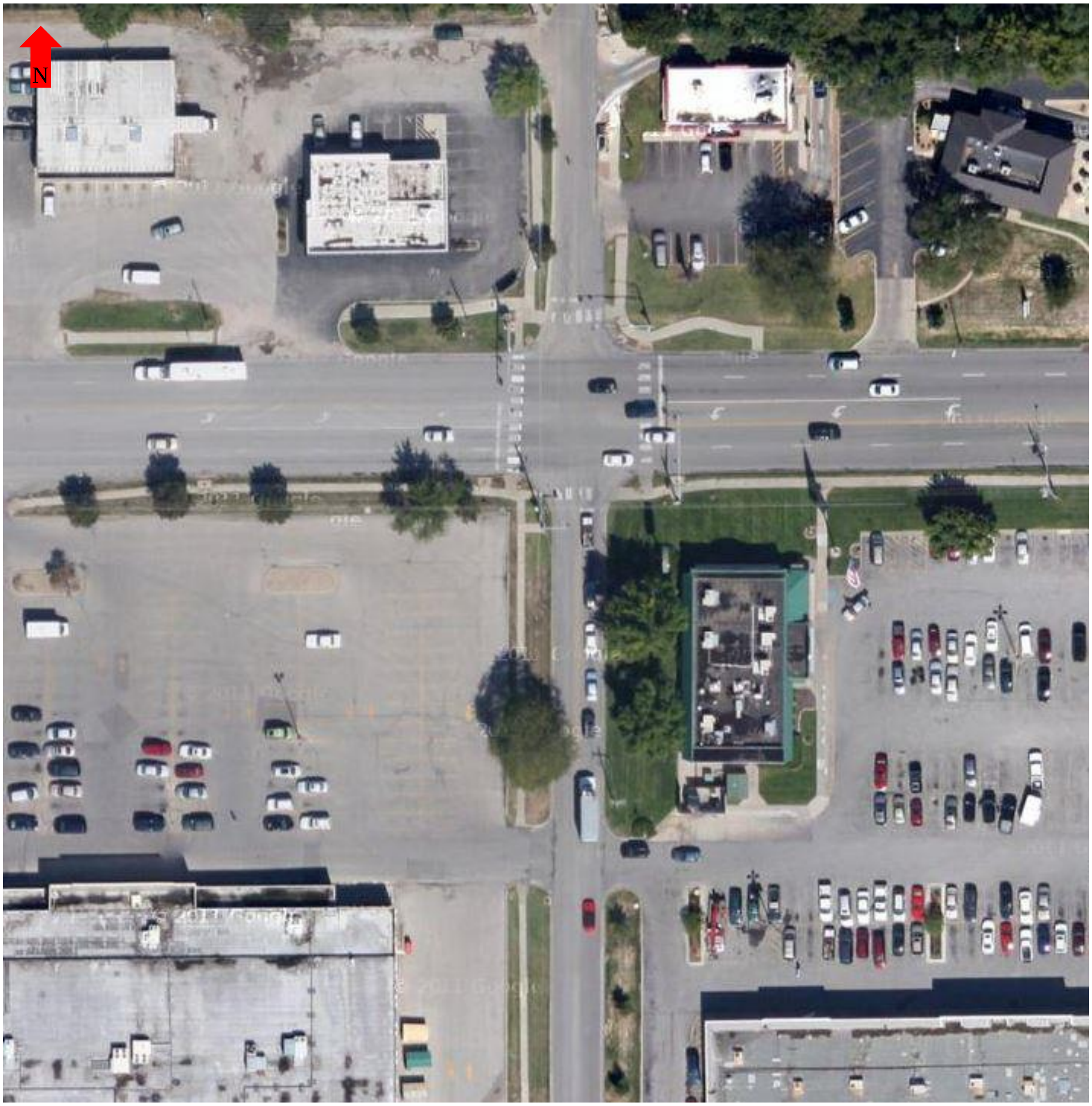


Figure 16: Aerial view of 23rd Street & Ousdahl Road

4.5.3. 23rd Street & Naismith Drive

The intersection of Naismith Drive and 23rd Street (K-10) is located east of Ousdahl Road and is the third signalized intersection of the study area. All the approaches to the intersection had a single lane protected left-turn. The intersection was fully actuated controlled and coordinated, and the signal timings were as shown in Table 6. The intersection had commercial establishment on all four quadrants, as shown in Figure 17. It also shows that the westbound and northbound approaches had a driveway close to the intersection.

Table 6: 23rd Street & Naismith Drive Existing Signal Timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
	3	8	8	7	4	4	5	2	2	1	6	6
Phasing	L	T	R	L	T	R	L	T	R	L	T	R
Movement	1	1	1	1	1	-	1	2	-	1	2	-
No. of Lanes	13	33	49	72	30	41	60	1127	4	17	834	145
Volume (veh./hr.)	120	120	120	120	120	120	120	120	120	120	120	120
Cycle Length (sec)	44	44	44	44	44	44	44	44	44	44	44	44
Offset (sec)	1	2	2	1	2	2	1	2	2	1	2	2
All-red clearance (sec)	4	4	4	4	4	4	4	4	4	4	4	4
Yellow (sec)	6	6	6	6	6	6	6	6	6	6	6	6
Min. green (sec)	15	27	27	15	27	27	17	48	48	8	39	39
Max. green (sec)	20	33	33	20	33	33	22	54	54	13	45	45

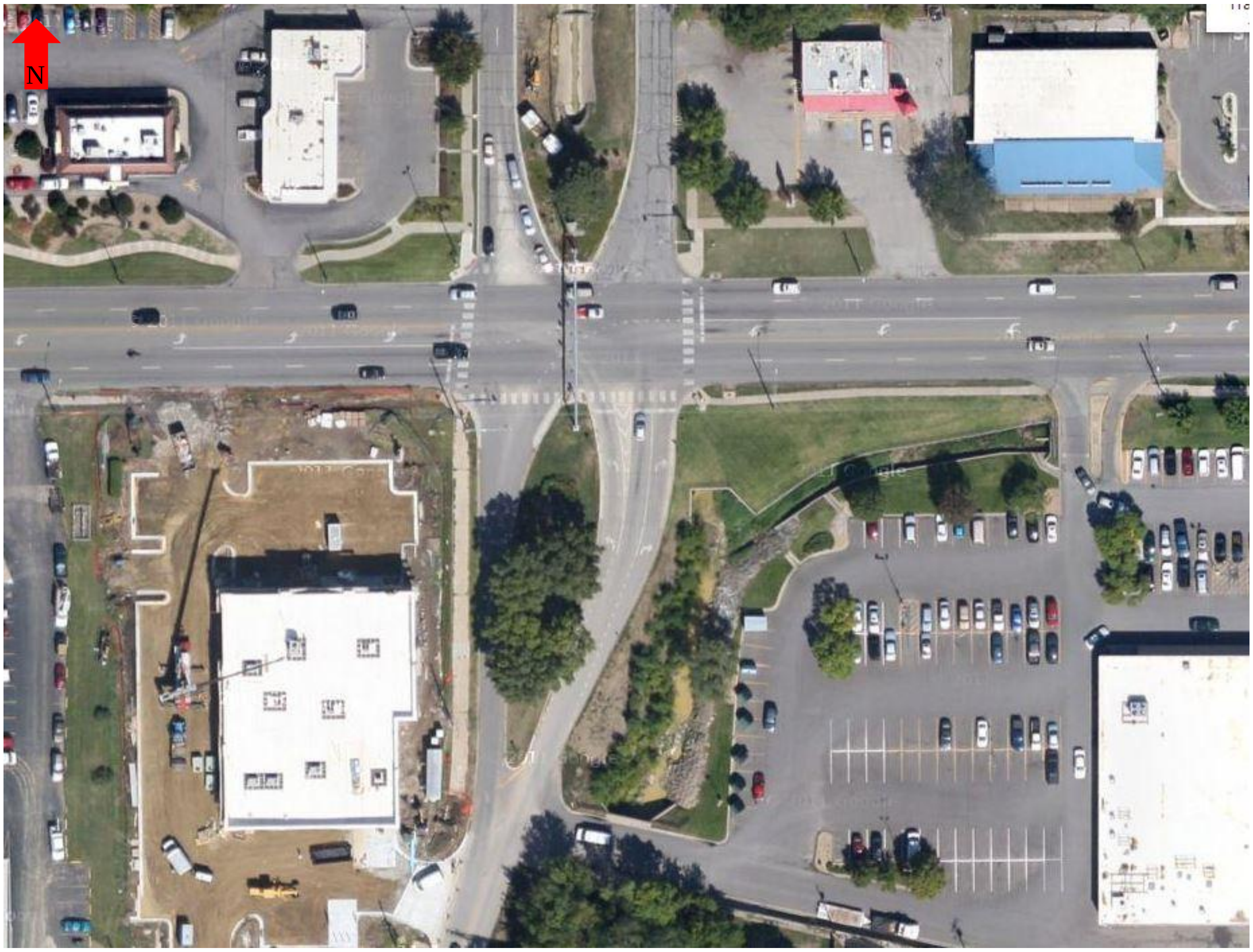


Figure 17: Aerial view of 23rd Street & Naismith Drive

4.5.4. 23rd Street & Alabama Street

The intersection of Alabama Street and 23rd Street (K-10) is located east of Naismith Drive and is the fourth signalized intersection. All approaches to the intersection include a protected and permitted left-turn phase. Between 11 p.m. and 4 a.m., Alabama Street signals flashed yellow and red due to low traffic volumes in the middle of the night. The intersection was actuated controlled and coordinated, and the signal timings were as shown in Table 7. The intersection had commercial establishment on all four quadrants, as shown in Figure 18. It also showed that the westbound and southbound approaches had a driveway close to the intersection. Driveways for the commercial establishments were also located close to the intersection, downstream of westbound, eastbound, and southbound approaches.

Table 7: 23rd Street & Alabama Street Existing Signal Timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
	3	8	8	7	4	4	5	2	2	1	6	6
Phasing	L	T	R	L	T	R	L	T	R	L	T	R
Movement	1	1	-	1	1	-	1	2	-	1	2	-
No. of Lanes	51	79	115	11	9	11	50	1144	54	37	934	16
Volume (veh./hr.)	120	120	120	120	120	120	120	120	120	120	120	120
Cycle Length (sec)	67	67	67	67	67	67	67	67	67	67	67	67
Offset (sec)	1	1	1	1	1	1	1	1	1	1	1	1
All-red clearance (sec)	4	4	4	4	4	4	4	4	4	4	4	4
Yellow (sec)	6	6	6	6	6	6	6	6	6	6	6	6
Min. green (sec)	15	50	50	15	50	50	15	40	40	15	40	40
Max. green (sec)	20	55	55	20	55	55	20	45	45	20	45	45

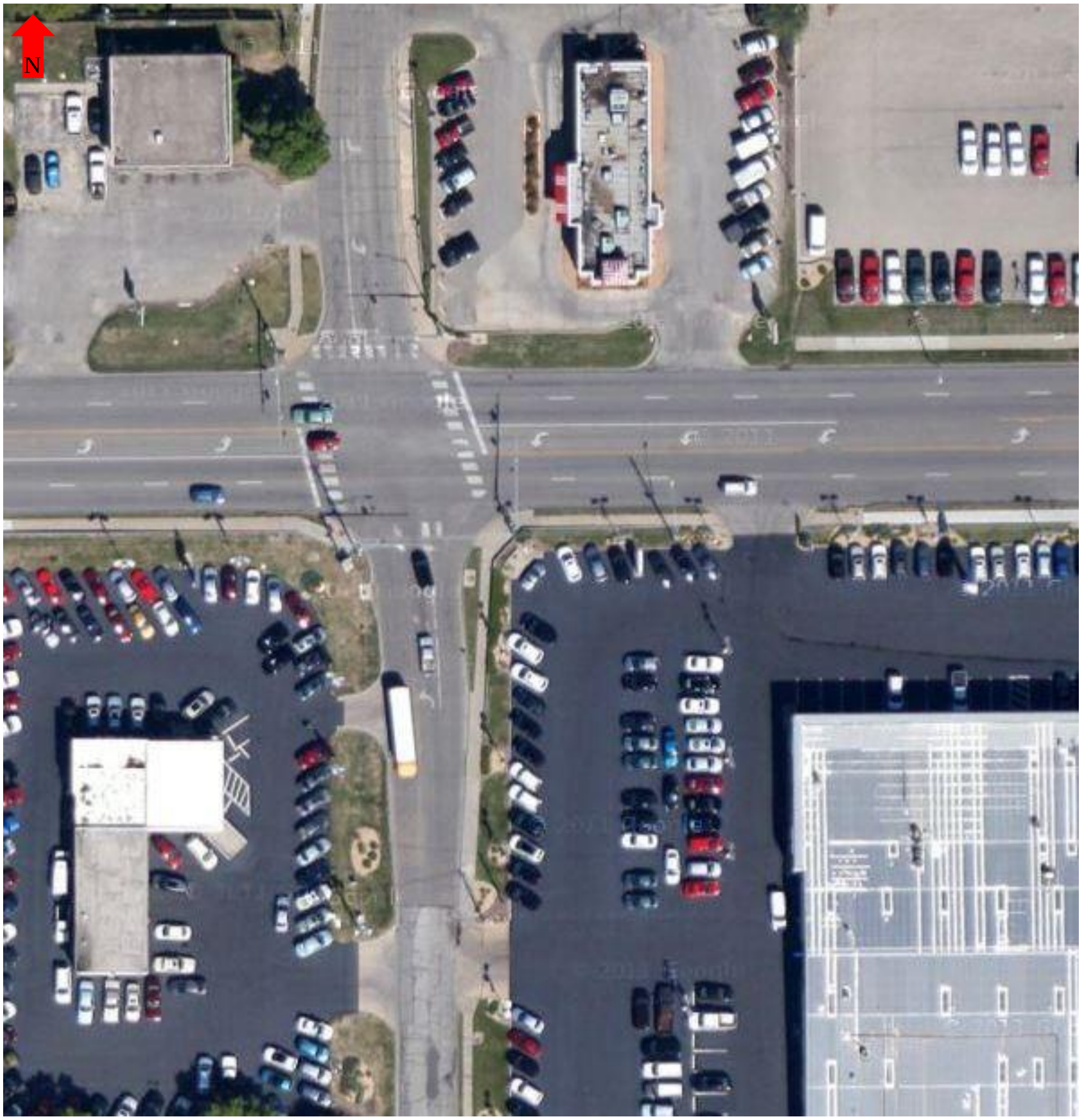


Figure 18: Aerial view of 23rd Street & Alabama Street

4.5.5. 23rd Street & Louisiana Street

The intersection of Louisiana Street and 23rd Street (K-10) is located west of Massachusetts Street. North and southbound approaches to the intersection operated with a protected and permitted left-turn phase. The intersection was actuated controlled and coordinated, and the signal timings were as shown in Table 8. The intersection had commercial establishment on all four quadrants, as shown in Figure 19. It also shows that the westbound and southbound approaches had a driveway close to the intersection. Driveways were also located close to the intersection, downstream of westbound, eastbound, and southbound approaches.

