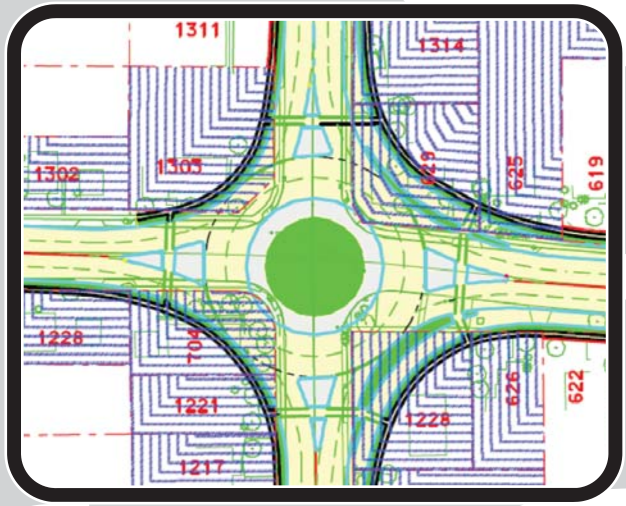
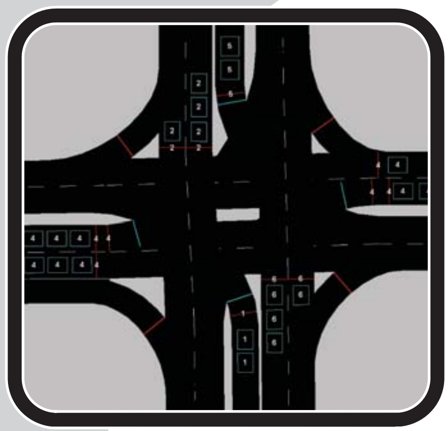
Toolbox to Assess Tradeoffs between Safety, Operations, and Air Quality for Intersection and Access Management Strategies





Final Report, November 2008

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16. Abstract

Significant transportation agency resources are allocated to meet maintenance, operations, safety, and air quality goals. Although there is a significant amount of overlap between these areas, decisions to meet agency goals in one area often do not consider goals in the others and, as a result, miss opportunities to leverage funds and make better informed decisions overall.

There are a number of areas of overlap between capital improvements designed to improve operations, maintenance, safety, and air quality goals that provide a rich opportunity to leverage funds and use resources more cost-effectively while meeting agency goals in two or more of the areas.

The objective of this research is to develop analytical tools that can efficiently evaluate common capital projects used to meet agency goals in one area (operations, safety, air quality, and maintenance) but that also have a significant impact on the others.

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TOOLBOX TO ASSESS TRADEOFFS BETWEEN SAFETY, OPERATIONS, AND AIR QUALITY FOR INTERSECTION AND ACCESS MANAGEMENT STRATEGIES

Final Report
November 2008

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1. INTRODUCTION

Significant transportation agency resources are allocated to meet maintenance, operation, safety, and air quality goals. Although there is a significant amount of overlap between these areas, decisions to meet agency goals in one area often do not consider agency goals in the others and, as a result, miss opportunities to leverage funds and make better informed decisions about overall impact. For instance, an agency may consider using safety improvement funds to either add left-turn lanes or a roundabout at an intersection that has a significant number of serious accidents. The decision to select one or the other based solely on safety considerations is a missed opportunity to make positive improvements that may significantly affect air quality. That is, both alternatives may provide similar safety benefits, but the roundabout may offer much more significant air quality benefits while left-turn lanes may have significantly lower maintenance costs. Considering the different areas in the decision-making process would allow better allocation of resources and provide the opportunity, in some cases, to leverage funds. For instance, if the project in the example discussed above had a significant air quality benefit, it may qualify for Congestion, Mitigation, and Air Quality (CMAQ) funding and state or local safety improvement funds.

Decisions to invest in strategies designed to improve safety, reduce congestion and improve traffic flow to improve operations, or meet air quality goals are generally coordinated individually at some jurisdictional level by local, state, or national standards. At present, there are no standard measures to quantify or compare the efficiency of different projects across different agency goals.

There are a number of areas of overlap between capital improvements designed to improve operations, safety, and air quality goals that provide a rich opportunity to leverage funds and use resources more cost-effectively while meeting agency goals in two or more of the areas. The objective of this research is to provide decision support information about operations, safety, maintenance, and air quality that agencies can use to assess the ways capital improvement project goals in one area impact the other areas so that resources can be leveraged and used more efficiently.

Based on this research, this toolbox covers the following general topics:

- Roundabouts
- Left-turn lanes
- Median treatments
- Driveway consolidation
- U-turns
- Signalization and traffic signal spacing
- Alternative access roads

These topics will be examined individually in sections 2 through 8 of this report. Areas discussed include access management, traffic flow, safety, fuel consumption and air quality, and economic impacts.

Additionally, because information was lacking for these topics in several areas, three case studies were conducted to evaluate the trade-offs between different strategies. These case studies are included in the discussions of the various improvement types in sections 2 through 8, and section 9 explains the case studies and their results in more detail.

2. ROUNDABOUTS

This section summarizes information and presents case studies about the safety, operations, access management, and air quality impacts of roundabouts. Roundabouts are touted as having significant safety benefits over other intersection configurations, and in general the team found that most studies indicated this as being the case. Roundabouts have been successfully used as part of access management, although this application is not mature. Roundabouts are generally considered to improve traffic flow and improve air quality, since unnecessary delay due to idling at intersections is removed. However, all vehicles must slow at a roundabout, and as a result the traffic flow and air quality impacts depend on a number of factors, as discussed in the following sections. The results of the case study discussed in section 2.4 suggest that installing roundabouts does prompt a discussion of tradeoffs.

2.1. Roundabouts as Part of Access Management

Roundabouts are considered a viable option to assist with access management. The following access management strategies complement roundabout design:

- Continuous raised medians
- Restricted turning movements
- Right-in-right-out movements
- Use of U-turns

In particular, roundabouts complement the use of raised medians. When drivers are prohibited from making a left turn into a business, they are forced to pass their destination and make a U-turn. A roundabout facilitates a safe U-turn and can provide an opportunity to sell access management to business owners (Alternate Street Design 2008).

Roundabouts were used along the South Golden Road project in Golden, Colorado, for access control and improved operations (Ariniello 2004). After the roundabouts were constructed, a 50% reduction in the average access point delays (i.e., the time it takes to enter the roadway from the driveway/parking lot) and a 67% reduction in the maximum access point delays were reported.

The Transportation Research Board Access Management Committee (TRB 2003) has recently begun investigating the effects of roundabouts and access management strategies (i.e., the impacts of intersection spacing).

Access control at interchange ramp terminal intersections often involves a large percentage of left turning traffic and potentially limited queuing storage on the bridges, which can cause corridor and intersection congestion in these areas. The close proximity of the two (typically) ramp terminal intersections, as well as adjacent intersections and access points, also create challenges in determining the appropriate traffic control. The Wisconsin Department of Transportation (2005) identifies two benefits of roundabouts at ramp terminal intersections. First, the intersection sight distance required is typically smaller and, second, the spacing of vehicles turning onto the on-ramp tends to be more random, which may be helpful during peak periods.

2.2. Traffic Flow Impacts of Roundabouts

Roundabouts are generally considered to improve traffic flow, since unnecessary delay due to idling at intersections is removed. However, all vehicles must slow at a roundabout. As a result, the traffic flow impacts of implementing a roundabout depend on a number of factors, such as volume, fleet mix, intersection characteristics, whether the roundabout is located within a coordinated signal system, etc.

2.2.1. Summary of Information from Other Sources

The Federal Highway Administration's (FHWA) *Roundabouts: An Informational Guide* (Robinson et al. 2000) discusses delay and capacity comparisons and suggests the following:

- Roundabouts usually provide higher capacity and lower delays than all-way-stop control under the same traffic volume and right of way limitations.
- Roundabouts are not likely to have lower delay than intersections with two-way stop control (TWSC) when minor movements are not experiencing operational problems under the TWSC.
- Single lane intersections that do not exceed the peak-hour volume warrants for signals can be assumed to operate within their capacity.
- Roundabouts that operate within capacity in general will have lower delays than signals under the same traffic volume and right-of-way limitations.
- Roundabout are likely to result in substantially lower delay than all-way-stop control, and the main benefit of a roundabout is during off-peak periods.
- One of the delay reduction benefits of roundabouts over signals occurs during the off-peak period.

Bared and Edara (2005) used VISSIM microscopic traffic simulation software to evaluate the performance of a roundabout within a coordinated set of signals. The authors modeled a corridor with three intersections separated by 1/4 mile. Initially, they evaluated the corridor with all three intersections signalized. Signal coordination was optimized using TRANSYT-7F software. Next, the authors replaced the middle intersections with a roundabout. VISSIM results indicated that when the system was operating below capacity, the roundabout scenario resulted in lower delay. When the corridor approached capacity, the authors found that the coordinated signals scenario resulted in slightly lower overall delay.

Bergh et al. (2005) evaluated traffic flow for 10 northern Virginia signalized intersections that were determined to be good candidates for a roundabout based on volume and intersection geometry. The authors evaluated performance for the existing control and then compared that with the hypothetical situation of replacing the existing control with a roundabout using aaSIDRA software. The analysis was based on data collected during peak periods for two days. The authors determined that the overall average vehicle delay would be 17% to 92% lower for the roundabout alternatives than for signalization.

Using aaSIDRA, Sisiopiku and Oh (2001) compared roundabouts to yield, two-way, and four-way stop controls using different variations in volumes, turning volume splits, number of approach lanes, and lane width. The authors found that roundabouts were the best alternative for two-lane approaches that carry heavy thru or left turning volumes. They suggest that two-way stop and yield can be effective with light demand. All-way stop control resulted in greater delays under both light and heavy traffic, compared to roundabouts and signalization. The authors found that roundabouts performed better at intersections with two-lane approaches and heavy volumes, while intersections with signals performed better with heavy volumes and heavy left turns.

South Golden Road in Golden, Colorado, is a corridor with a series of strip malls, grocery stores, fast food restaurants, and other businesses (see Figure 2-1). The one-half–mile corridor has an average daily traffic (ADT) over 20,000. Two alternatives were considered for the corridor: (1) signalized intersections with center medians and restricted left turns and (2) roundabouts at the junctions with center medians to restrict left turns. The city determined that the roundabout alternative provided better access to businesses and was more pedestrian friendly, so this alternative was selected.

Figure 2-1. South Golden Road in Golden, Colorado: before (left) and after (right) (Hartman 2004)

In the South Golden Road case, traffic operations were compared before and after installation of the roundabouts, as well as with the alternative of adding a third signal to the corridor. Travel time decreased by 10 seconds while, at the same time, the 85th percentile speed decreased from 47 to 33 mph. The queues in the parking lots were nearly eliminated because the vehicles did not have to wait to make left turns. Instead, they made right turns and used the roundabouts for U-turns. Safety also improved along the corridor: prior to construction of the roundabouts, there were 10 injury crashes per year, and in the four years after the roundabout was constructed only 1 injury crash was reported (Hartman 2004).