Table 8: 23rd Street & Louisiana Street Existing Signal Timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
	3	8	8	7	4	4	5	2	2	1	6	6
Phasing	L	T	R	L	T	R	L	T	R	L	T	R
Movement	1	1	1	1	1	1	1	2	-	1	2	-
No. of Lanes	71	273	191	69	168	85	193	1039	38	121	831	119
Volume (veh./hr.)	120	120	120	120	120	120	120	120	120	120	120	120
Cycle Length (sec)	91	91	91	91	91	91	91	91	91	91	91	91
Offset (sec)	1	2	2	1	2	2	1	2	2	1	2	2
All-red clearance (sec)	4	4	4	4	4	4	4	4	4	4	4	4
Yellow (sec)	6	6	6	6	6	6	6	6	6	6	6	6
Min. green (sec)	15	34	34	13	32	32	15	34	34	17	36	36
Max. green (sec)	20	40	40	18	38	38	20	40	40	22	42	42

Figure 19: Aerial view of 23rd Street & Louisiana Street

4.5.6. 23rd Street & Massachusetts Street

The intersection of Massachusetts Street and 23rd Street (K-10) is at the west end of the study corridor. The intersection connects the historic downtown district of Lawrence to 23rd Street. It was noted that all approaches to the intersection operated with a protected and permitted left-turn phase. The intersection was actuated controlled and coordinated, and the signal timings were shown in Table 9. The intersection had residences on all four quadrants, as shown in Figure 20. It also shows that the driveways were not close to the intersection.

Table 9: 23rd Street & Massachusetts Street Existing Signal Timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
	8	8	8	4	4	4	5	2	2	1	6	6
Phasing	L	T	R	L	T	R	L	T	R	L	T	R
Movement	1	1	-	1	1	1	1	2	-	1	2	-
No. of Lanes	31	17	4	151	28	84	252	969	78	32	956	333
Volume (veh./hr.)	120	120	120	120	120	120	120	120	120	120	120	120
Cycle Length (sec)	53	53	53	53	53	53	53	53	53	53	53	53
Offset (sec)	2	2	2	2	2	2	1	2	2	1	2	2
All-red clearance (sec)	4	4	4	4	4	4	4	4	4	4	4	4
Yellow (sec)	6	6	6	6	6	6	6	6	6	6	6	6
Min. green (sec)	34	34	34	34	34	34	20	56	56	13	49	49
Max. green (sec)	40	40	40	40	40	40	25	62	62	18	55	55

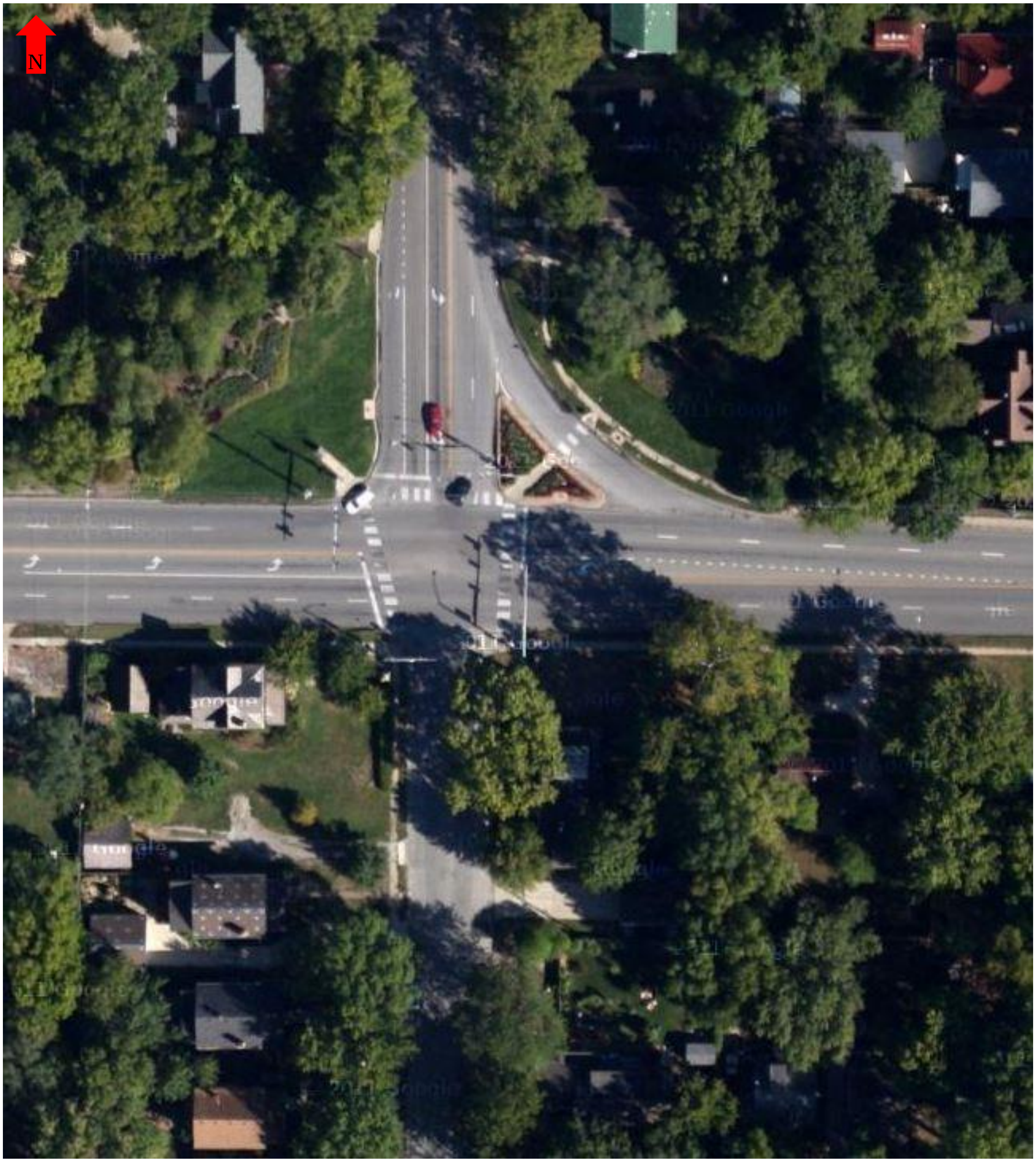


Figure 20:Aerial view of 23rd Street & Massachusetts Street

4.6. Unsignalized Intersections

4.6.1. 23rd Street & Ridge Court

This intersection lies between Iowa Street and Ousdahl Road, with stop sign control on the northbound and southbound approaches. Ridge Court provides alternative access to the adjoining commercial establishments such as El Mezcal and US Bank. Figure 21 shows the geometry of the intersection.

Figure 21: 23rd Street & Ridge Court

4.6.2. 23rd Street & Ohio Street

This intersection is immediately east of Louisiana Street, with stop sign control on the northbound and southbound approaches. Left turns onto Ohio Street were prohibited between 7:00 to 9:00 in the morning and 4:00 to 6:00 in the evening Monday through Friday. Figure 22 shows the geometry of the intersection.

Figure 22: 23rd Street & Ohio Street

4.6.3. 23rd Street & Tennessee Street

This intersection the immediately east of Ohio Street, with stop sign control on the northbound and southbound approaches. Left turns onto Tennessee St. were prohibited between 7:00 to 9:00 in the morning and 4:00 to 6:00 in the evening Monday through Friday. Figure 23 shows the geometry of the intersection.

Figure 23: 23rd Street & Tennessee Street

4.6.4. 23rd Street & Vermont Street

This intersection the immediately west of Massachusetts Street, with stop sign control on the northbound and southbound approaches. Left turns of eastbound vehicles from 23rd Street onto Vermont Street were prohibited between 7:00 to 9:00 in the morning and 4:00 to 6:00 in the evening Monday through Friday. Figure 24 shows the geometry of the intersection.

Figure 24: 23rd Street & Vermont Street

It was noted that the signalized intersections of the corridor were coordinated. Of the six intersections, for eastbound and westbound directions three intersections had protected left turn phases while the other three have protected/permitted phases.

4.7. Business Characteristics

There are 54 commercial establishments along the corridor. The establishments included grocery stores, pharmacies, banks, restaurants, cafes, car dealerships, gas stations, and apparel stores. It was also observed that very few businesses had shared driveways or cross access. Additionally, it was reported that the many businesses had more than one access, with some on the collector streets.

4.8. Field Data Collection

Calibration of VISSIM model required travel times for the corridor. There are many ways to collect travel times the manual test vehicle method was selected because it is easy and inexpensive. This method requires a driver, passenger, stopwatch, and a test vehicle. The driver operated the vehicle while the passenger recorded the time at pre-defined checkpoints. The driver should ensure that he is entering the corridor at different times and phases of the first signalized intersection.

The next step was to determine the minimum number of travel time runs needed to make sure that the travel times are within the 95 percent confidence interval. The minimum number of runs required can be calculated using the following equation

$$Sample\ size = n = \left(\frac{t\ \times c.v.}{e}\right)^2$$

Where,

t – t value from the student's t-distribution, based on confidence interval (95 percent)

c.v. – Coefficient of variation is the variability of travel time. Table 10 gives approximate values for the coefficient of variation based on the traffic signal density

e – relative allowable error in the estimate of the travel time (± 10 %)

Table 10: Coefficient of Variations for the Test Vehicle Technique on Arterial Streets (Source: Lomax et. al., 1997)

Arterial Streets	
Traffic Signal Density (signals per mile)	**Average Coefficient of Variation**
< 3	9
3 to 6	12
> 6	15

For the study corridor the 95 percent level of confidence was selected, the signal density was 4.54 signals per mile and the relative allowable error was assumed to be ± 10 percent. The sample size was determined to be 8.

The travel times were measured from a fixed point after the Iowa Street to a fixed point after the Massachusetts Street in either direction. Figure 25 shows the fixed points where the time was recorded. The green mark is where the time starts and the red mark is where the time is stopped.

Figure 25: Start and Stop Points of Recording Time

Table 11: Observed Travel Times

AM				PM			
Time of Day	**Eastbound (Sec)**	**Time of Day**	**Westbound (Sec)**	**Time of Day**	**Eastbound (Sec)**	**Time of Day**	**Westbound (Sec)**
7:58	172	7:34	180	16:06	173	16:13	177
8:08	199	7:50	268	16:18	248	16:26	306
8:24	170	8:03	182	16:36	171	16:41	310
8:38	157	8:15	314	16:48	177	16:55	198
8:51	162	8:29	223	17:00	165	17:06	316
9:00	179	8:43	302	17:13	214	17:21	323
9:12	170	8:55	185	17:28	301	17:36	317
9:23	155	9:05	319	17:43	297	17:50	303
	_	9:17	207	-	-	-	-

The variation in the travel times was attributed to the fact that the test vehicle entered the corridor at different phases of starting signalized intersection. Also, it can be observed from the travel times that they are low in the beginning of the peak period, highest in the middle of the peak period, and start decreasing again at the tail end (See Table 11).

4.9. Trip Generation and Redistribution

The Institute of Transportation Engineer (ITE) Trip Generation Manual 2008 was used to generate the entering and exiting volumes for each business type along the corridor. The number of trips generated were then divided by the number of driveways for each business. For example if a business had two driveways the trips were divided equally (50 percent) between the two. For strip malls, trips were calculated as a whole and not for individual units. Table 12 shows the trip generation rates for sample businesses. Similar trip generation was done for all the businesses and residence that had direct access to the corridor.

Table 12: Trip Generation Example

Morning Peak									
Business Name	**Sq. Ft**	**Units**	**ITE Code**	**ITE Factor**	**Total Trips**	**Enter**		**Exit**	
						%	**Trips**	**%**	**Trips**
Wendy's	3000		934	54.81	164	0.51	84	0.49	80
BP Gas Station		8	853	17.03	136	0.5	68	0.5	68
Checkers	55000		850	10.05	553	0.49	271	0.51	272
McDonalds	6400		934	54.81	351	0.51	179	0.49	172

The trip generation table provided a basis to distribute the vehicles. As shown in Table 12, trip generation provides the entering and exiting vehicles. At driveways located close to an intersection (TWLTL was converted into a left turn lane at the intersection), vehicles were assumed to be entering and exiting by making a right turn only. The vehicle counts at the signalized intersections are the actual counts and were not changed. After placing the entering and exiting volumes at all the businesses, the volumes at the next intersection were more than that the actual vehicle counts. These vehicles were unloaded from the traffic network at the intersection.

For example consider the section between Iowa Street and Ousdahl Road. Based on the turning volumes provided 1274 vehicles entered this section at Iowa Street and 1034 vehicles exited the section at Ousdahl Road. The section had 240 vehicles more than the number of vehicles exiting at Ousdahl Road. Table 13 shows the eastbound trips for the businesses between Iowa Street and Ousdahl Road. The trip generation manual has 306 entering trips and 90 exiting trips between the section of Iowa Street and Ousdahl Road. Effectively, the section has 216 trips entering the business, and still the section has 24 vehicles more than the vehicles exiting at Ousdahl Road. These 24 vehicles are unloaded at the unsignalized intersection at Ridge Court making the section balanced. Figure 26 shows the graphical representation of the trip distribution. The number of vehicles entering the business are in white boxes while the number of vehicles exiting are in black boxes. The number in the red box indicates the extra vehicles that will be exiting the section at the unsignalized intersection of Ridge Court an 23rd Street.

Table 13: Iowa to Ousdahl Trip Distribution

Eastbound Iowa to Ousdahl		
Business Name	**Entering Vehicles**	**Exiting Vehicles**
CVS and El Mezcal	80	30
US Bank	22	4
Hobby Lobby	62	16
Hastings	0	10
Presto	72	20
Yokohama	35	8
Jimmy John's	30	2
T-Mobile	5	0
Total	**306**	**90**
Effective Entering Trips = 216		

Figure 26: Trip Distribution for Iowa Street to Ousdahl Road

4.10. Interviews with Experts

Opinions were received from four industry experts, Mike Walshstead from TransSystems, David Cronin of City of Lawrence, and Jamie Gilbert and Amanda Anderson from George Butler and Associates (GBA) on what kind of access management strategies can best be implemented along the corridor. They were also asked to comment on what might be considered as low, medium, and high level of access management strategies. The researcher came up with draft plans for the various levels of access management strategies before meeting the experts, by referring to the access management guide for Kansas.

The researcher met with Mike Walstead first and presented the draft for the medium and high level of access management, assuming that the current condition was the lowest. He agreed with the placement of the medians and consolidating driveways for the medium level. For the high level, he did not like the idea of having the raised median throughout the corridor, so he asked the researcher to consider a few mid-block openings. He also suggested various types of median openings such as left-in-right-out and left-in-left-out. He had some reservations about allowing U-turns at the intersection, due to the minimum turning radii of most of the vehicles.

David Cronin was approached with a draft, which included Mike Walstead's suggestions. Being the City Engineer for Lawrence he had good insight on the corridor. Mr. Cronin provided the access management plan that HNTB and Kansas Department of Transportation (KDOT) had come up with in 1993. After comparing the medium level draft with that of HNTB and KDOT's plan, it was observed that the way in which the corridor was laid out was similar. He also suggested consideration of a scenario where there was only consolidation of driveways and no raised median along the corridor. Mr. Cronin was very confident that it would be possible for most of the vehicles to make a U-turn at signalized intersections.

Lastly, the researchers met with Jamie Gilbert and Amanda Anderson from GBA. Ms. Anderson previously worked on the original study that HNTB and KDOT carried out in 1993. She also suggested the idea of having another level between medium and the existing with no raised medians and only consolidation of driveways. Mr. Gilbert recommended that the geometry be reviewed before locating the consolidated driveways.

All the opinions given by the experts were included in this research. It was then decided to have four models instead of the originally planned three. Some of the driveways were retained with a right in-right out access.

4.11. Modeling in VISSIM

Microsimulation is one of the most used tools to compare multiple designs. Modeling and analyzing access management strategies involves stop controlled or signalized intersection along with a number of driveways connecting the street with businesses and residences. This type of modeling is mostly based on driver behavior.

Links and connectors were drawn into the model using an aerial image of the study area obtained from the City of Lawrence. The vehicle volumes and the turning movements obtained from the City of Lawrence and loaded into the model at the end signalized intersections. VISSIM distributed the volumes based on the routing decisions and this was based on the turning volume percentage, which is explained later. The vehicle composition can also be altered, and was based on a percentage of the total vehicles. Since the study is in an urban area, it was determined to keep the heavy vehicle percentage at one percent. VISSIM applies speed distribution to each vehicle entering the model. Each vehicle tries to be in the speed distribution depending on geometry, vehicle type, and driver characteristics. Although the posted speed limit was 35 mph, the specified speed distribution was between 29.8 to 36 mph (Figure 27). Reduced speed areas were also defined for turning movements.

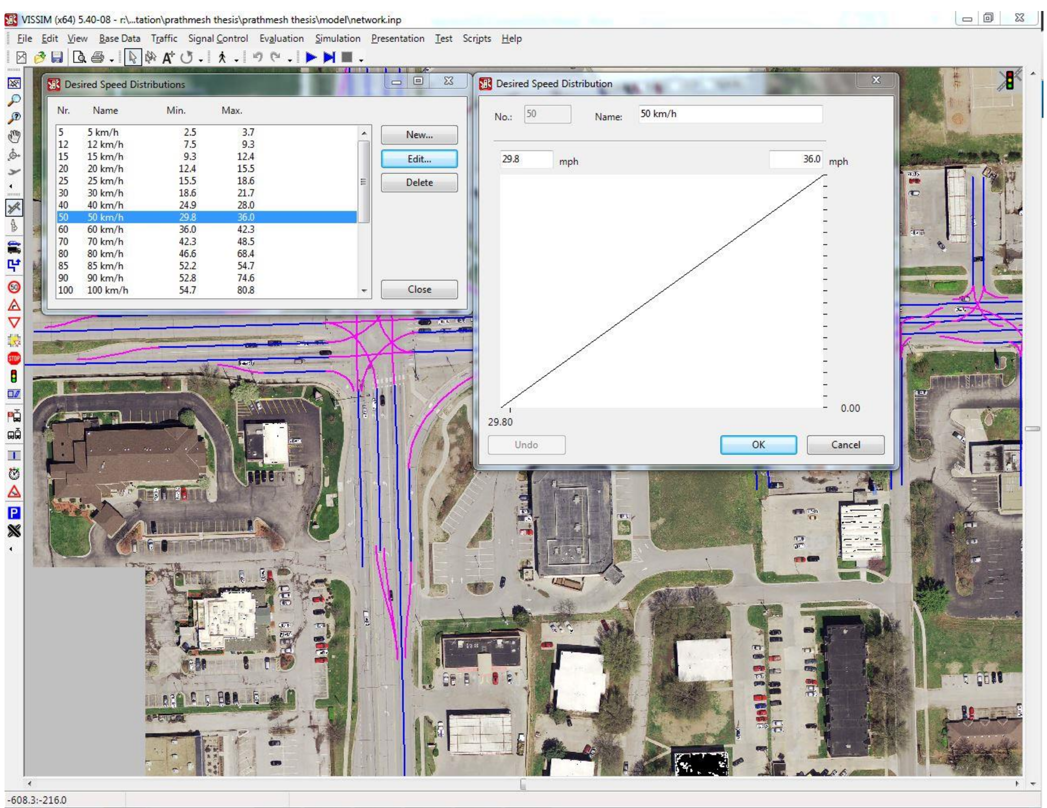


Figure 27: Desired Vehicle Speed Distribution

To evaluate the impact of various levels of access management strategies, four models were created and compared. The four models created were existing conditions (doing nothing), low level (driveway consolidation, no median treatment), medium level (driveway consolidation, raised median with mid-block openings), and high level (driveway consolidation and raised median with no mid-block openings). The following calibration tools were used in all the models:

- Links and connectors
- Conflict areas
- Routing decisions
- Reduced speed areas
- Driver behavior

4.11.1. Links and Connectors

A link is the basic element of the VISSIM traffic network, which represents single/multiple lane roadway with a particular direction. A traffic network is built by connecting links with the help of connectors. The geometry of the intersection and approaches should be studied in order to make the model similar to the field conditions. Unlike other simulation software, VISSIM does not allow any curved links or connectors, thus horizontal curve must be created by adding multiple points to each link or connector. Figure 28 shows links and connectors for an intersection. While Figure 29 shows the entire VISSIM traffic network for the study area, along with the background image, on which the links and connecters were built. For detailed images of base model, please refer to Appendix A.

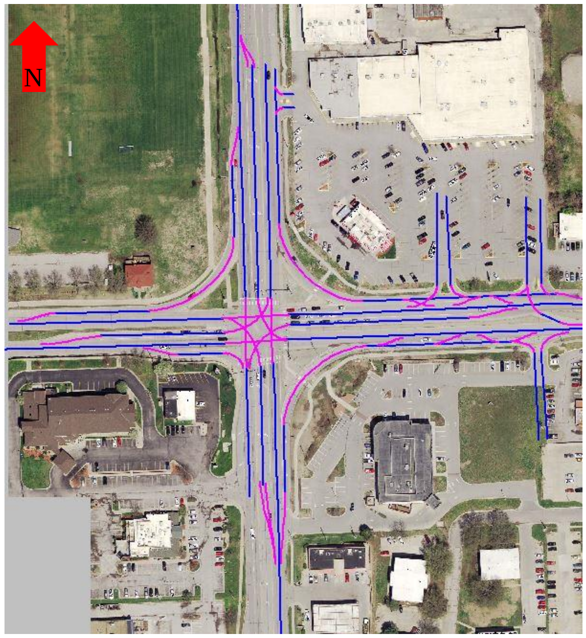


Figure 28: Links and Connectors

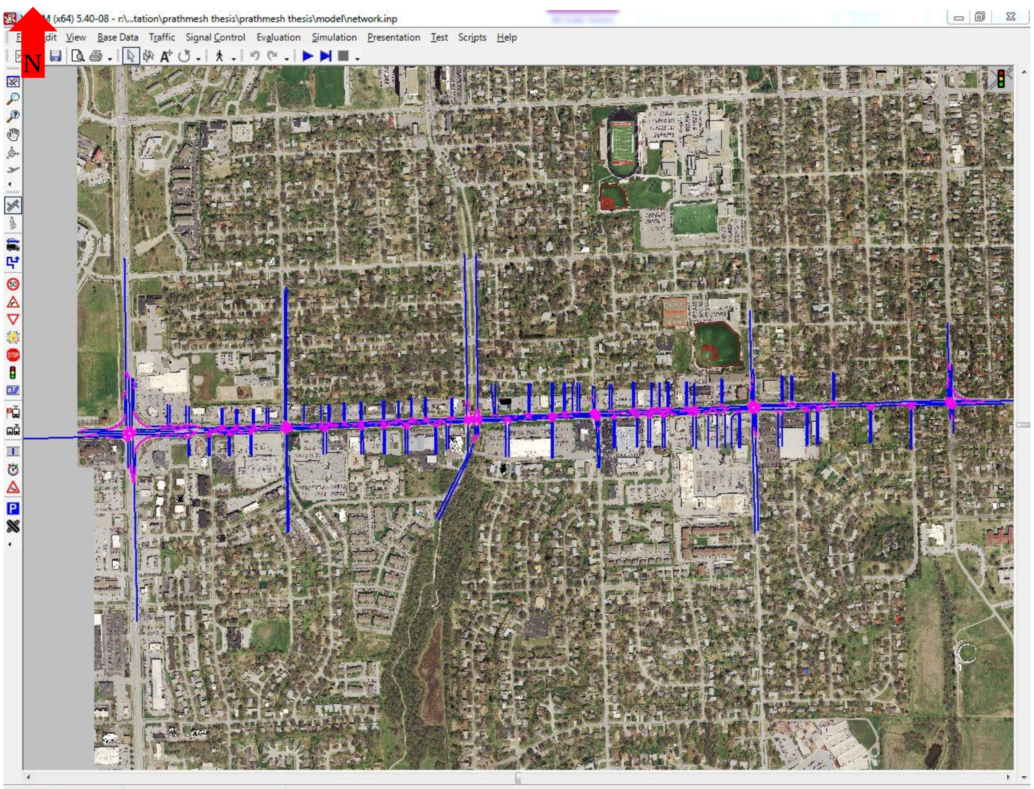


Figure 29: Base Model in VISSIM

4.11.2. Conflict Areas

To replicate real world conditions, it is important that the simulated traffic does not crash into each other. A conflict area is defined as where two links or connectors cross each other in the VISSIM network. For each conflict area, the user can select which of the conflicting links has the right of way. Drivers' plan on how to cross the conflict area. A yielding driver observes the approaching vehicles in the main stream and decides for which gap he wants to go. Vehicles in the main stream react to the conflict area as well, if a crossing vehicle could not complete the crossing because the driver estimated the situation too optimistically, the vehicle in the mainstream will brake or even stop. Figure 30 shows some of the conflict areas defined in the VISSIM traffic network. The links/connectors having a green bar next to them have the right of way over links/connectors with red bars. If both links/connectors have red bars, then the vehicles have to "see" each other, but there is no right of way for either of them, this is usually used for branching conflicts.

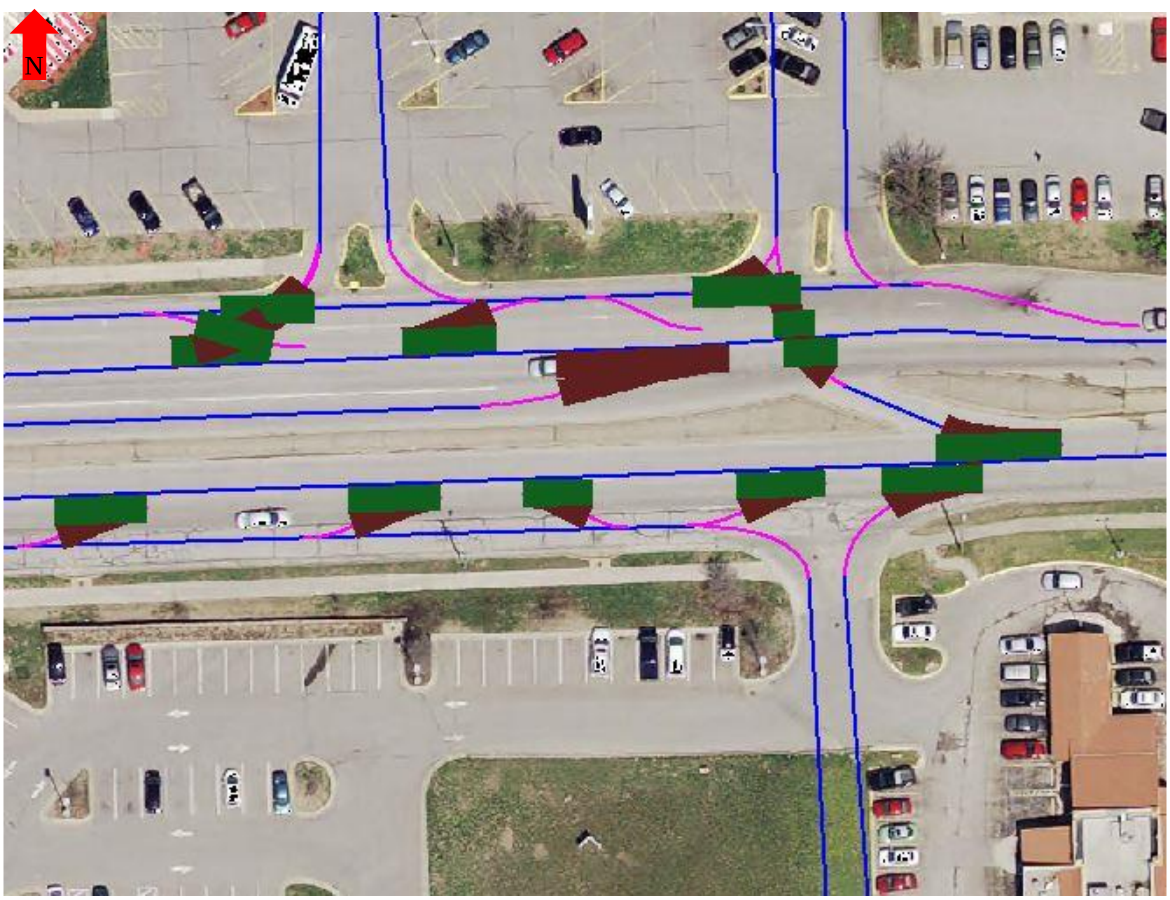


Figure 30: Conflict Areas

4.11.3. Volume and Routing Decisions

Turning movement volumes provided by the City of Lawrence were used to create entry points at the east and west end of the study corridor. North-south entry points were also created at each signalized intersection. The unsignalized streets and driveways were used to load and unload vehicles and achieve the recorded volumes at the intersections.

When the volumes were added to the network, they did not have any routing information. In this case, vehicles move to the nearest connector and try to get out of the network in minimum time. Routing is a sequence of links and connectors starting at a routing decision (red bar) to at least one destination cross-section (green bar). A single start routing decision can have multiple destination cross-sections. The routing decisions are coded into VISSIM as a percentage or an exact volume of vehicles per hour turning left or right, or going through. The routing decisions are applicable to a particular class of vehicles or without any routing information. If a vehicle has a route assigned to it, then it will have to pass the destination cross section before it is able to receive any new route information. Figure 31 shows the various routing decisions for a section of the traffic network. A yellow line shows one of the routes for northbound left turning vehicles. A vehicle at an intersection has an option of making a left turning, through, or right turning movement. The percentage of vehicles making a particular movement was coded for the evaluation time. It was noted that depending on the design the model, it may or may not reach the desired turning movements thus not replicating the field conditions.