A series of roundabouts was implemented along West 70th Street in Edina, Minnesota. The three roundabouts are near a large retail area (Galleria Shopping Mall) near West 70th Street and France Avenue (Figures 2-2 and 2-3). A Super Target and a new hotel were also coming to the area, which was heavily retail. West 70th Street was a four-lane roadway that reduced to a two-lane roadway in the vicinity of the three roundabouts, which were constructed along the corridor.

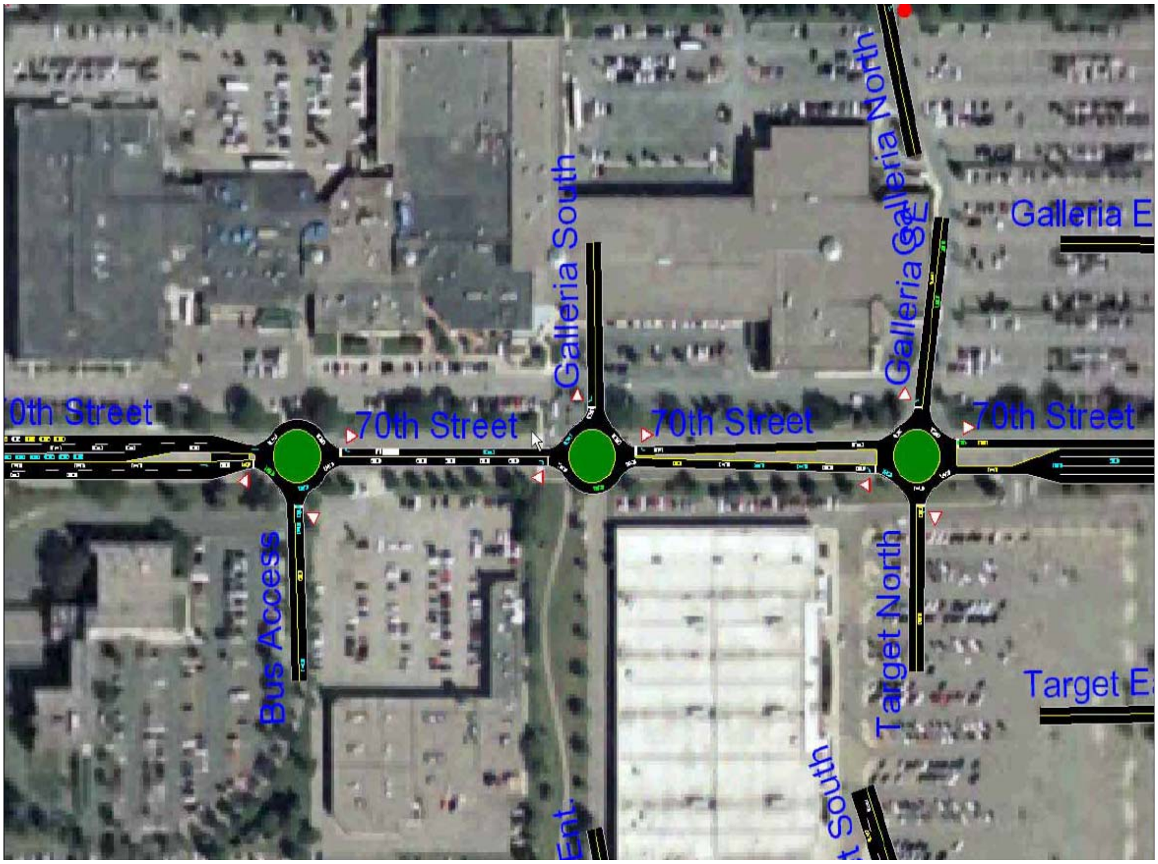


Figure 2-2. Series of roundabouts along West 70th Street in Edina, Minnesota (Rickart et al. 2008)

Figure 2-3. Roundabout along West 70th integrated with commercial activity (Rickart et al. 2008)

Prior to installation of the roundabouts in Edina, traffic during peak travel times had a difficult time entering the West 70th Street corridor. There were also concerns about pedestrian and bicyclist safety. The corridor carries about 16,000 vehicles per day, and traffic turning onto side streets along the corridor was experiencing delay (SRF 2006). Access management and a series of three roundabouts were designed and used along the corridor to solve the traffic operation and safety problems. Although the roundabouts have only been open for a short time, the city indicates that vehicle operations have improved from a level of service (LOS) between B and F prior to opening to an LOS between A and D after opening. The city also found no reduction or change in access (Rickart et al. 2008).

2.2.2. Traffic Flow Impacts Case Studies

Using VISSIM software, the research team also evaluated the operational impacts of including a roundabout in a signalized corridor. Using existing roadways in Iowa and Minnesota, the analysis compared average corridor travel time, delay, stop time, and travel speeds for each instance. This analysis was intended to gain insight into the interaction of signals and roundabouts on the same corridor. The following sections provide a summary of the results.

US 69/Grand Avenue—Ames, Iowa

The first case study was US 69 (Grand Avenue), a signalized corridor in Ames, Iowa. There are five signalized intersections, shown with blue X’s on the aerial in Figure 2-4, along the 1.4 mile section of the corridor used in the analysis. Intersections are spaced at 1/4 mile, 1/3 mile, 1/2 mile, and 1/4 mile, respectively. The corridor is a four-lane major collector with an annual

average daily traffic (AADT) of 17,000 with 97% passenger vehicles. Aerial images shown in this report are courtesy of the Iowa Department of Transportation.

The majority of land use along the corridor is residential, with the exception of the area surrounding North Grand Mall, which also includes a Wal-Mart, a Cub Foods supermarket, and various small retail establishments. US 69 throughout the study area is an undivided paved four-lane curb-and-gutter arterial street with residential driveways, local streets, and neighborhood collector streets directly intersecting the highway. There are sidewalks on both sides of the street and at least 15 ft of clear zone on each side.

The intersection at 13th Street and Grand Avenue has 2,900 entering vehicles during peak hour and is the most congested intersection along the corridor. The intersection serves the city as a cross point for two major arterials that lead either to Iowa State University heading westbound or to Mary Greeley Medical complex heading eastbound. The intersection is surrounded by private residences, a local church on the northwest side of the intersection, and a small business on the southeast side. No left-turn lanes are currently present, which causes significant delay. In July 2007, the city of Ames requested a feasibility study for the intersection of 13th Street and Grand Avenue to investigate possible alternatives to improve travel time through the corridor and to improve safety. The city reported that this intersection performed at a LOS of F, with an average peak-hour delay of 207 seconds.

Using VISSIM, three alternatives were considered. The first is the existing situation. Existing vehicle volumes and intersection timing plans were obtained from the City of Ames and used to code a base scenario in VISSIM. The intersection at 13th Street and Grand Avenue currently is operating with a split-phase traffic signal to accommodate left turning vehicles. The city uses this intersection as the zero point of offset coordination, and the other four intersections were offset between 20 and 80 seconds. The existing scenario was optimized so that the base signal timing plan for the first alternative was the most efficient that could be achieved given existing traffic conditions.

In addition to optimizing signal timing for the existing intersection, both a roundabout and the addition of left-turn lanes were considered as alternatives to improve operations at the intersection. In all, the three alternatives evaluated in VISSIM for the 13th Street and Grand Avenue intersection include (1) optimized signal timing with existing geometry, (2) a two-lane roundabout, and (3) optimized signal timing with left-turn lanes The left-turn lanes alternative utilized protected/permitted phasing. The existing layout of the intersection and a schematic of the two alternatives are shown in Figures 2-5 to 2-7.