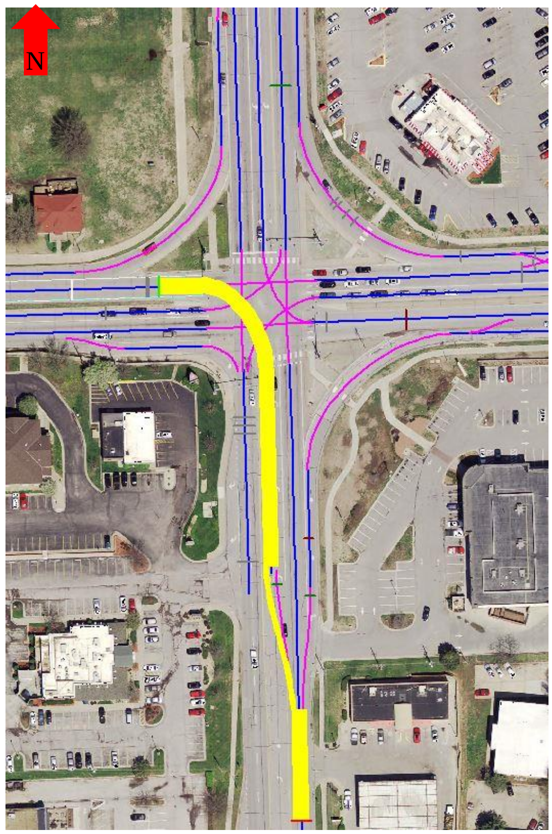


Figure 31: Routing decisions

4.11.4. Reduced Speed Areas and Desired Speed Decisions

VISSIM allows the user control of the speed of the turning movements, in order to match the field speeds. Even though the posted speed limit for the corridor was 35 mph, the drivers reduce their speeds while turning. Reduced speed areas were introduced to allow the vehicles to slow down before turning. Reduced speed areas were also defined in the TWLTL, as it was unrealistic to have vehicles entering at 29.8 to 36.0 mph. As shown in Figure 32, the green boxes represent the reduced speed areas. All the vehicles (cars, heavy vehicles, buses) will have a reduced speed between 18.6 to 21.7 mph.

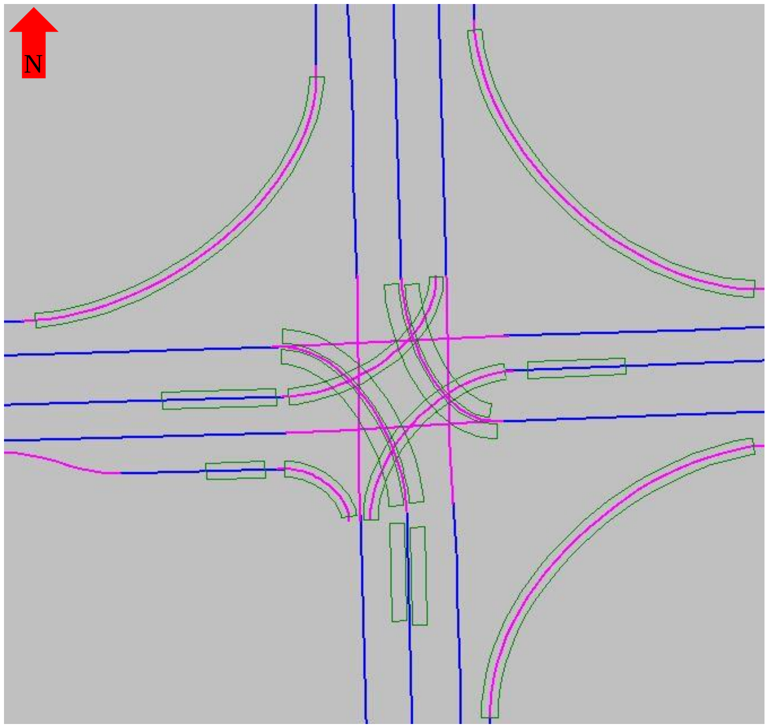


Figure 32: Reduced Speed Areas

4.11.5. Driving Behavior

Driving behavior is one of the more important aspects that will make the traffic network as close as possible to the real traffic conditions. This basically includes how the vehicles should brake, accelerate, follow other vehicles, etc. There are three car following models VISSIM offers, namely Wiedemann 74, Wiedemann 99 and no interaction. Each model has its own characteristic parameters, which are suitable for a particular type of setting (urban, rural, freeway). The manufacturer suggests the use of the Wiedemann 74 car following model in urban traffic, and so this was utilized for this research.

4.12. Calibration and Validation of VISSIM Model

The initial evaluation of the model was performed with ten simulation runs of one hour each with a loading period of 30 minutes. A random number generator was used to generate a set of random seed numbers. The modeled travel times were compared with the travel times collected in the field. Probe vehicles were used to calculate the travel times. The probe vehicles travelled the entire length of the corridor between Iowa Street and Massachusetts Street. The points between which the travel times should be measured were same to the points used for field data collection. Table 14 illustrates the travel times observed in the field and that generated using VISSIM. The difference between the average travel times for both scenarios was considered acceptable and the base model was considered to be replicating the exiting road conditions.

Table 14: Travel Time Comparison

	Actual Eastbound (sec)	Actual Westbound (sec)	Base Model	
			Eastbound (sec)	Westbound (sec)
	172	180	168	217
	199	268	196	290
	170	182	177	246
	157	314	174	276
	162	223	177	265
	179	302	192	277
	170	185	180	238
	155	319	172	201
	-	207	170	254
	-	-	183	274
Average	170.5	242.2	178.9	253.8

4.13. Model Structures

Four models were developed according to the level of access management strategies implemented, namely base model (do nothing), low level, medium level, and high level. The technique described in the previous section was used for the development of the base model.

Low level: The proposed corridor was created using the techniques described above. This level included consolidation of driveways without any raised medians. The model had 43 driveways compared to 58 in the existing level. The routing decisions for the driveways were also modified. The existing signal timings were retained for this model. Figure 33 shows the entire low level model. For detailed images of the low model, please refer to Appendix B.

Figure 33: Proposed Low Model

Medium Level: The proposed corridor was created using the techniques described above. This level included consolidation of driveways along with raised medians. The routing decisions for the driveways were also modified. U-turns were allowed at all the signalized intersections. Eight median opening for left turns into the driveways were provided. Left turns were not permitted out of the driveways. The number of driveways remained the same as that of the low model. The existing signal timings were retained for this model. Figure 34 shows the entire medium level model. For detailed images of the medium model, please refer to Appendix C.

Figure 34: Proposed Medium Model

High Level: The proposed corridor was created using the techniques described above. This level included consolidation of driveways and raised medians. U-turns were allowed at all the signalized intersections. Five median opening for left turns into the driveways were provided. The routing decisions for the driveways were also modified. Left turns were not permitted out of the driveways. The number of driveways remained the same as that of the low model. The existing signal timings were retained for this model. Figure 35 shows the entire high level model. For detailed images of the high model, please refer to Appendix D.

Figure 35: Proposed High Model

The Table 15 shows the number of driveways and median for all the access management levels.

Table 15: Characteristics of Access Management Levels

Level of Access Management	Base	Low	Medium	High
Number of Driveways	58	43	43	43
Number of Median Openings	No Raised Median	No Raised Median	8	6

4.14. Analyzing Conflicts in Surrogate Safety Assessment Model

The SSAM is automated conflict analysis software developed by FHWA. According to Pu and Joshi (2008), SSAM operates as a post processor for the vehicle trajectory data driving through the traffic facility and identify conflicts. The SSAM vehicle trajectory data are generated by the traffic simulation software in a trajectory file format (file labeled with .trj extension). SSAM then calculates the surrogate measures of safety corresponding to each vehicle-to-vehicle interaction. According to Pu and Joshi (2008):

> The vehicle trajectory input data for SSAM are generated by traffic simulation software in a trajectory file format (where files are labeled with a .trj file extension), specially designed for SSAM. SSAM calculates surrogate measure of safety (TTC and PET) for all the vehicle-to-vehicle interactions and determines whether the criteria are satisfied to be deemed as a conflict. SSAM provides a table of all conflicts analyzed from the trajectory file, it also includes time, location, and measures of conflict severity. It also provides a summary of conflicts by type (unclassified, crossing, rear-end, lane change). Figure 36 illustrates the workflow for using SSAM.

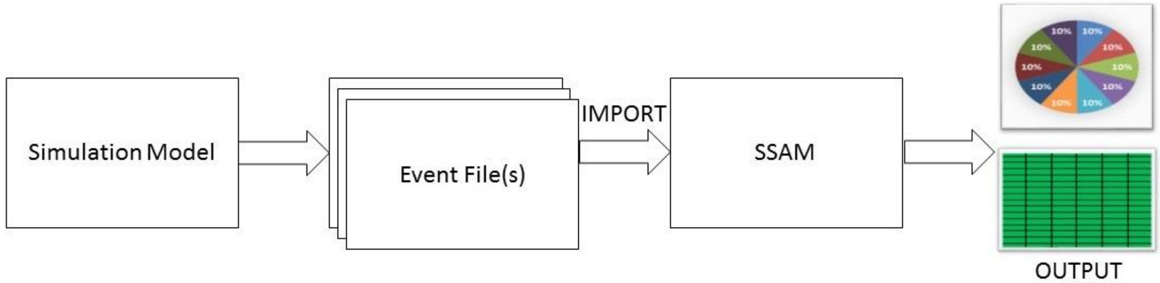


Figure 36: SSAM Work Flow Diagram (Source: Pu and Joshi, 2008)

The first step is to export the SSAM vehicle trajectory data from VISSIM. Figure 37 shows how to export the vehicle trajectory data from VISSIM. Since VISSIM is a stochastic model, the vehicle trajectories are different for different random seed number.

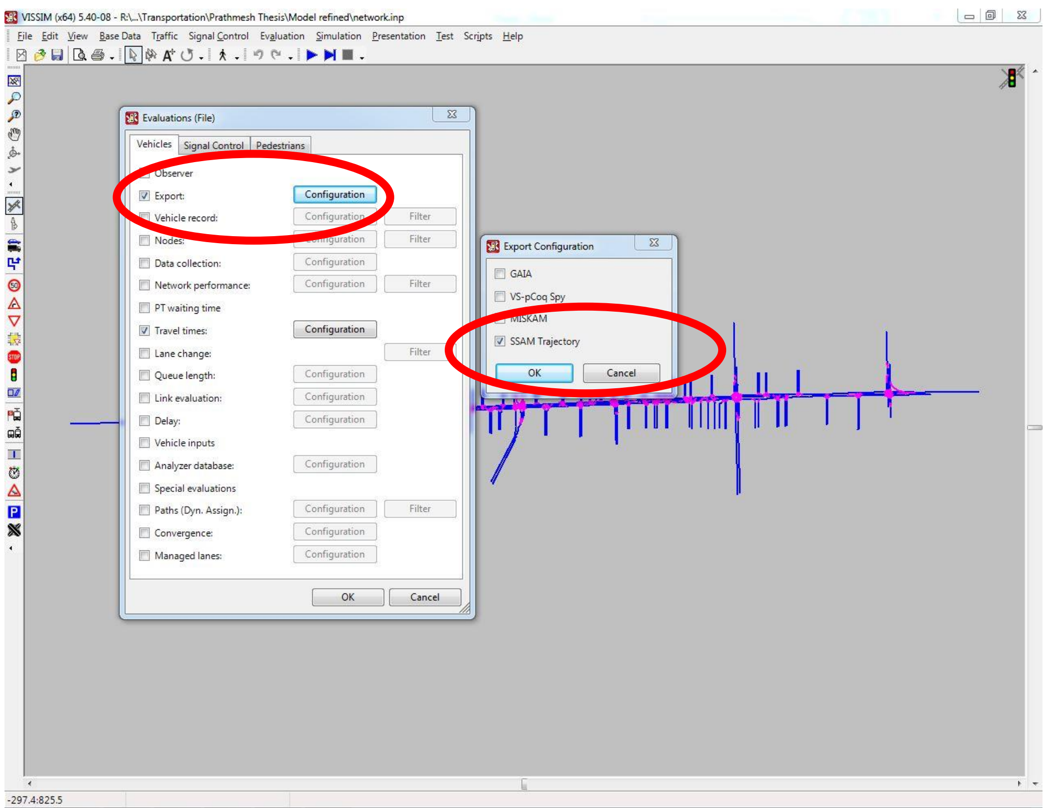


Figure 37: Exporting SSAM Vehicle Trajectory Data

The next step is to load the trajectory files into SSAM. Figure 38 shows trajectory data added to the SSAM.

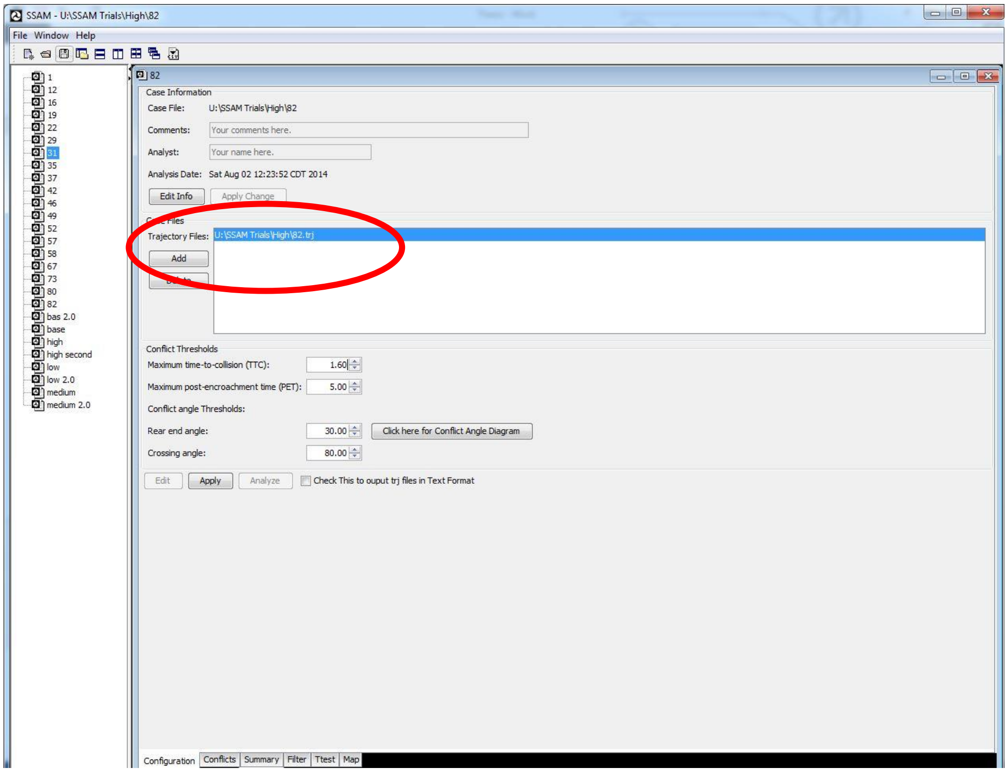


Figure 38: Adding Trajectory File in to SSAM

SSAM allows one to set the TTC and PET threshold values to determine which vehicle-to-vehicle interactions should be considered as conflicts. The maximum default value of TTC is 1.5 seconds as suggested by (Sayed, Brown, Navis, 1994) and the default maximum PET value of 5 seconds. This means that the SSAM will record the conflicts that have TTC value less than 1.5 seconds and PET value less than 5 seconds. These default values were used in the study.

For evaluation of each model, 30 simulation runs of one hour each with a loading period of 30 minute were conducted. Then, SSAM was used to conduct conflict analysis on all the 30 vehicle trajectories generated for each model. 30 runs were conducted so that it can be assumed that the data is normal and z-test can be performed on the data.

CHAPTER 5: RESULTS

This chapter presents the descriptive statistics of travel times and conflicts generation by SSAM and VISSIM.

5.1. Travel Time

The trend here is consistent with the expectation that the travel time would increase as the number of vehicles in the travelling through the section increases due to a lesser number of driveways and no mid-block left turns. The U-turns permitted at the intersection also contributed to the increased travel times at the intersections where the left turns had a protected-permitted phase. Table 16 shows the comparison of travel times as percent changes. As shown, the travel times increased with increasing levels of access management as compared to the base level, except in the case where westbound of the medium level scenario where a slight decrease is observed.

Table 16: Comparison of Travel Time

	Level of Access Management Strategies	**Base**	**Low**	**Medium**	**High**
Eastbound	**Travel Time (sec)**	179	184	182	183
	Percent Change	-	2.79%	1.68%	2.23%
Westbound	**Travel Time (sec)**	254	257	252	264
	Percent Change	-	1.18%	-0.79%	3.94%

5.2. SSAM Conflict Analysis

Figures 31, 32, 33, and 34 shows the total, crossing, rear-end, and lane change conflicts predicted by SSAM from the VISSIM vehicle trajectories files. The overall trend is consistent with the expectations that the total (crossing, rear-end, lane change) number of conflicts will increase because of the rise in the rear-end conflicts. The increase in rear-end conflicts might be because of the increasing number of vehicles trying to make right turns or mid-block left turns at fewer locations compared to the existing conditions. The crossing conflicts trend is also consistent with the expectation that the conflicts reduced from the existing condition to low level condition. The increase from low level to medium level may be due to the fact that the number of vehicles making mid-block left turns is concentrated at a few locations. Even though the number of mid-block left turns openings is reduced from medium level to high level, there was a reduction in crossing conflicts due to vehicles using minor streets to access the businesses by making left turns or U-turns at signalized intersections.

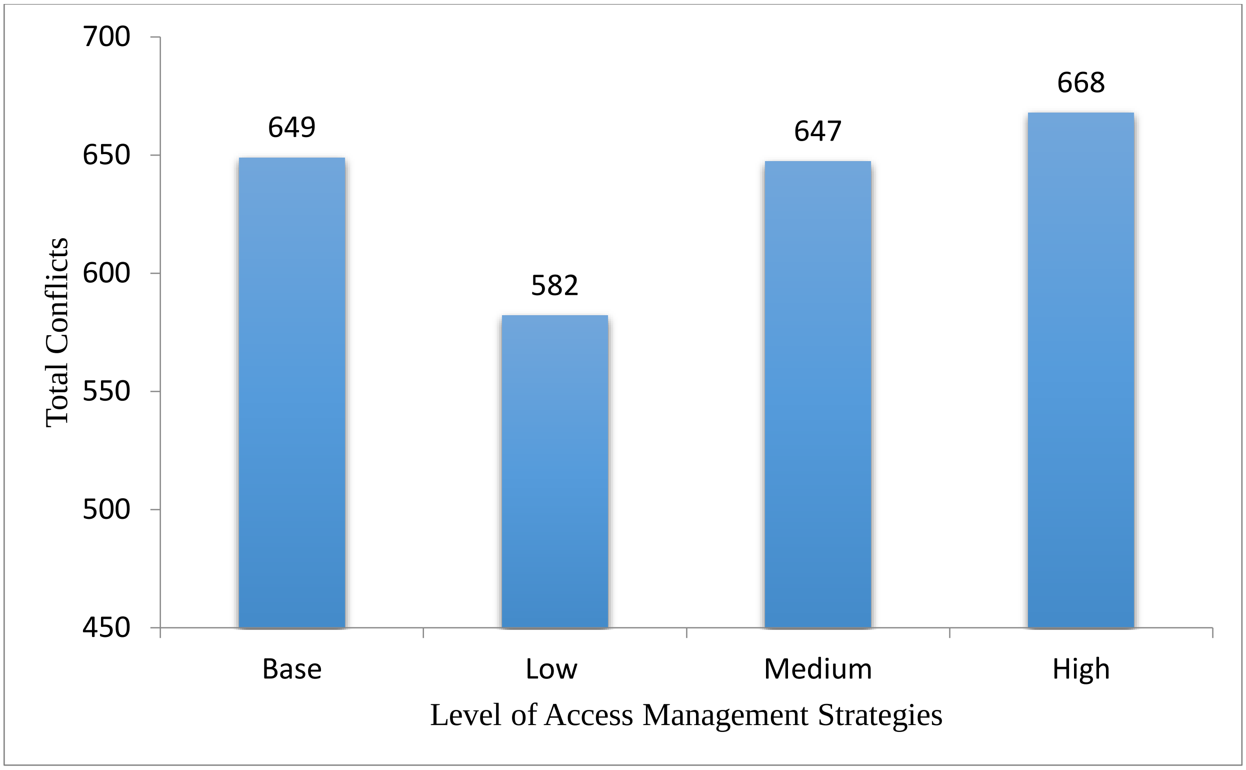


Figure 39: Total Conflicts

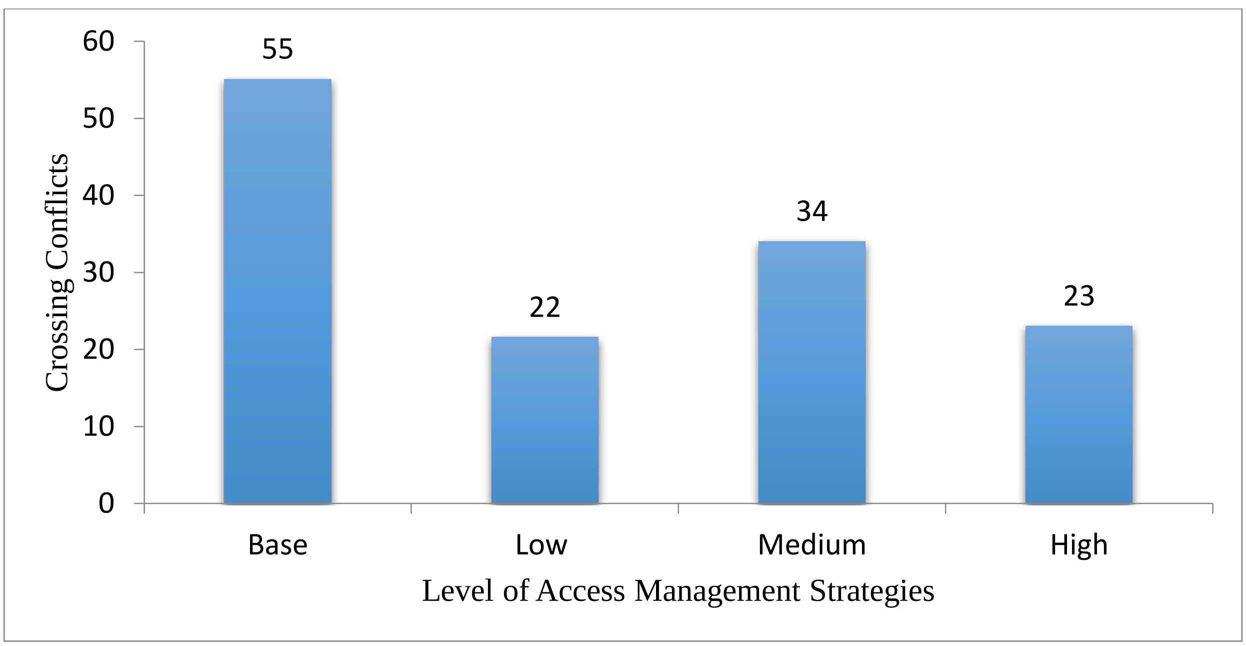


Figure 40: Crossing Conflicts

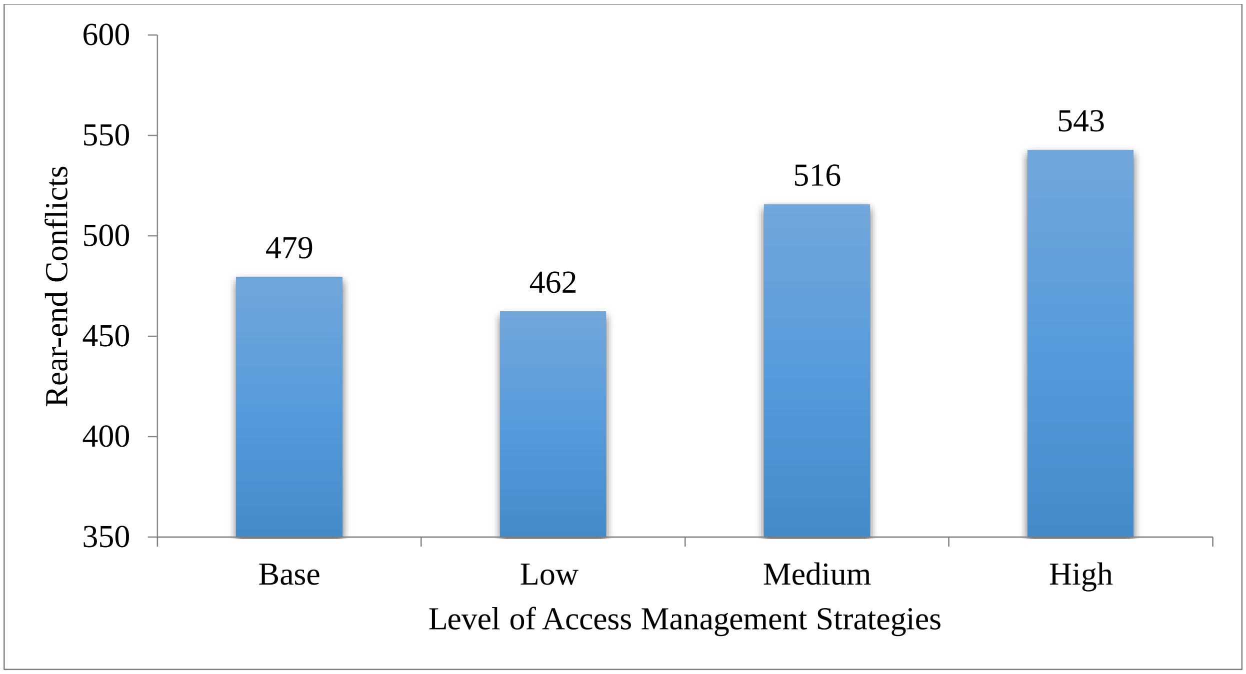


Figure 41: Rear-end Conflicts

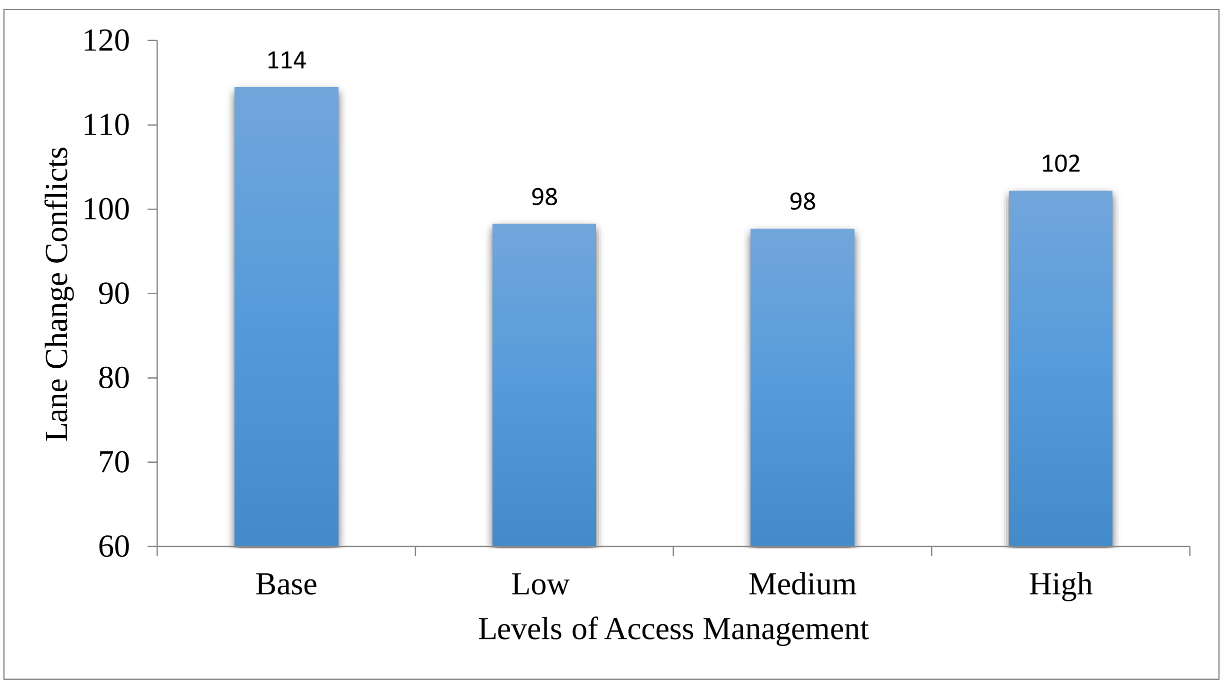


Figure 42: Lane Change Conflicts

5.3. Statistical Analysis

5.3.1. Comparison of Simulated Conflicts

The objective of the research was to compare various levels of access management strategies and come up with best possible alternative for the study corridor. The number of conflicts was used as a surrogate measure for crashes. Conflicts occur more frequently than crashes, which rare and random events. However, a reduction in conflicts means there may be a reduction in crashes.

5.3.2. Methodology

The simulated conflicts were used as a metric to compare the changes in all the proposed models. To compare the simulated conflicts, a test of proportions was used to determine if the change in conflicts were statistically significant. The conflict analysis using SSAM was conducted 30 times and the data were assumed to be normally distributed. To determine the differences between the two sample proportions, which approximately followed a normal distribution, the Z-test statistic was deemed appropriate.

The calculated z-test statistic was compared to a Z table with $\alpha = 0.05$ to achieve a confidence level of 95 percent. If the calculated Z was greater than 1.96, then the resulting decrease in simulated conflicts was statistically significant. Similarly, if the calculated Z was less than -1.96, then the resulting increase in simulated conflicts was statistically significant.

5.3.3. Analysis of Total Simulated Conflicts

Table 17 shows the percentage change in the total number of conflicts for each level of access management compared to the existing level. For the low and medium level total number of conflicts reduced by 10.32 percent and 0.31 percent respectively, while for the high level there was an increase of 2.93 percent.

Table 17: Percentage Change in Total Conflicts

Access Management Level	Number of Conflicts	Percent Change
Existing	649	-
Low	582	-10.32%
Medium	647	-0.31%
High	668	2.93%

Table 18: Results of Total Simulated Conflict Analysis

Access Management Level	Number of Conflicts	p-value		
		Low Level	Medium Level	High Level
Existing	649	<0.0001[A]	0.86	0.034[A]
Low	582	-	0.127	<0.0001[B]
Medium	647	-	-	0.014[C]
High	668	-	-	-

[A] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the model of existing corridor

[B] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the low model

[C] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the medium model

Table 18 shows the results of the z-test. There was a large reduction in the number of total conflicts for the low level of access management strategies compared to the existing conditions and it was statistically significant at 95 percent level of confidence. Even though there was a decrease in the number of total simulated conflicts for the medium level compared to the existing level, it was found not to be statistically significant at 95 percent level of confidence. While for the high level there was an increase in the number of total simulated conflicts, which was found to be statistically significant at the 95 percent level of confidence.