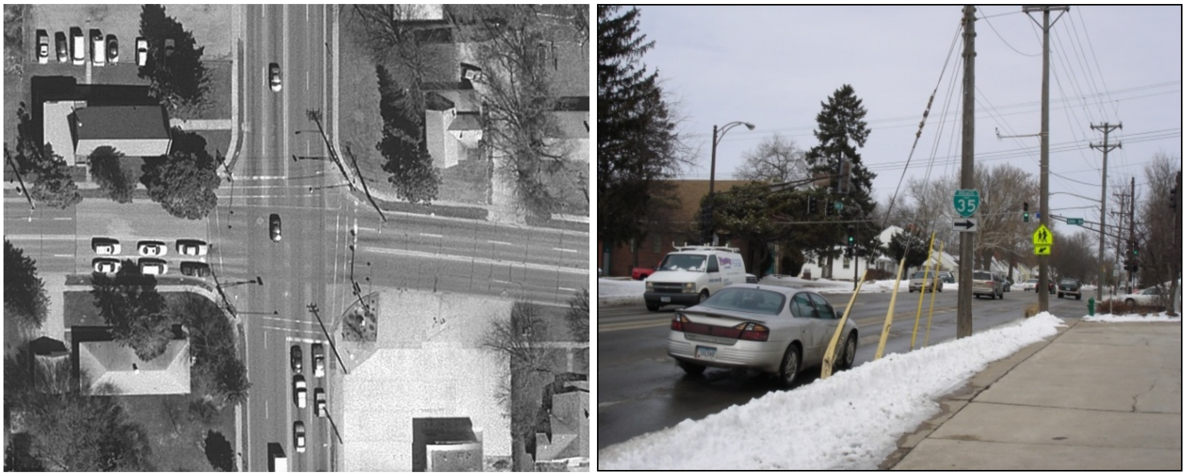


Figure 2-5. Existing scenario at 13th Street and Grand Avenue

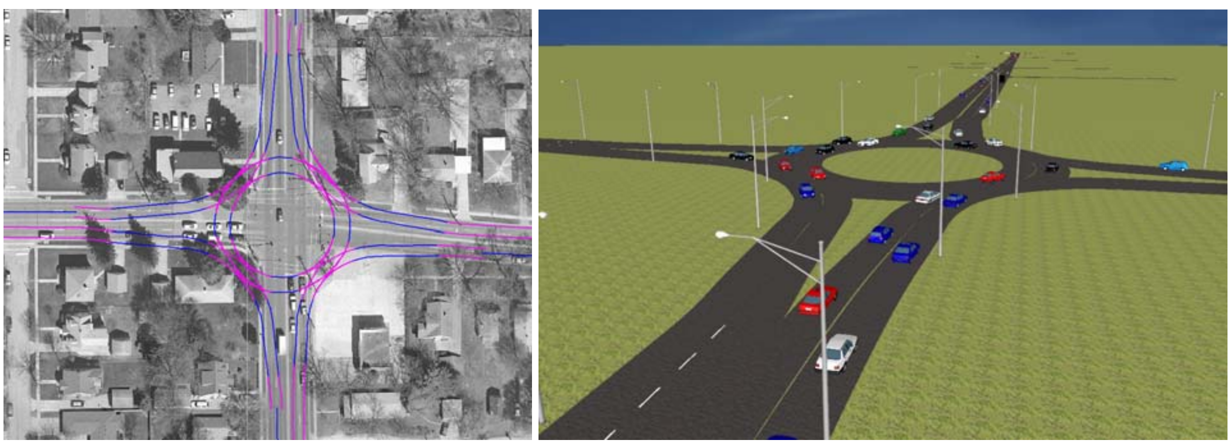


Figure 2-6. Roundabout alternative at 13th Street and Grand Avenue

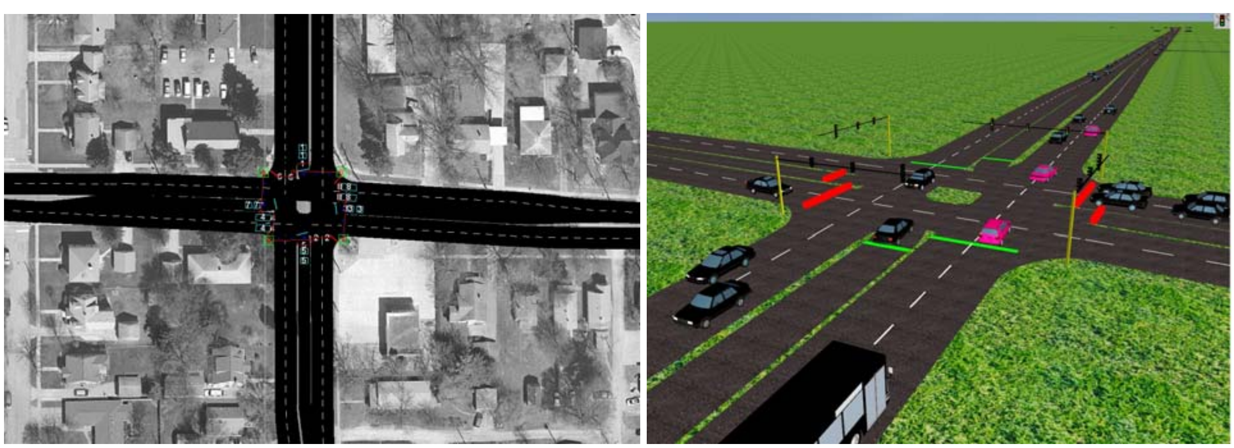


Figure 2-7. Alternative with addition of left-turn lanes at 13th Street and Grand Avenue

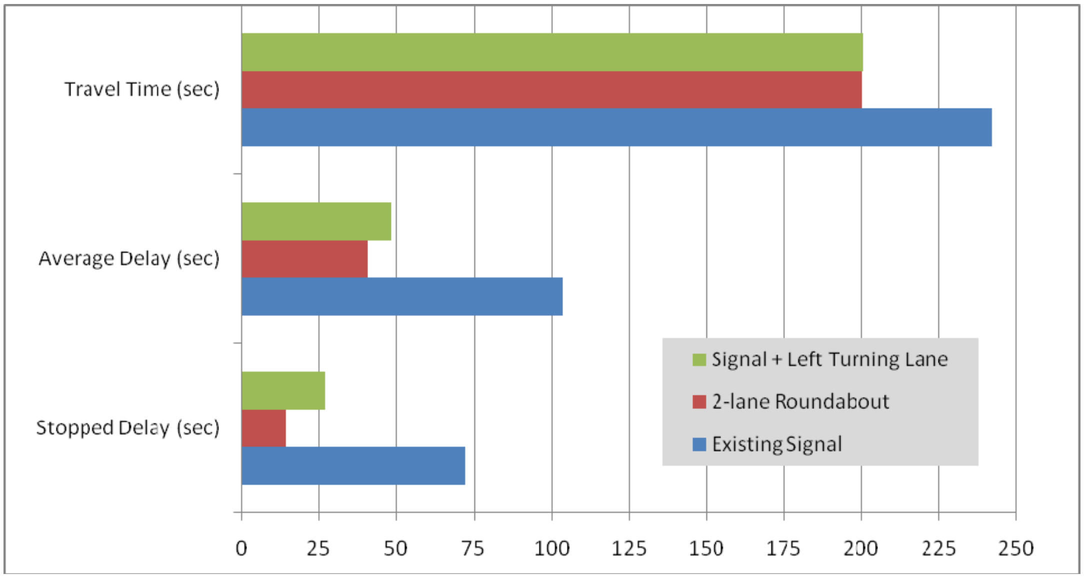
Once the system was calibrated to replicate existing conditions, an attempt was made to optimize signal times and coordinate the system for each alternative. Due to geometry and other constraints, an optimal coordination plan could not be achieved. However, the best possible scenario was sought using offsets and signal timings.

A full discussion of each intersection, how the corridor was coded into VISSIM, input values, assumptions used in the model, and other relevant information are provided in section 9.1.4 in this report. The present section summarizes the study to provide information about comparing the three alternatives in terms of traffic flow impacts.

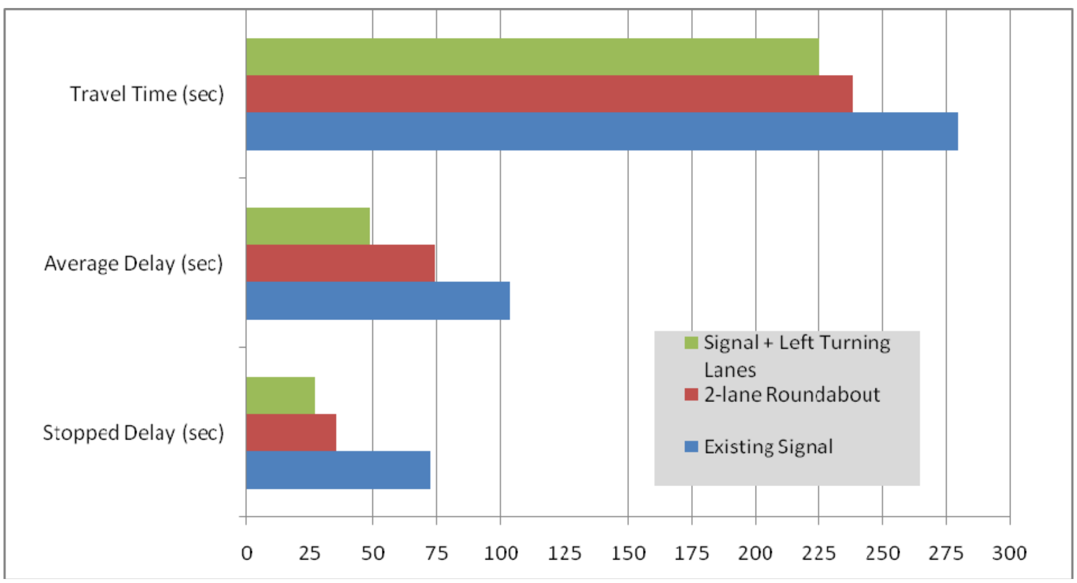
Results are presented for the p.m. peak hour (5:00–6:00 p.m.). Several measures of effectiveness were output for each alternative. Figure 2-8 shows the results for each alternative during the peak hour by direction. The data show delay and travel time for passenger vehicles travelling through the system. Vehicles turning onto and off of the system mid-corridor were not included in the analysis.

The existing alternative has a much higher travel time, stopped delay, and average delay than the other two alternatives. The roundabout alternative has a lower average delay and stopped delay than the alternative with signals and left-turn lanes for the northbound direction of travel, but the roundabout alternative has almost identical travel times. The signal with left-turn lanes alternative has a lower average delay, stopped delay, and travel time for the southbound direction of travel than the roundabout alternative.

Overall, the signals with left-turn lanes and roundabout alternatives have similar results, suggesting that the roundabout does not provide a significant advantage in terms of traffic operations through the corridor.



Northbound



Southbound

Figure 2-8. Comparison of alternatives for the Grand Avenue Corridor in Ames, Iowa

Radio Drive—Woodbury, Minnesota

A second corridor, Radio Drive/CSAH 13 in Woodbury, Minnesota, which has three major intersections, was evaluated. The corridor has signals for the two northernmost intersections, shown with blue X's on the aerial in Figure 2-9. The four-way stop control at the southern intersection was constructed as a roundabout in 2007, shown with a blue circle. The spacing between intersections is 0.6 miles between Bailey Road and Commonwealth Avenue and 0.4 miles between Commonwealth Avenue and Lake Road.

Radio Drive is a four-lane divided roadway north of Bailey Road and a two-lane undivided roadway to the south. Bailey Road is a two-lane roadway. Radio Drive and Bailey Road have an AADT of 9,000 and 7,000, respectively. The Radio Drive and Bailey Road intersection has 1,200 entering vehicles during peak hour.

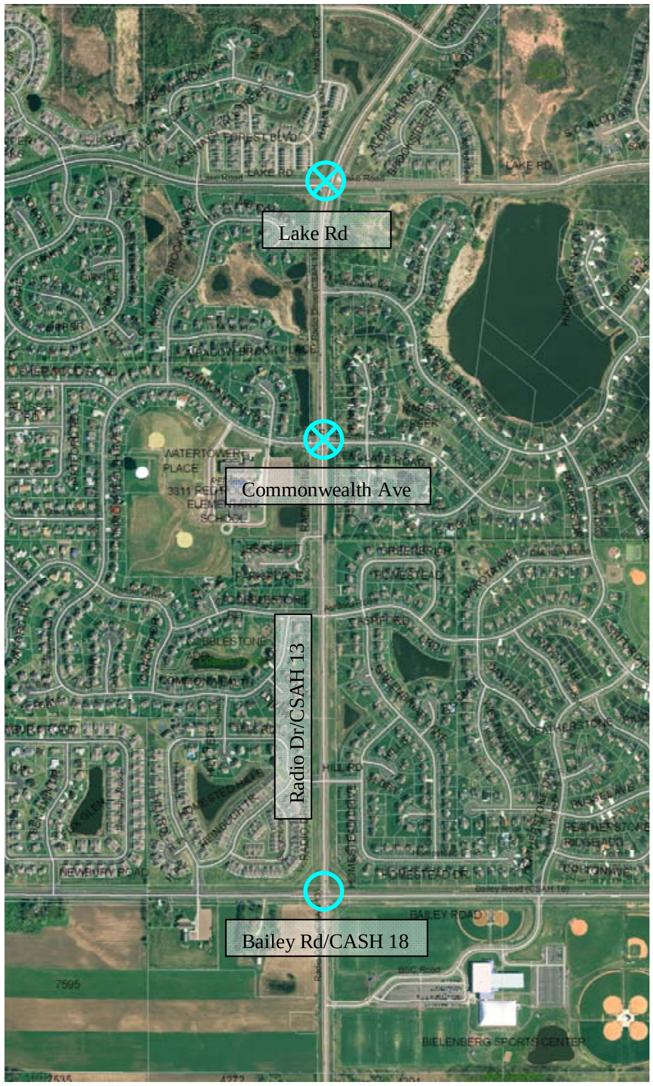


Figure 2-9. Radio Drive in Woodbury, Minnesota

Two alternatives were evaluated for the corridor. The two northern intersections are currently signalized. The alternatives considered two options for the third intersection. For the first alternative, the intersection of Bailey Road and Radio Drive was modeled using a four-way stop, and for the second alternative the intersection was modeled using a two-lane roundabout. Both alternatives were modeled in VISSIM, and results are shown in Figure 2-10. The data show average delay, stopped delay, and travel time for passenger vehicles traveling through system. Vehicles turning onto and off of the system mid-corridor were not included in the analysis.