The results also indicated that there was an increase in the medium and high level for the number of total simulated conflicts when compared with the low level. The increase in the medium level was not statistically significant while that of the high level was statistically significant at 95 percent level of confidence.

Finally, there was an increase in the high level for the number of total simulated conflicts when compared with the medium level and it was statistically significant at the 95 percent level of confidence.

The results indicate that there was a decrease in the total simulated conflicts going from the existing conditions to the low level of access management strategies. The total simulated conflicts start to increase when the levels of access management strategies increase.

5.3.4. Analysis of Crossing Simulated Conflicts

Table 19 shows the percentage change in the number of crossing conflicts for each level of access management compared to the existing level. For the low, medium, and high level number of crossing conflicts reduced by 60 percent, 28.18 percent, and 58.18 percent respectively.

Table 19: Percentage Change in Number of Crossing Conflicts

Access Management Level	Number of Conflicts	Percent Change
Existing	55	-
Low	22	-60.00%
Medium	34	-38.18%
High	23	-58.18%

Table 20: Results of Crossing Simulated Conflict Analysis

Access Management Level	Number of Conflicts	p-value		
		Low Level	Medium Level	High Level
Existing	55	<0.0001[A]	<0.0001[A]	<0.0001[A]
Low	22	-	<0.0001[B]	0.370
Medium	34	-	-	<0.0001[C]
High	23	-	-	-

[A] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the model of existing corridor

[B] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the low model

[C] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the medium model

Overall, the results in Table 20 show that there was a decrease in the number of simulated crossing conflicts compared to the existing conditions across all the levels of access management strategies and were statistically significant at the 95 percent level of confidence. The decrease may be due to decrease in the number of driveways, fewer number of mid-block crossing, and left turning vehicles compared to the existing conditions.

There was a statistically significant increase in the simulated crossing conflicts from the low level to the medium level of access management. This increase could be because of the few mid-block left turns permitted for the medium level and U-turns permitted at the signalized intersections. There was an increase in the simulated crossing conflicts from the low level to the high level of access management and it was not statistically significant at the 95 percent level of confidence.

Finally, there was a statistically significant decrease in simulated crossing conflicts from the medium level to the high level of access management. This could be due to increased use of collector streets to access the business leading to less mid-block left turns.

5.3.5. Analysis of Rear-end Simulated Conflicts

Table 20 shows the percentage change in the number of crossing conflicts for each level of access management compared to the existing level. For the low level number of rear-end conflicts reduced by 3.55 percent, while the medium and high saw an increase of 7.72 percent, and 13.36 percent respectively.

Table 21: Percentage Change in Rear-end Conflicts

Access Management Level	Number of Conflicts	Percent Change
Existing	479	-
Low	462	-3.55%
Medium	516	7.72%
High	543	13.36%

Table 22: Results of Rear-end Simulated Conflict Analysis

Access Management Level	Number of Conflicts	p-value		
		Low Level	**Medium Level**	**High Level**
Existing	479	0.002[A]	<0.0001[A]	<0.0001[A]
Low	462	-	<0.0001[B]	<0.0001[B]
Medium	516	-	-	<0.0001[C]
High	543	-	-	-

[A] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the model of existing corridor

[B] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the low model

[C] Change in simulated conflicts is statistically significant at 95 percent level of confidence compared to the medium model

Table 22 indicates that, except for the statistically significant decrease in the number of rear-end simulated conflicts compared to the exiting condition, there was an increase in the number of rear-end simulated conflicts. The increase was statistically significant at 95 percent level of confidence for all the other comparisons. The increase in the number of rear-end conflicts could be due to the increase in volumes of vehicles travelling the corridor due to the decrease in the number of driveways. The increase in volume could be due to vehicles having less opportunities to turn into driveways and have to travel to the nearest mid block opening or a signalized intersection.

CHAPTER 6: SUMMARY OF FINDINGS

6.1. Introduction

The objective of the research study was to study and quantify the safety effects of access management on the 23rd Street in Lawrence, Kansas, using the microsimulation software VISSIM and the conflict analysis software SSAM. The researcher compared the safety effects of three levels of access management strategies namely low, medium, and high. The low level reduced the number of driveways from 58 for the existing conditions to 43. The medium level had 43 driveways and a raised median throughout the corridor with 8 median openings. The high level had 43 driveways and a raised median throughout the corridor with 6 median openings.

The existing conditions of the 23rd Street corridor in Lawrence, Kansas were coded into VISSIM. One hour of data were collected from the model using VISSIM's analysis tool, with 30 minutes of loading time. The base model was calibrated by comparing simulated travel time and field collected travel time. Three models with increasing levels of access management were coded using VISSIM. Conflict analysis was then performed using SSAM for all the models, using the vehicle trajectory files generated from the VISSIM model.

It was found that the travel times increase by an average of 1.8 percent with the increase in the level of access management compared to the existing condition. It was observed a 1.5 percent reduction in the travel time while the level of access management changed from the low level to the medium level. The travel observed a little change with the implementation of access management strategies, but statistical analysis of vehicle travel time was out of scope of this study.

6.2. Research Findings

Firstly, a reduction of 10.3 percent and 0.3 percent in the total number of conflicts was reported for the low level and the medium level compared to the existing condition. There was an increase of 2.9 percent in total number of conflicts in case of the high level compared to the existing condition. Secondly, for crossing conflicts, a reduction of 60 percent, 38.2 percent, and 58.2 percent was reported in case of the low level, the medium level, and the high level respectively, as compared to the existing condition. Thirdly, The number of rear-end conflicts increased for the medium and the high level by 7.7 percent and 13.4 percent respectively compared to the existing condition. Also, there was a reduction of 3. percent in the low level compared to the existing condition. Finally, there was a reduction of 14 percent, 14 percent, and 10.5 percent in lane change conflicts in the case of the low level, medium level, and high level respectively, as compared to the existing condition.

This study showed that access management can have a positive effect on the safety of the corridor. Implementation of raised median and consolidation of driveways, as access management strategies will have a slight negative impact on the operations of the corridor, as the vehicle travel time increased for all levels of access management strategies as compared to the existing conditions. The travel time in the study corridor increased as the level of access management increased when compared to the existing conditions.

6.3. Conclusions

From the study, the researcher drew the following conclusions:

- Access management does affect the travel conditions by increasing travel time.
- The safety of the corridor increased with the implementation of the access management strategies at the low and the medium level compared with the existing condition.
- The safety significantly decreased at the high level of access management compared to the existing condition.
- The low level had a high safety benefit compared to the medium and high level of access management strategy.

6.4. Limitations

The researchers observed that microsimulation software and SSAM had the following limitations:

- Simulation models do not take in to account the roadside environment, which affects the driver behavior.
- Length of the sections have to be manually adjusted, there is no option to directly enter the length of the section.

6.5. Contribution to Highway Safety

The research study has shown that VISSIM and SSAM used to analyze the effects of access management strategies can provide safety and operational benefits in the following ways:

- Access management reduces the number of conflicts, which may result in fewer crashes.
- Allows transportation engineers and planners to compare various alternatives and choose the one, which benefits the safety and operations most.

6.6. Concluding Remarks

This research study has shown that access management strategies do improve the safety of a corridor and was observed that the vehicle travel time increased on an average by 1.8 percent. The researchers noted that increasing the level of access management might not necessarily mean improvements in the safety of the corridor. With increasing traffic volumes in the city and 23rd Street being one of the major arterials of the city, along with improving the efficiency of the corridor, safety should also be addressed. VISSIM and SSAM will allow the city to have quantifiable estimates of safety in terms of conflicts for a number of alternatives and improve design.

6.7. Future Research

This study quantified the effects of access management strategies using VISSIM and SSAM. It is recommended that:

- Cost-benefit analysis of various levels of access management strategies should be conducted.
- Similar studies should be conducted for various corridors in the country to be able to provide guidelines for access management in urban areas to improve safety.

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APPENDIX A

This section contains the detailed images of the base model.

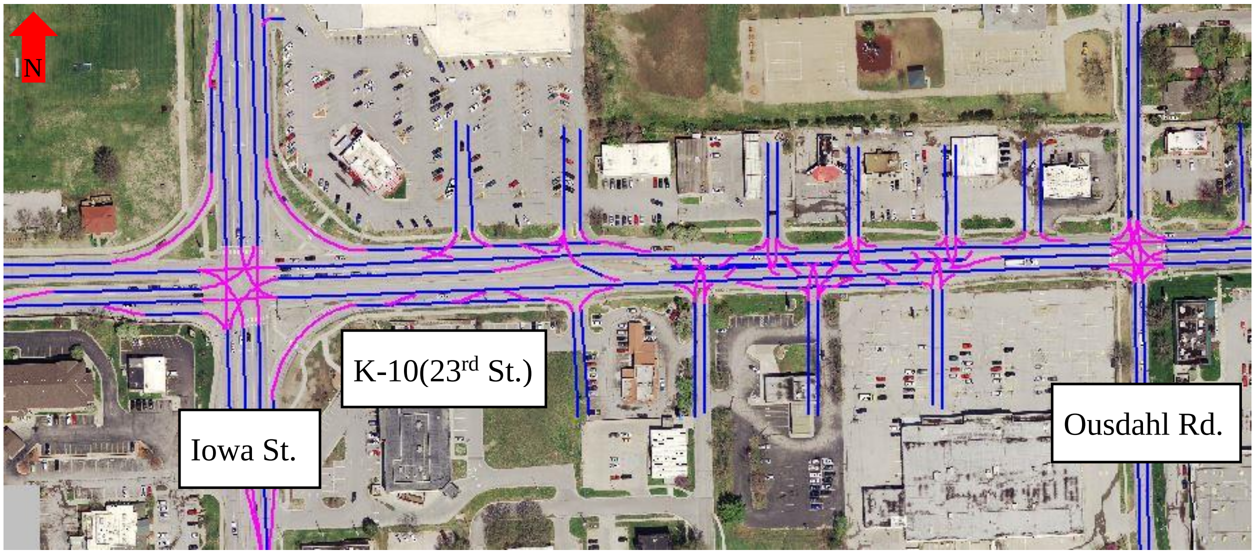

Figure A-1: Iowa St. to Ousdahl Rd.

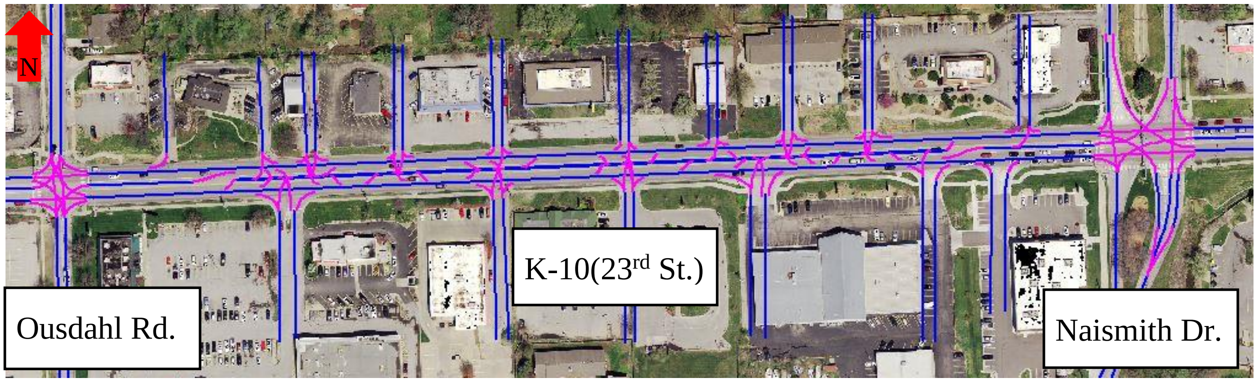

Figure A-2: Ousdahl Rd. to Naismith Dr.

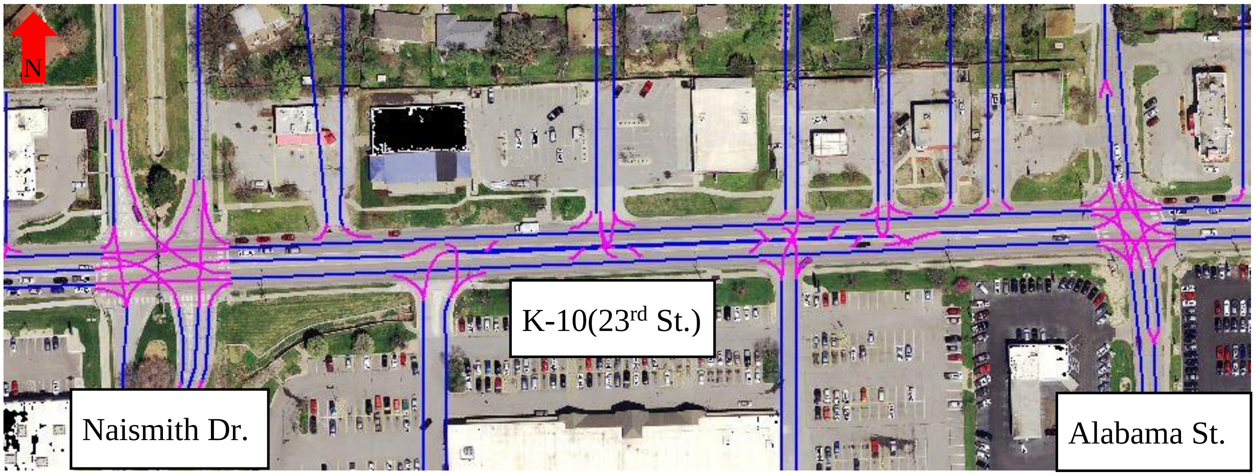

Figure A-3: Naismith Dr. to Alabama St.

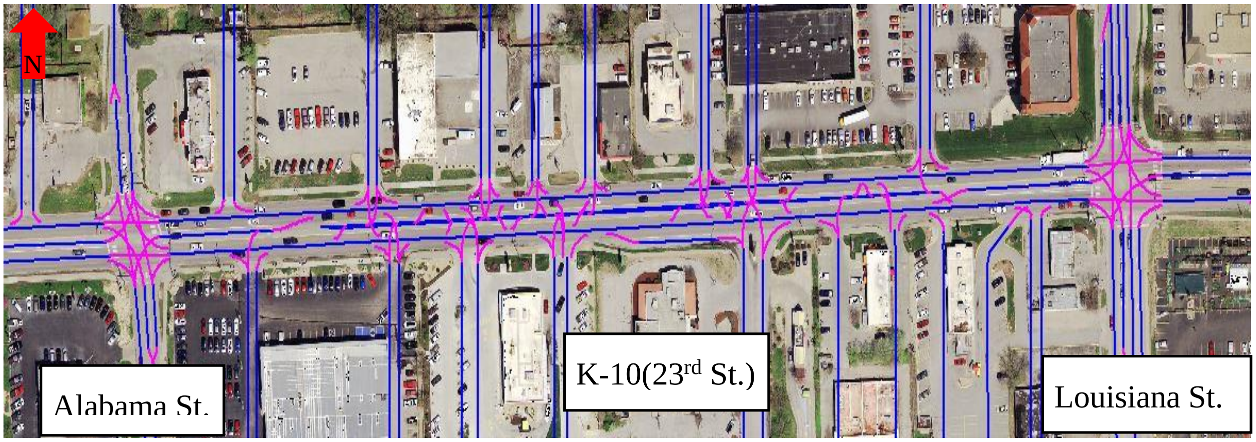

Figure A-4: Alabama St. to Louisiana St.

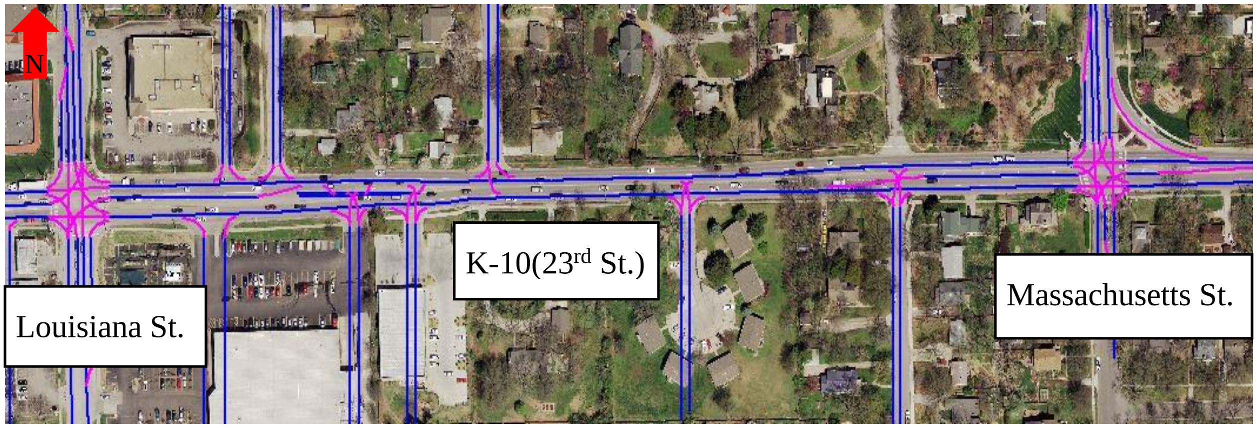

Figure A-5: Louisiana St. to Massachusetts St.

APPENDIX B

This section contains the detailed images of the low model. The following changes were made for the low model compared to the base model:

- Iowa St. to Ousdahl Rd.: North of W 23rd St., six driveways were consolidated into three driveways, one each near Hastings, Presto, and Jimmy Johns. South of W 23rd St., three driveways were consolidated into two driveways one each near El Mezcal and Hobby Lobby.
- Ousdahl Rd. to Naismith Dr.: North of W 23rd St., nine driveways were consolidated into six driveways, one each near Dunn Bros Coffee, Scotch laundry, Car Toyz, Chipotle, Taco Bell, and Truity Credit Union. South of W 23rd St., six driveways were consolidated into four driveways one each near Arby's, Oriental Bistro, Party America, and Natural Grocers.
- Naismith Dr. to Alabama St.: All the driveways were retained in this section of the corridor.
- Alabama St. to Louisiana St.: North of W 23rd St., eight driveways were consolidated into six driveways one each near KFC, Laird Noller Collision Center, Liberty Tax Service, Pizza Hut, and Goodscents Subs. South of W 23rd St., eight driveways were consolidated into six driveways one each near Laird Noller Auto Dealership, McDonalds, Carol O'Kellys's, Dunkin Donuts, Wendy's and BP Gasoline Station.
- Louisiana St. to Massachusetts St.: All the driveways were retained in this section of the corridor.

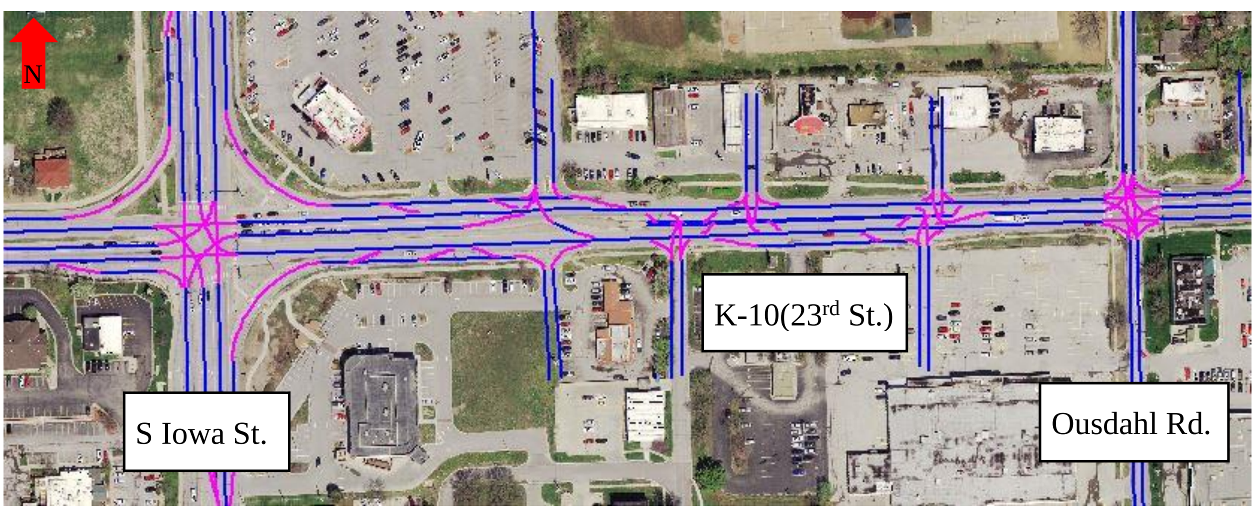

Figure B-1: Iowa St. to Ousdahl Rd.

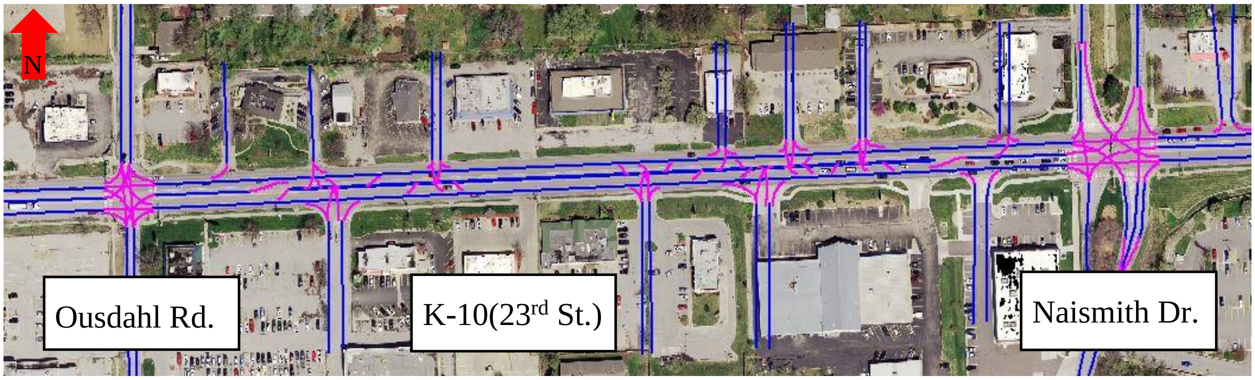

Figure B-2: Ousdahl Rd. to Naismith Dr.

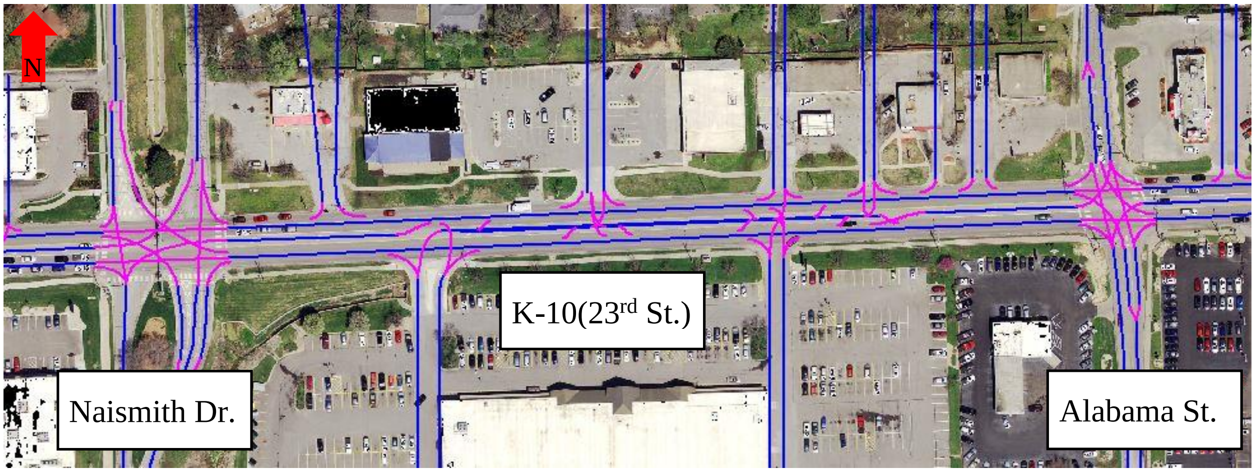

Figure B-3: Naismith Dr. to Alabama St.

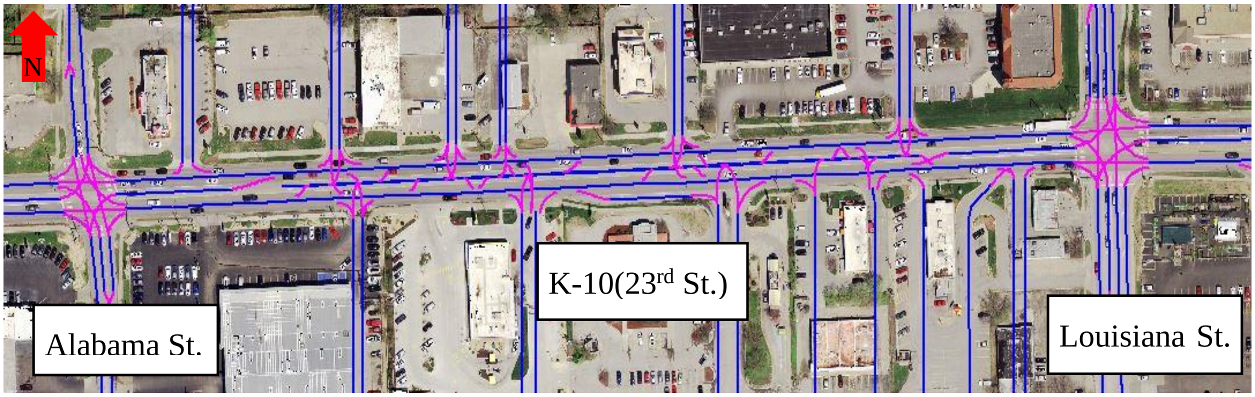

Figure B-4: Alabama St. to Louisiana St.

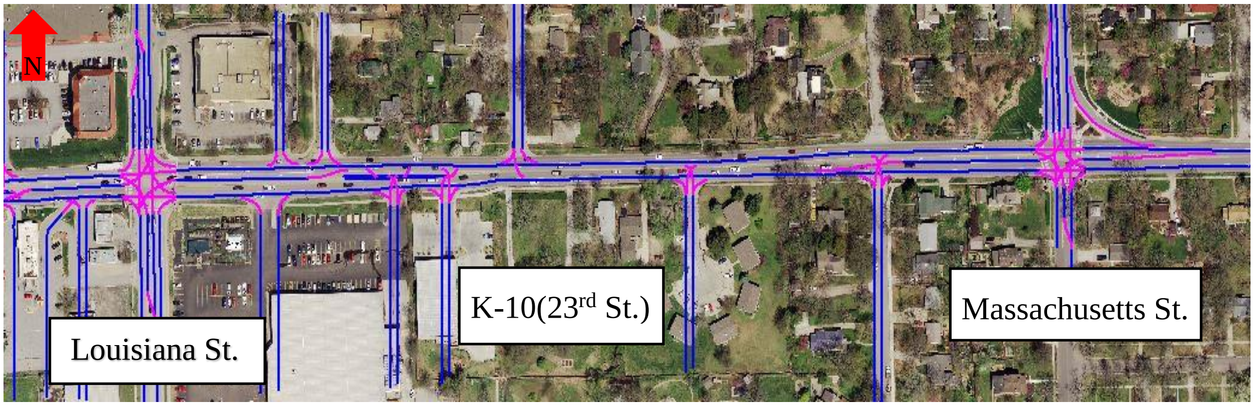

Figure B-5: Louisiana St. to Massachusetts St.

APPENDIX C

This section contains the detailed images of the medium model. The following changes were made for the medium model in addition to those listed in appendix B:

- All the changes made for the low model were retained in the medium model.
- Iowa St. to Ousdahl Rd.: Raised median was modeled in this section with two openings for Ridge Ct., Yokohama, and Hobby Lobby.
- Ousdahl Rd. to Naismith Dr.: Raised median was modeled in this section with three openings for Arby's, Dunn Bros Coffee, Oriental Bistro, Car Toyz, Party America, and Taco Bell.
- Naismith Dr. to Alabama St.: Raised median was modeled in this section with one opening for Dillons and Phillips 66.
- Alabama St. to Louisiana St.: Raised median was modeled in this section with two openings for McDonalds, Liberty Tax Services, Carol O'Kelly's, and Panera Bread.
- Louisiana St. to Massachusetts St.: No additional changes were made on this section.

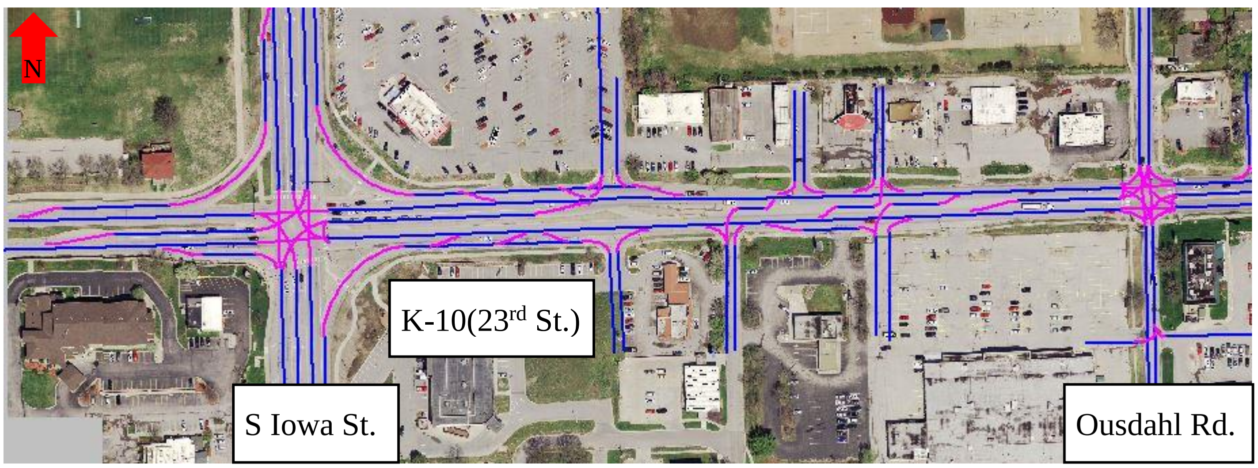

Figure C-1: Iowa St. to Ousdahl Rd.