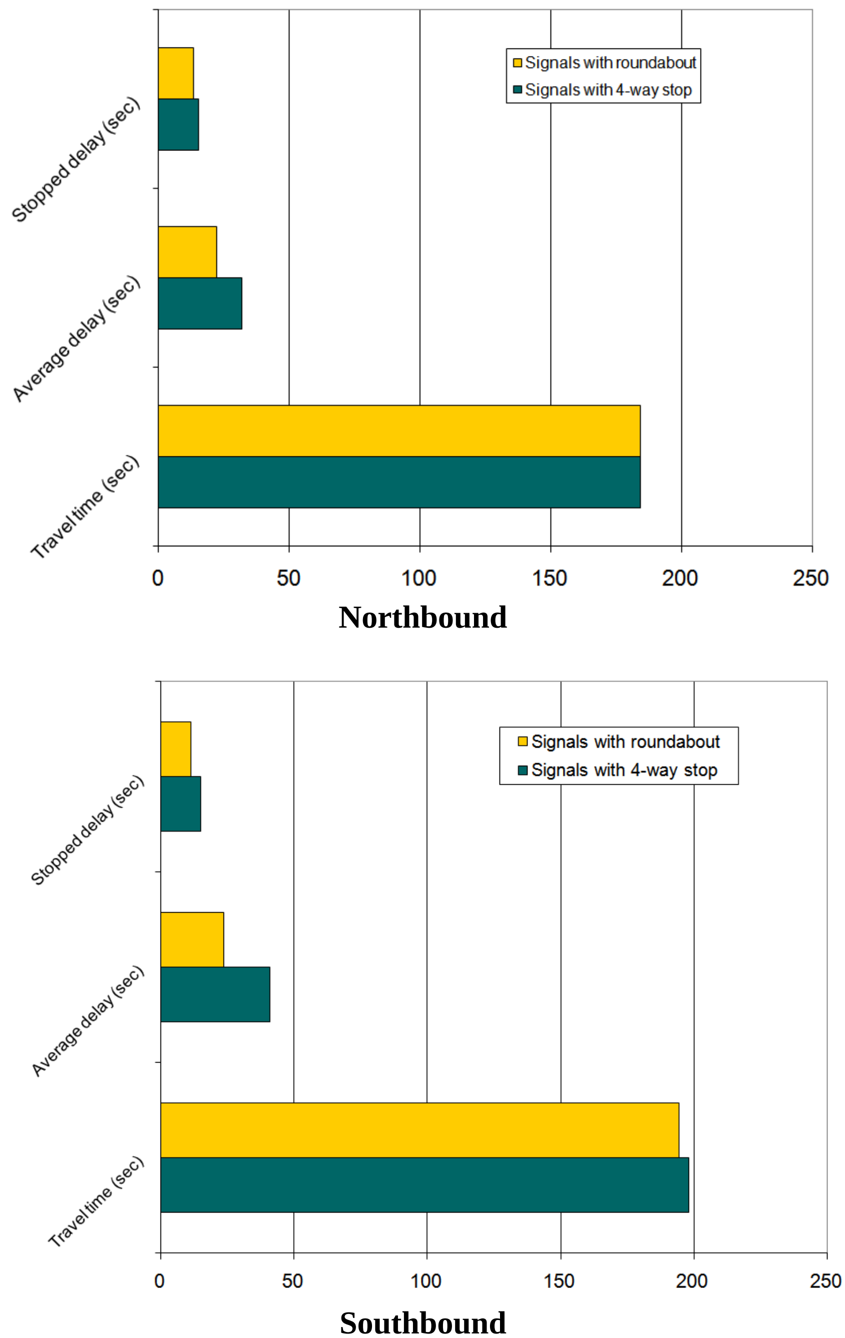


Figure 2-10. Corridor comparison for Radio Drive, Minnesota

As Figure 2-10 shows, there was very little difference between the two alternatives in terms of total travel time for both the northbound and southbound corridors. Average delay was 10 and 17 seconds longer with the four-way stop alternative for both the northbound and southbound directions of travel, respectively, than for the roundabout alternative. Stopped delay was slightly longer for the alternative with the four-way stop for the northbound and southbound directions than for the roundabout alternative, but the differences were minor.

Northwest Ash Street and Prairie Ridge Drive—Ankeny, Iowa

The intersection of Northwest Ash Street and Prairie Ridge Drive is located near an urban residential area, a park/baseball/public pool complex, Northview Middle School, the Ankeny City Library, and multiple religious properties, as shown in Figure 2-11. Northwest Ash Street and Prairie Ridge Drive are both two-lane collectors. The high school is located off Northwest Ash Street approximately 1/2 mile from the intersection. The combination of the school and other traffic result in high morning and afternoon peak-hour volumes. In addition to normal school traffic, a parking lot within the Northview Middle School campus is used as a transfer point for school buses. As a result, 10 to 16 buses from Northview Middle School enter the southbound approach of the intersection during peak traffic periods. A four-way stop is currently in place at the intersection, as shown in Figure 2-12. Since a number of parents are dropping off or picking up children, the morning peak period has a larger number of left turning vehicles from the north and south approaches. A larger number of right turning vehicles are present on the west and east approaches. During the morning and afternoon peak hours, congestion and queuing results, with queues in the southbound lane of Prairie Ridge Drive that reach up to 25 vehicles in length.

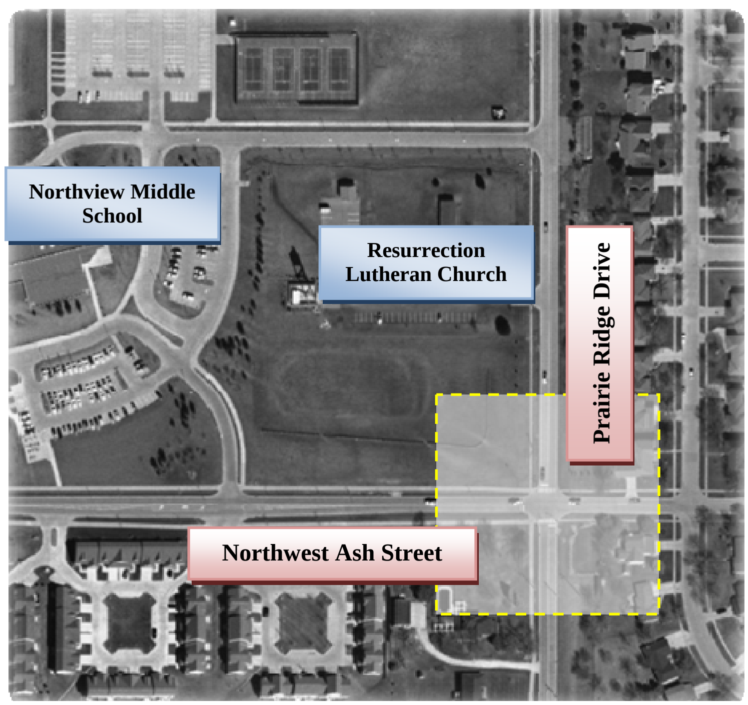


Figure 2-11. Land use around Northwest Ash Street and Prairie Ridge Drive

Figure 2-12. Existing four-way stop intersection looking north

This intersection was selected for analysis due to its unique location, limited right of way, and unbalanced turning movement volumes. Three potential alternatives selected include (1) two-way stop, (2) single-lane urban roundabout, and (3) signalization. In all cases, the existing geometry was maintained. Each alternative, including the existing scenario, was modeled using VISSIM.

A full discussion of each intersection, how the corridor was coded into VISSIM, input values, assumptions used in the model, and other relevant information are provided in section 9.3 in this report. The present section summarizes the study to provide information about comparing the three alternatives in terms of traffic flow impacts.

Alternative 1, Two-way Stop. The first alternative was to remove two stop signs, in the eastbound and westbound directions, on Northwest Ash Street, which has the major traffic movements. Prairie Ridge Drive remained stop-controlled. In the simulation, vehicles traveling north or south were required to stop at the stop sign and then decide if enough gap time was available in both directions to make the turning movement. The model was evaluated using VISSIM, as shown in Figure 2-13.

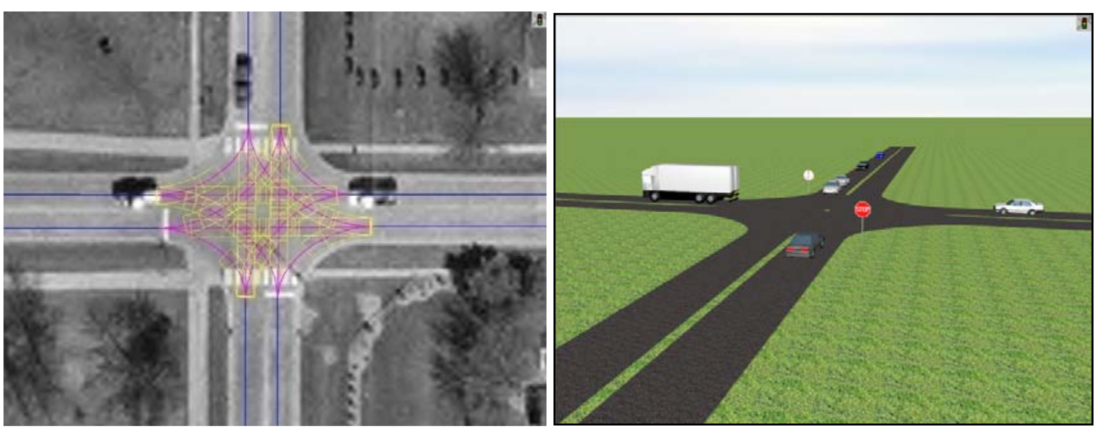


Figure 2-13. Two-way stop VISSIM setup and 3-D model in operation

Alternative 2, Single-lane Roundabout. The next alternative was a single-lane roundabout. The roundabout was designed using AutoCad software based on design recommendations from FHWA's *Roundabouts: An Informational Guide* (Robinson et al. 2000). The single-lane roundabout is 115 ft in diameter with 18 ft–wide circulating lanes, as illustrated in Figure 2-14. After design details were finalized, the line work from AutoCAD was brought into VISSIM. Similar to the procedure described in the Ames roundabout model, links, nodes, driver behavior, and reduced speed areas were created, and the same values were used. Since the roundabout consists of one circulatory lane, priority rules were minimal, with a coded gap time of 3.0 seconds for cars and heavy vehicles to enter the roundabout.

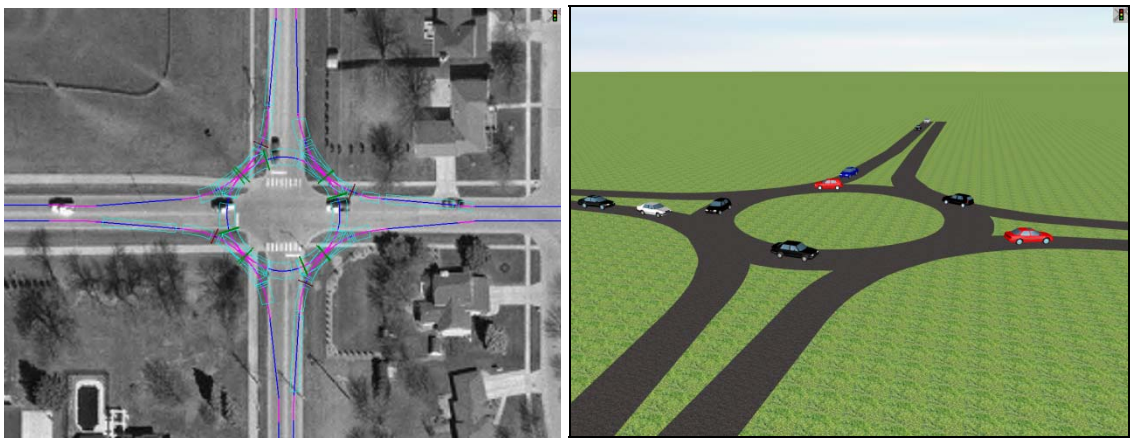


Figure 2-14. Single-lane roundabout setup and 3-D model in operation

Alternative 3, Signal with Split Phasing. The third alternative was to signalize the intersection. Several different phases, cycle lengths, and timing plans were considered using Synchro 6 software. The existing geometry, high bus volumes, and unbalanced left turning movement made it difficult to find a conventional timing plan. Finally, a split phasing plan was selected and other signal timing parameters were optimized to provide the least delay. The alternative, shown in Figure 2-15, was also modeled in VISSIM.

Signal timing for the intersection of Northwest Ash Street and Prairie Ridge Drive was determined based on the morning approach volumes and using the program Synchro 6. Similar to a fully split-phase signal timing plan, each approach was given a minimum and maximum green time, with vehicle detectors placed at each approach with no coordinated phase, since the signal is isolated. To make the signal plan, a half split-phase plan, a ring barrier plan was created, and National Electrical Manufacturers Association (NEMA) phase 1 and 2 started the plan (eastbound and westbound). With vehicle detectors in both the east and west approaches, whenever a phase reached its maximum green time or no vehicles were detected in one of the two approaches to extend the green time, the signal controller would move on to phase 3 (northbound) and then to phase 4 (southbound).

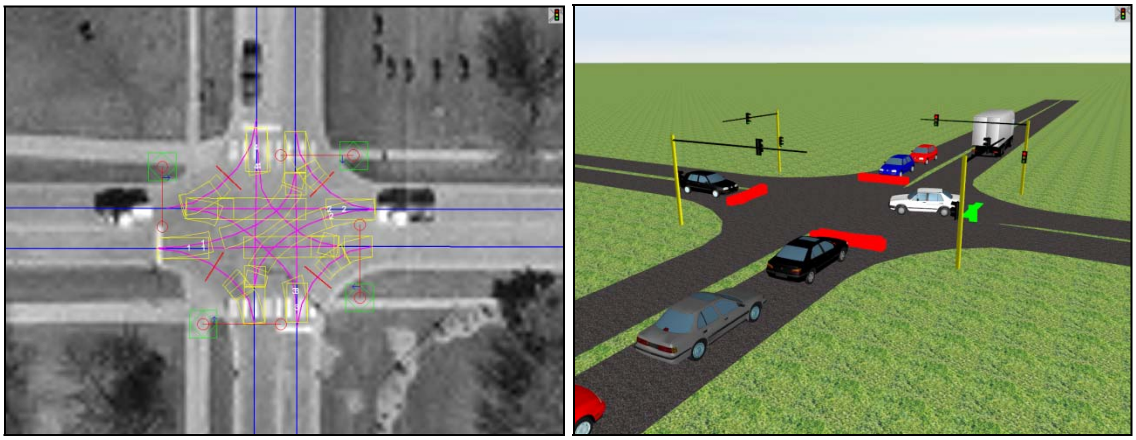


Figure 2-15. Split-phase VISSIM setup and 3-D model in operation

Results are presented for the morning peak period (7:00–8:00 a.m.). Several measures of effectiveness were output for each alternative. Figures 2-16 to 2-19 show the results for each alternative during the peak hour by direction. The data show delay and travel time for passenger vehicles traveling through the system. Vehicles turning onto and off of the system mid-corridor were not included in the analysis. As shown, due to the need for a split phase, the signal alternative performed worst in all cases for delay and queue lengths. The roundabout overall resulted in the least amount of delay for northbound and southbound traffic, while the two-way stop control alternative performed best for eastbound and westbound traffic, which is the dominant direction of travel for the analysis period.

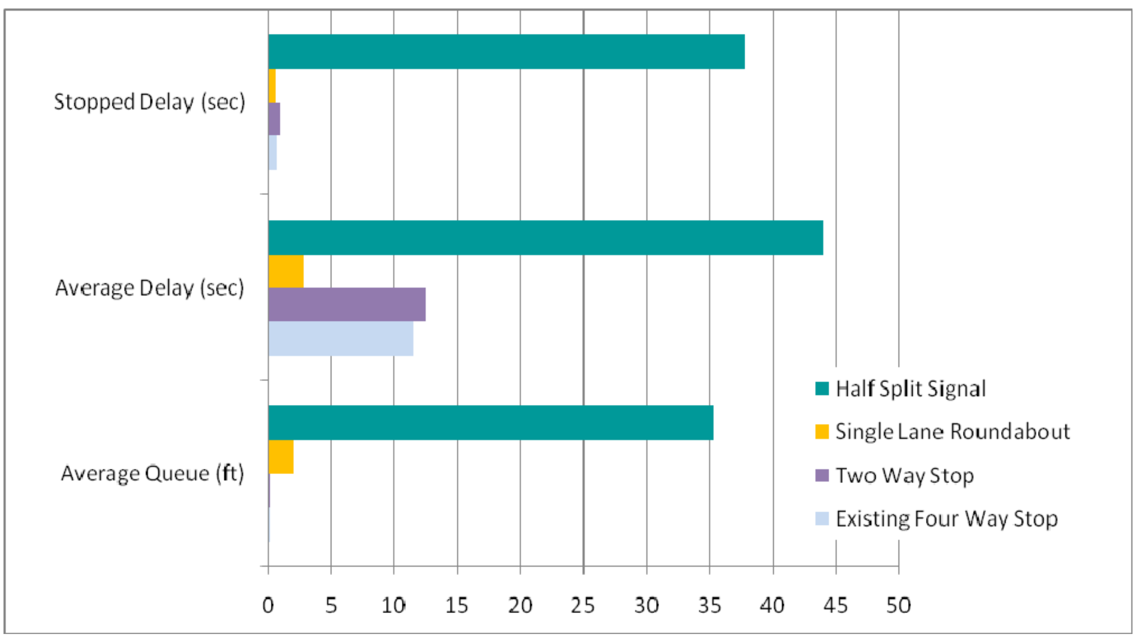


Figure 2-16. Comparison of alternatives for Northwest Ash Street and Prairie Ridge Drive northbound

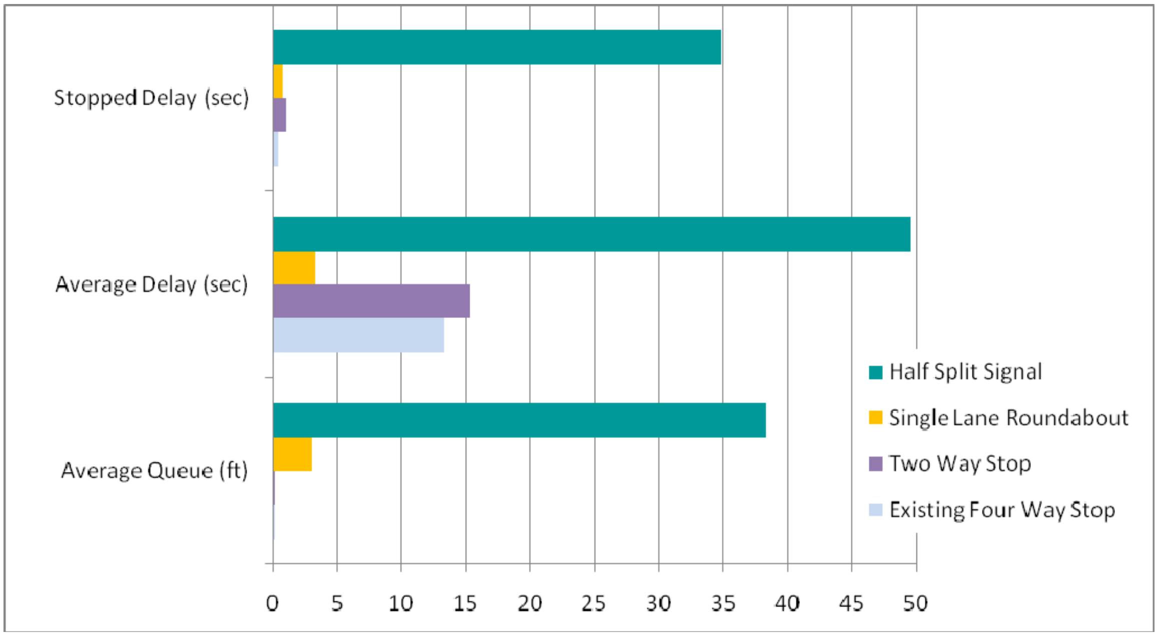


Figure 2-17. Comparison of alternatives for Northwest Ash Street and Prairie Ridge Drive southbound