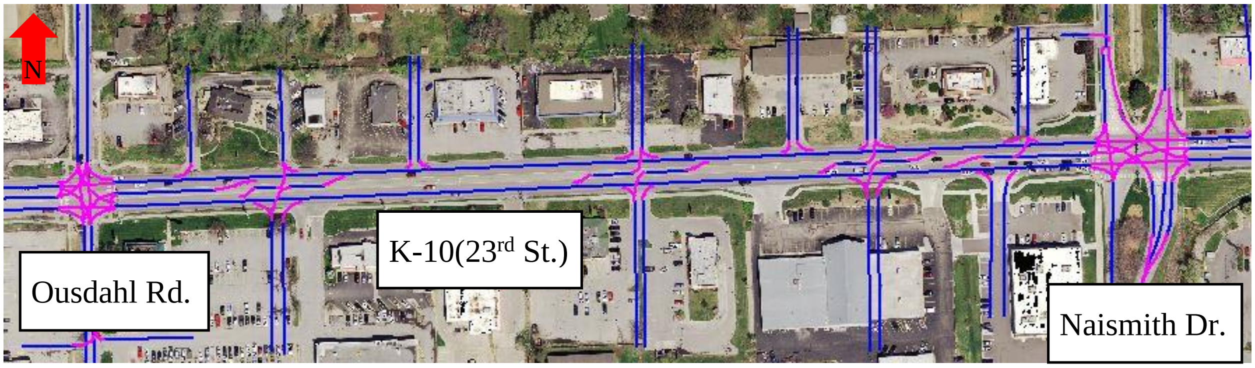

Figure C-2: Ousdahl Rd. to Naismith Dr.

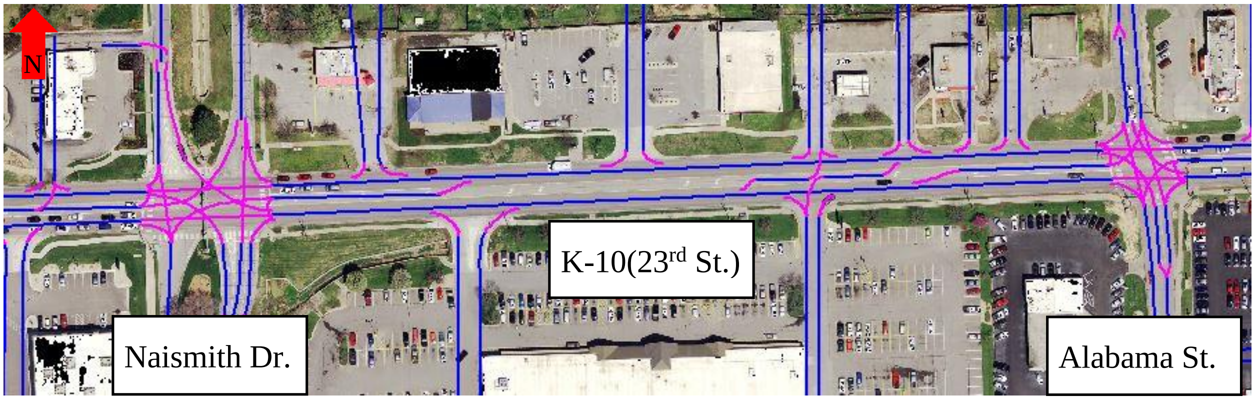

Figure C-3: Naismith Dr. to Alabama St.

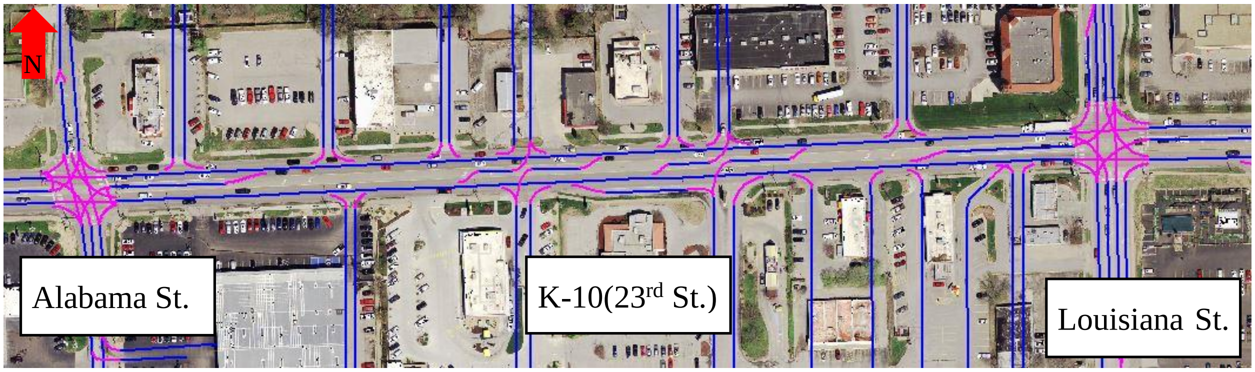

Figure C-4: Alabama St. to Louisiana St.

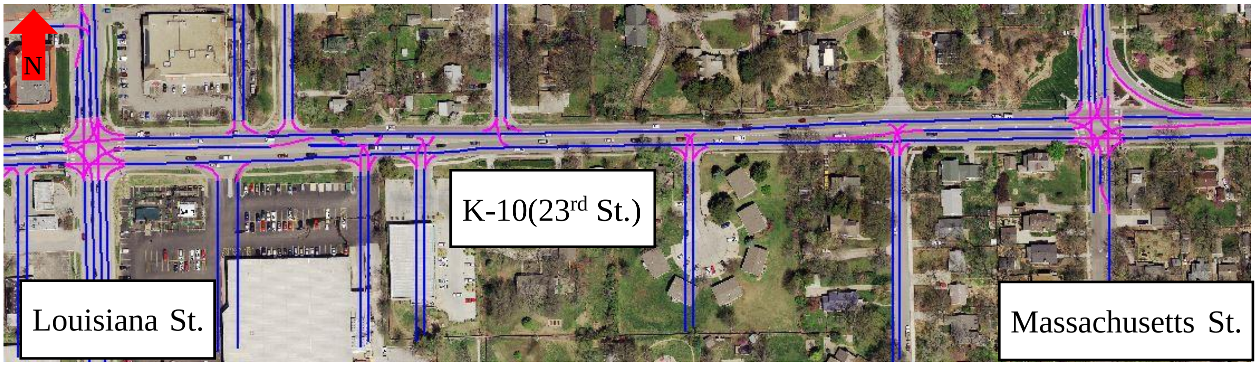

Figure C-5: Louisiana St. to Massachusetts St.

APPENDIX D

This section contains the detailed images of the high model. The following changes were made for the medium model in addition to those listed in appendix B and C:

- All the changes made for the low and the medium models were retained.
- Two median openings were eliminated compared to the medium model located near Dillons and Party America.

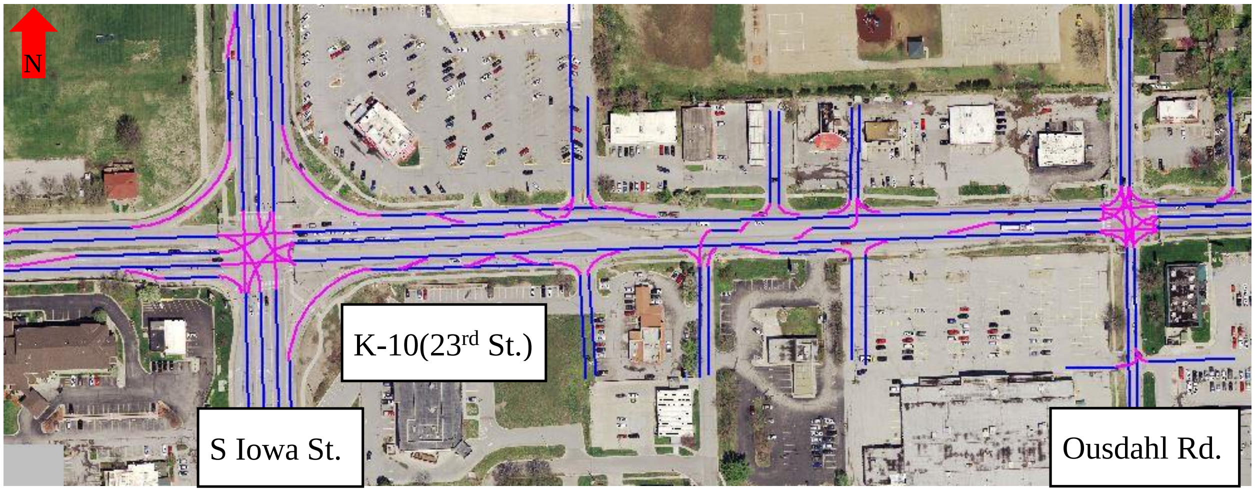

Figure D-1: Iowa St. to Ousdahl Rd.

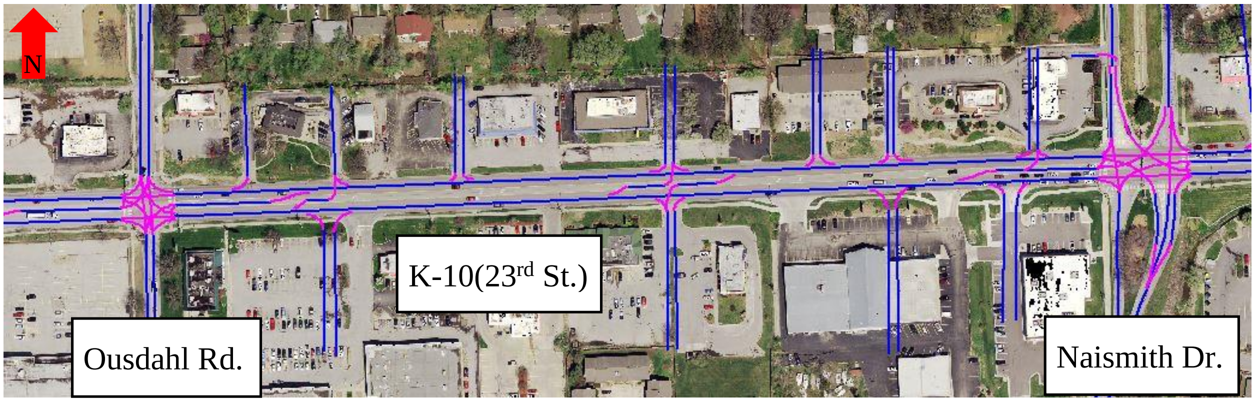

Figure D-2: Ousdahl Rd. to Naismith Dr.

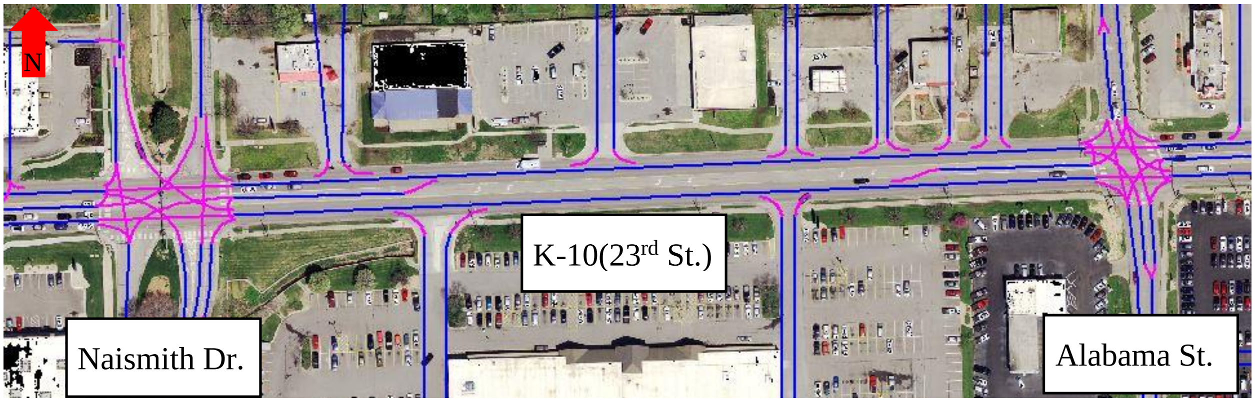

Figure D-3: Naismith Dr. to Alabama St.

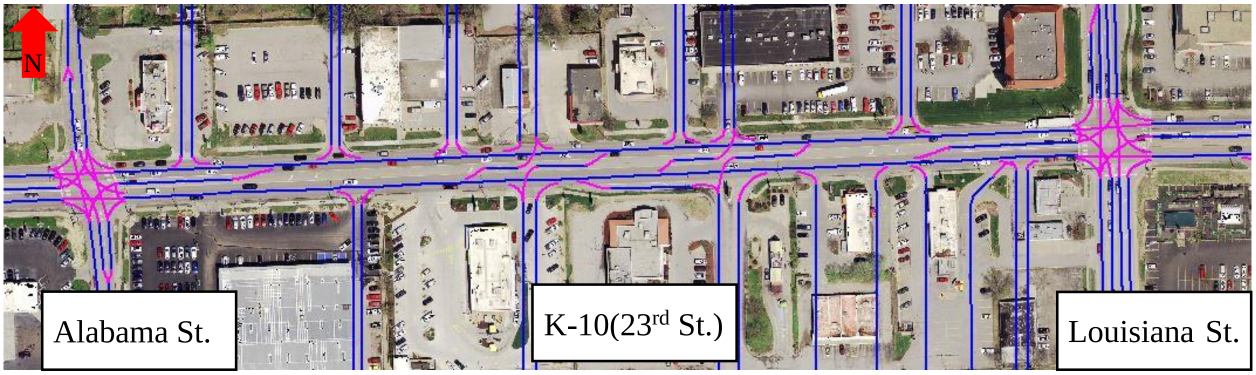

Figure D-4: Alabama St. to Louisiana St.

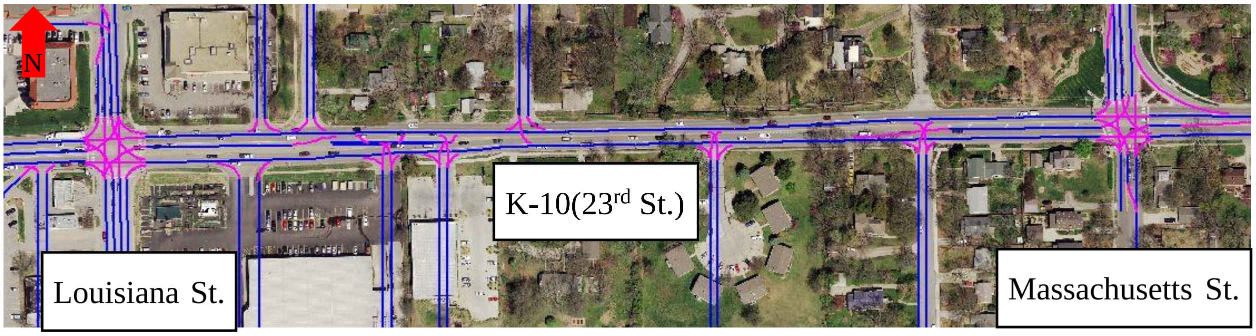

Figure D-5: Louisiana St. to Massachusetts St.