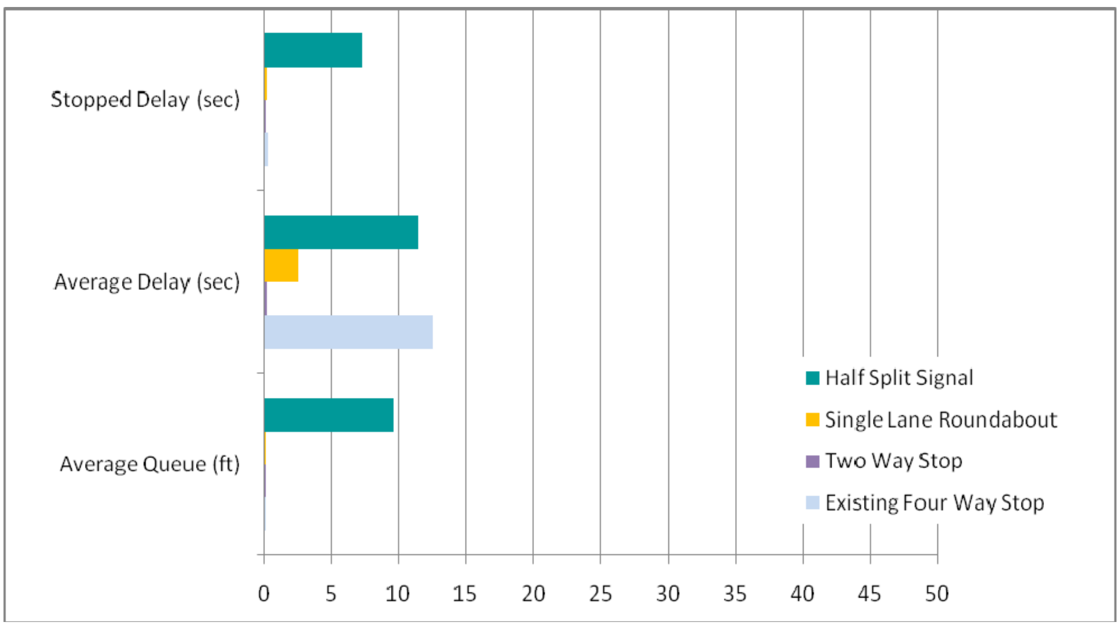


Figure 2-18. Comparison of alternatives for Northwest Ash Street and Prairie Ridge Drive eastbound

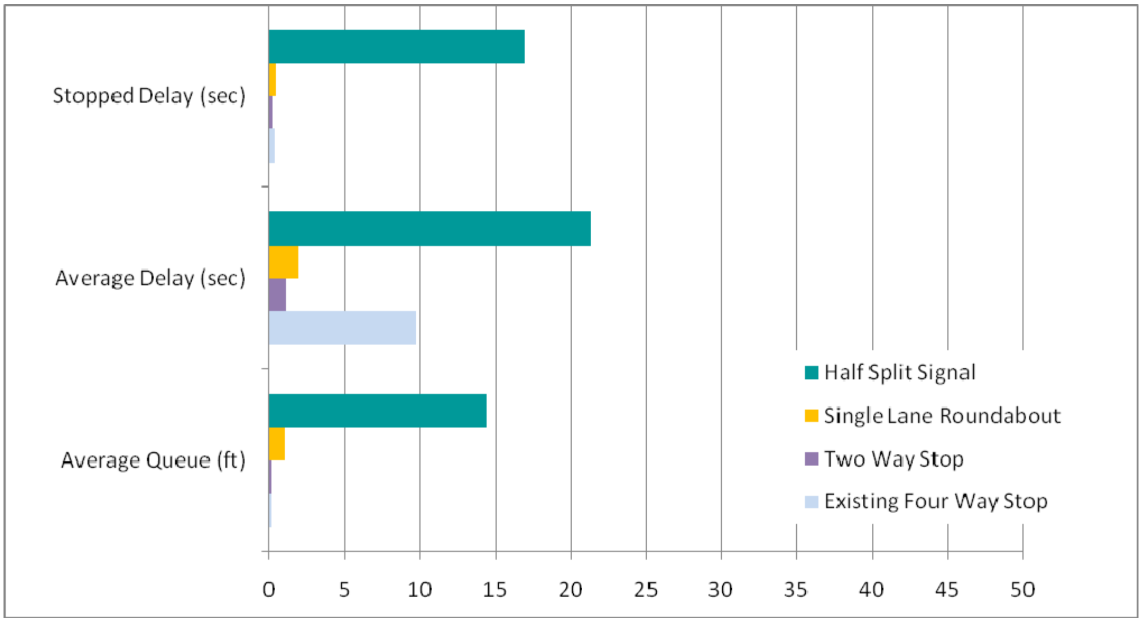


Figure 2-19. Comparison of alternatives for Northwest Ash Street and Prairie Ridge Drive westbound

2.3. Safety of Roundabouts

Roundabouts are generally expected to reduce crashes by eliminating or altering conflict types and reducing speeds. The FHWA's *Roundabouts: An Informational Guide* (Robinson et al. 2000) cites several studies that indicate the following:

- Roundabouts typically perform better than other types of intersection control.
- Single-lane roundabouts, particularly, have safety benefits over TWSC intersections.
- Crash frequency is not always lower, but usually results in reduced injury rates. An overall reduction of 37% in total crashes and 51% in injury crashes after conversion to a roundabout was found at 11 sites.

A study by Persuad et al. (2000) used empirical Bayes to measure the reduction in crashes after 24 intersections in 8 states were converted to roundabouts from stop and signal control. The authors found a 39% reduction for all crashes and a 76% reduction in injury crashes. Fatal and incapacitating injury crashes were reduced by approximately 90%.

The FHWA (2007b) produced a toolbox of intersection countermeasures and their potential effectiveness. The toolbox suggests the following crash reduction factor (CRF) for all crashes when an intersection is converted to a roundabout, depending on the previous control:

- CRF of 18 to 72 when converted to a roundabout from two-way stop control
- CRF of -3 when converted to a roundabout from four-way stop control
- CRF of 1 to 67 when converted to a roundabout from a signal

The following crash reduction factors were found for fatal and injury crashes when converting to a roundabout:

- CRF of 72 to 87 when converted to a roundabout from two-way stop control
- CRF of -28 when converted to a roundabout from four-way stop control
- CRF of 60 to78 when converted to a roundabout from a signal

2.4. Fuel Consumption and Air Quality Impacts of Roundabouts

One benefit attributed to the use of roundabouts over traditional stop or signal control intersections is reduced emissions. Roundabouts are expected to provide smoother flow, reduce idle time, and result in fewer stops, leading to reduced emissions and fuel consumption. As a result, roundabouts are increasingly being included as CMAQ projects.

2.4.1. Summary of Information from Other Sources

The air quality benefits of roundabouts, however, have not been completely quantified. The FHWA's *Roundabouts: An Informational Guide* provides minimal information about estimating environmental benefits, though it does caution that models should be calibrated for current U.S. conditions because a number of publications on roundabouts are based on European literature (Robinson et al. 2000).

Roundabouts are expected to reduce emissions as a result of reduced delays and stops; however, roundabouts slow all vehicles to speed ranges where emissions may be higher, while signals stop and delay only a portion of vehicles. This is particularly the case with intersections that have unbalanced flows between approaches. Roundabouts may also increase the amount of acceleration and deceleration for all vehicles. Emissions are correlated to these modal events, and therefore the impacts should be considered in the evaluation of roundabouts. Additionally, studies that evaluate emission reductions due to roundabouts use default values from roundabout design software to calculate delay and emissions rather than typical United State Environmental Protection Agency (USEPA) models, such as MOBILE (Reddington 2001).

Several studies have shown that roundabouts produce lower emissions than other types of control. Other studies suggest that roundabouts may increase emissions, since they interrupt traffic flow. Mandavilli et al. (2003) evaluated three locations in Kansas at which a roundabout replaced a stop-controlled intersection. The authors videotaped the actual intersections and then used aaSIDRA to evaluate the difference before and after. Using aaSIDRA, they found a 38% and 45% reduction in carbon monoxide (CO) for the a.m. and p.m. analysis periods, respectively. They also found a 45% reduction for particulates, a 55% and 61% reduction in carbon dioxide (CO_2) for the a.m. and p.m. analysis periods, a 44% and 51% reduction in nitrogen oxides (NO_x) for the a.m. and p.m. analysis period, and a 62% and 68% reduction in hydrocarbons (HC) for the a.m. and p.m. analysis periods, respectively. The authors also found a statistically significant decrease in delay, queuing, and stopping compared to the all-way stop-controlled situation before implementation of the roundabout.

Varhelyi (2002) evaluated the driving patterns of vehicles before and after implementation of a roundabout and then used this information to estimate emissions. Test drivers in an instrumented car randomly selected vehicles to follow. The test drivers attempted to imitate the lead vehicle's driving pattern as closely as possible. Speed and acceleration were calculated from distance and speed. The authors also collected volume data at the study locations. Emissions and fuel consumption were calculated for each vehicle using emission and fuel consumption factors for specific speed and acceleration based on Swedish values. One location was signalized. The authors found that speeds through the intersection were lower, but traffic flow was smoother. The per-vehicle delay decreased by 11 seconds on average. The number of stopped vehicles decreased from 63% to 26% of the total. CO emissions decreased by 29%, nitrogen oxide emissions decreased by 21%, and fuel consumption decreased by 28%.

Hyden and Varhelyi (2000) evaluated speeds and emission before and after installation of small roundabouts in Sweden. Speed profiles were recorded using a chase car methodology, where lead vehicles were randomly selected and followed. Speed was recorded two times per second, and average speed profiles were developed. Overall, the authors found that roundabouts reduced speeds considerably both at the intersection and on links between roundabouts. Statistically significant reductions in mean speeds were reported at 7 of 10 approaches evaluated. The main factor in speed reduction was the lateral displacement forced by the roundabout. At an intersection that was initially not signalized, the authors found that delay increased for vehicles on the main road and decreased on the minor road after implementation of a roundabout. Since minor street traffic was only 30% of main road traffic, delay increased overall by an average of 0.75 sec/vehicle. After implementation of a roundabout at a previously signalized intersection, delay decreased overall by 11 sec per vehicle, and the number of vehicles stopping decreased from 63% to 26%. Emissions were calculated from the speed profiles for each vehicle using a Swedish car-testing model that has emissions for different levels of speed and acceleration. Emission factors are valid for speeds from 0 to 37 mph and for accelerations from -4.9 to 4.9 ft/s^2. Heavy vehicles could not be included. Emissions could only be calculated for gasoline cars. At the unsignalized intersection, CO increased by 6% and NOx by 4%. At the signalized intersection, CO decreased by 29% and NOx decreased by 21%.

Bergh et al. (2005) evaluated traffic flow for ten northern Virginia signalized intersections and one stop-controlled intersection, all of which were determined to be good candidates for a roundabout based on volume and intersection geometry. The authors evaluated performance for the existing control and then used aaSIDRA to compare those data with the hypothetical situation of including a roundabout. The analysis was based on data collected during peak periods for two days. The authors determined that average vehicle delay would be 17% to 92% lower for the roundabout alternative than for signalization. They used aaSIDRA to estimate a 16% reduction in fuel consumption.

One study was found that measured actual on-road emissions for roundabouts. Zuger and Porchet (2001) evaluated four locations in Switzerland that had each been converted to a roundabout. The authors instrumented a vehicle with a mobile exhaust gas measurement apparatus, which measured fuel consumption and actual emissions. The test vehicle was driven through each of the five intersections a number of times both before and after implementation of the roundabout. Four typical directions of travel were used for each of the test locations. The authors determined that hydrocarbon emissions were too low to be practically compared. They found that speeds and emissions depended on local conditions (amount of traffic, frequency of interruption of traffic, number of pedestrians, ratio of traffic density on different branches, etc.) and time of day. Specific results are summarized for each intersection, but in general the authors found that roundabouts are favorable for emissions when a light-controlled crossing is replaced by a roundabout. However, when a signal is replaced by a roundabout, the authors found unfavorable fuel consumption and emissions. They speculate that, in this case, a roundabout can disrupt previously uninterrupted flow.

In Zuger and Porchet's (2001) study, the first location was characterized by high traffic density. The intersection had been unsignalized with minor approach control. Installation of a roundabout resulted in a reduction of speed and an interruption of previously smooth traffic for the main direction of flow, with an improvement in flow for the minor direction of flow. An increase in fuel consumption, CO, NO_x, and CO_2 resulted. The next intersection evaluated had also been unsignalized with minor approach control. In the main direction of traffic, speeds decreased slightly. Fuel consumption, CO, and CO_2 increased, while NO_X decreased. The authors noted that the installation of the roundabout led to braking and acceleration on the main direction of travel, when previously the flow had been at constant speed. The third roundabout had also been unsignalized with control in the minor direction. No change in average speed or NO_x was observed, while fuel consumption, CO, and CO_2 decreased. The fourth intersection had previously had a traffic signal. Average speeds increased, and NO_x increased while fuel consumption, CO, and CO_2 decreased.

Zuger and Porchet (2001) concluded that the effects of roundabouts are different at different times during the day, depending on traffic density. They indicate that roundabouts are likely to have a negative impact when previously smooth flow is replaced by slowing and acceleration, and the effect could be even greater with grade. The authors suggested that if traffic flow on the minor street is lower than on the main direction by a factor of 5 to 10, unfavorable effects are expected in terms of speeds and emissions when a roundabout is used.

2.4.2. Air Quality Impacts Case Study

A case study was developed to further explore the air quality impacts of roundabouts versus other alternatives. For the case study, the air quality impacts of the different alternatives for the US 69 corridor in Ames, Iowa, were evaluated. As discussed in section 2.4 of this report, the air quality or fuel consumption impacts of roundabouts are typically compared to other alternatives using roundabout analysis models that model emissions using some aggregate emissions measures. These measures are not based on U.S. fleet emissions. It is more appropriate to use the USEPA's mobile source emission factor model, MOBILE, but MOBILE emission rates are based on average speeds. As a result, neither type of model is able to capture the differences that result from increases or decreases in acceleration, idling, and deceleration. A number of studies have shown a direct correlation between vehicle mode and emissions. The USEPA is in the process of finalizing the next mobile source emission rate model, MOVES, which will be able to estimate emissions based on vehicle mode. However, MOVES has not yet been released. In the interim, the University of California-Riverside's Comprehensive Modal Emissions Model (CMEM) is the only model that is based on testing for a large number of vehicles and the only model that can predict second-by-second tailpipe emissions for a wide variety of light-duty vehicles based on instantaneous vehicle operating mode (Barth et al. 2006).

VISSIM has the capacity to output second-by-second speed, acceleration, position, and other characteristics for individual vehicles modeled during the traffic simulation. These types of data were output for the intersection alternatives presented in the US 69/Grand Avenue case study, introduced in section 2.2.2. Since heavy-duty vehicle volumes were low, only light-duty vehicles were used in the model. Moreover, since no information was available about the types of light-duty vehicles that make up the case study fleet, the fleet mix for Riverside, California, used in the CMEM model was used. Vehicle traces for 25% of the vehicles were output, and vehicle traces were input into CMEM to estimate emissions. Emissions were then normalized to reflect actual volumes. As indicated in section 2.2.2, only vehicles traveling through the system were modeled. Results are presented in Figures 2-20 to 2-24 for fuel consumption and pollutants of interest.

The existing signalized alternative within a coordinated set of signals produced the highest emissions for all pollutants and the largest amount of fuel consumption for both northbound and southbound traffic. The signalized alternative that included the addition of left-turn lanes resulted in lower fuel consumption and lower emissions than the roundabout for all pollutants.

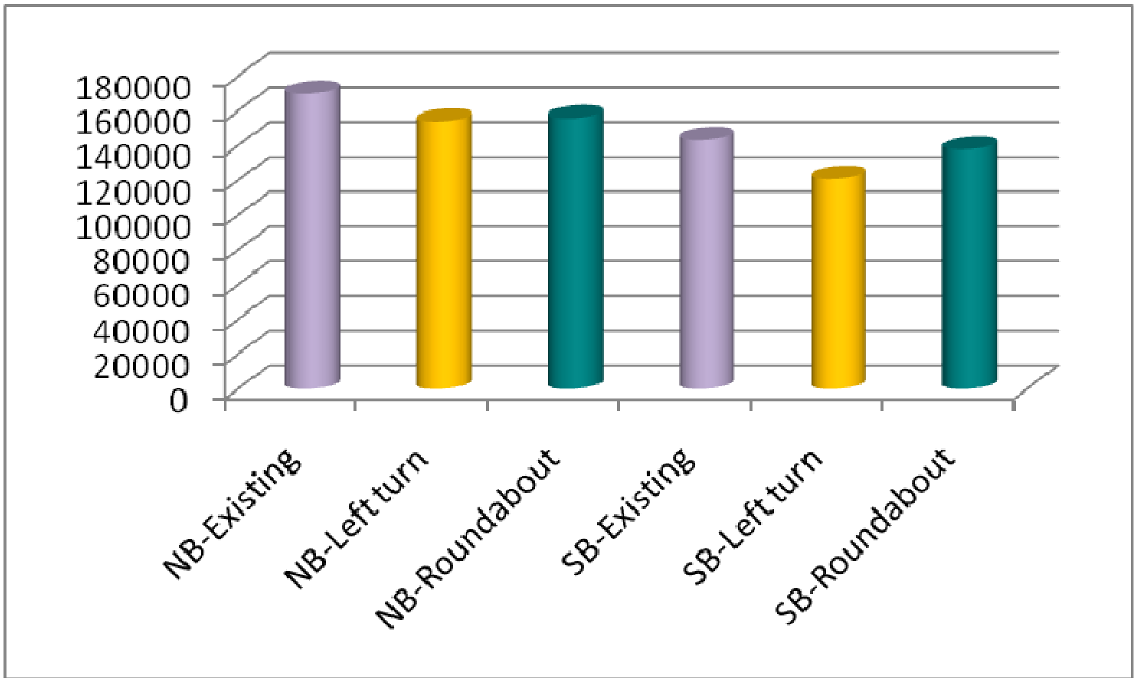


Figure 2-20. Fuel consumption (in grams) for US 69 corridor alternatives

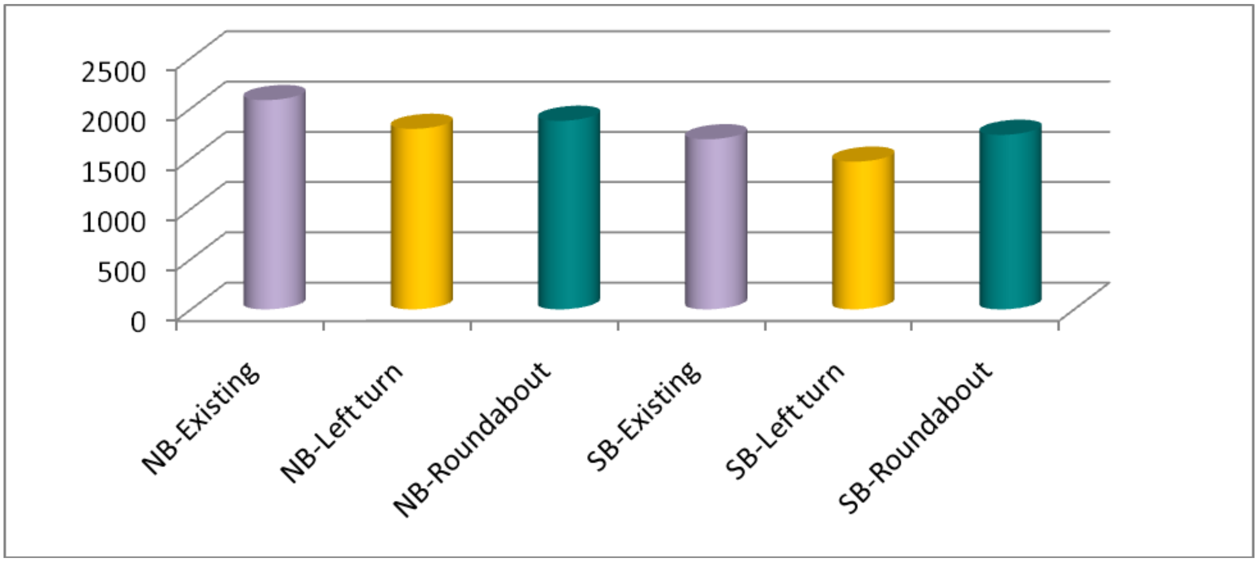


Figure 2-21. HC emissions (in grams) for US 69 corridor alternatives

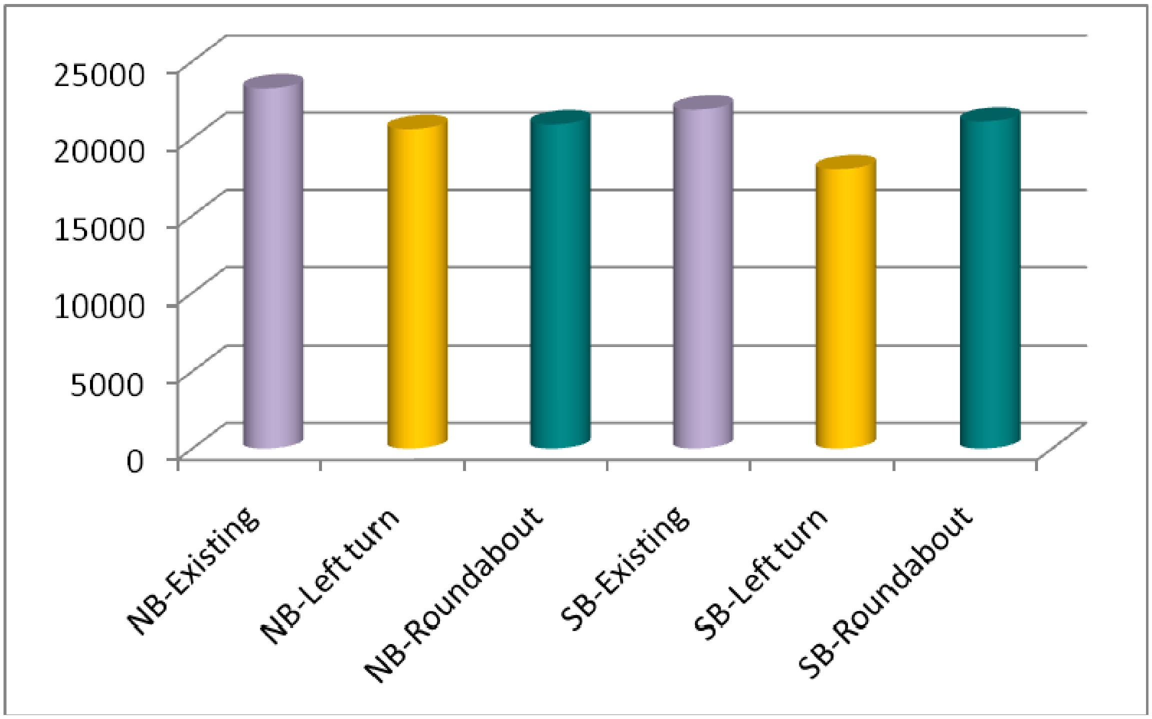


Figure 2-22. CO emissions (in grams) for US 69 corridor alternatives

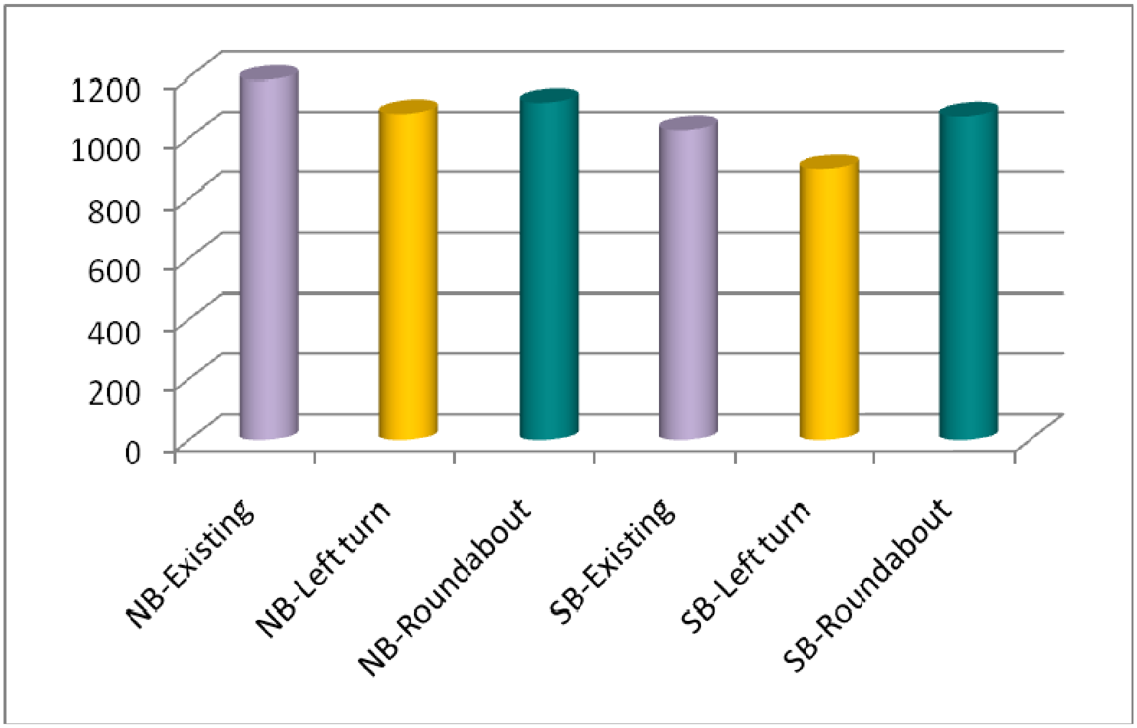


Figure 2-23. NO_x emissions (in grams) for US 69 corridor alternatives

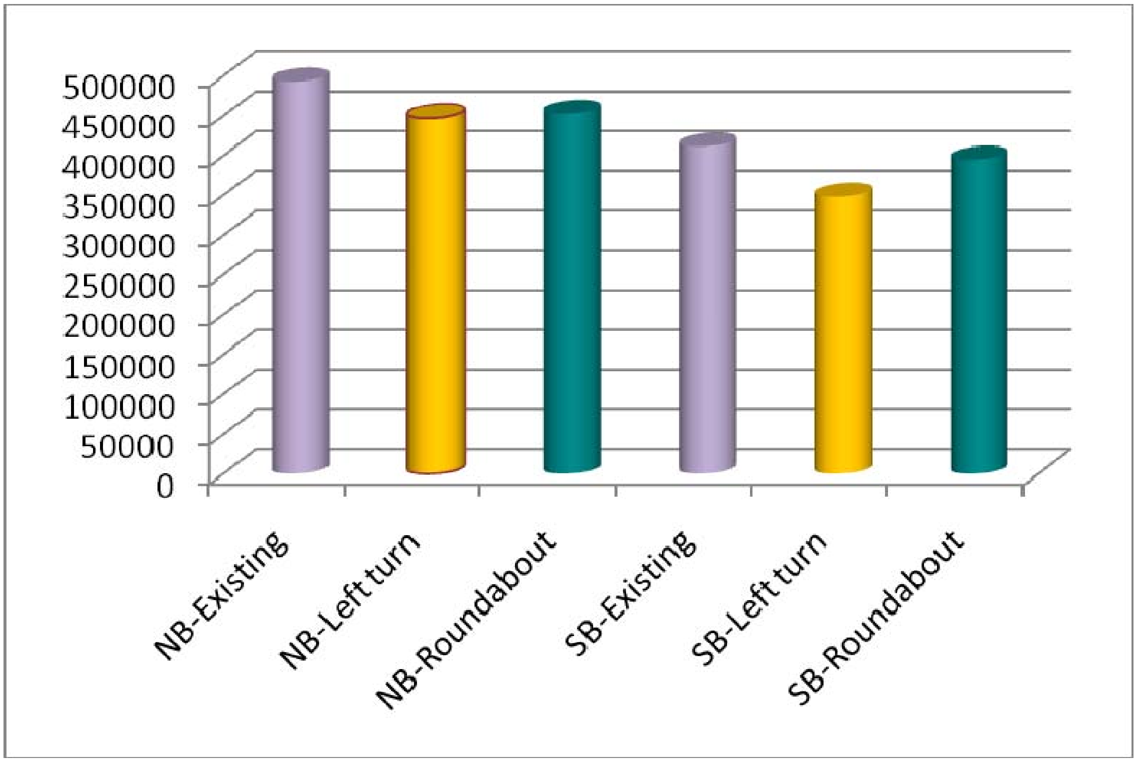


Figure 2-24. CO_2 emissions (in grams) for US 69 corridor alternatives

Table 2-1. Summary of effectiveness of roundabouts

Traffic flow	Safety	Fuel consumption/Air quality
• Usually provide higher capacity and lower delays (Robinson et al. 2000) • Main benefits occur during off-peak periods (Robinson et al. 2000) • Have slightly higher overall delays than coordinated signals when operating at capacity (Bared and Edara 2005) • Overall average vehicle delay could be 17% to 92% lower for roundabout than for signalization (Bergh et al. 2005) • Best alternative for two-lane approaches that carry heavy thru or left turning volumes (Sisiopiku and Oh 2001) • Provide better access to businesses (Hartman 2004) • More pedestrian friendly (Hartman 2004) • Improved LOS from B-F to A-D (Rickart et al. 2008). • Do not provide a significant advantage in terms of traffic operations (Ames, IA Case Study) • Stopped delay, average delay, and travel time were slightly lower (Woodbury, MN)	• Reduced all crashes by 39%, reduced injury crashes by 76% , and reduced incapacitating injury crashes by 90% (Persuad et al. 2000) • CRF for conversion from 4-way stop control was -3 for all crashes and -28 for fatal and injury crashes (FHWA 2007b) • CRF for conversion from 2-way stop control was 18 to 72 for all crashes and 72 to 87 for fatal and injury crashes (FHWA 2007b) • CRF for conversion from a signal was 1 to 67 for all crashes and 60 to78 for fatal and injury crashes (FHWA 2007b)	• May increase the amount of acceleration and deceleration, which may affect emissions • Slow all vehicles to speed ranges where emissions may be higher • Reduces levels of carbon monoxide, particulates, carbon dioxide, nitrogen oxides, and hydrocarbons during peak periods (Mandavilli et al. 2003) • Reduced levels of carbon monoxide and nitrogen oxide emissions by 29% and 21%, respectively, and decreased fuel consumption by 28% (Varhelyi 2002) • Fuel consumption reduced by 16% (Bergh et al. 2005) • Roundabouts are favorable when replacing a light-controlled crossing, but unfavorable when replacing a signal (Zuger and Porchet 2001) • Effect of roundabout is different at different times during the day depending on traffic density (Zuger and Porchet 2001) • Higher fuel consumption and emissions than the signalized alternative (Ames, IA Case Study)

3. LEFT-TURN LANES

Left-turn lanes at intersections remove turning vehicles from thru travel lanes and, as a result, reduce rear-end crashes and increase capacity, improve visibility of oncoming traffic for vehicles turning left, and help reduce right-angle collisions. This section summarizes information and presents case studies about the safety, operations, access management, and air quality impacts of left-turn lanes.

3.1. Left Turns as Part of Access Management

Left-turn lanes can improve traffic flow by providing turning opportunities at upstream intersections when raised medians, driveway consolidations, or other separations are used as part of access management along a corridor.

3.2. Traffic Flow Impacts of Left Turns

Left-turn lanes at intersections generally improve traffic flow by removing left turning vehicles from thru traffic. These lanes can also reduce delay for turning vehicles when protected phasing is used. The following sections summarize the traffic flow impacts of left-turn lanes from the available literature. Several case studies were also conducted to evaluate the impact of left-turn lanes on traffic flow compared to other alternatives.

3.2.1. Summary of Information from Other Sources

An earlier study by the Center for Transportation Research and Education (CTRE) evaluated a number of access management strategies. One location was Iowa Highway 192 in Council Bluffs, Iowa, which was a four-lane roadway with no turn lanes and high traffic volumes before improvements. Left-turn lanes and some signal improvements were made. The authors indicated that traffic flow and operations improved, although the amount of improvement was not quantified (Maze and Plazak 1997).

Capacity on thru approaches increases when left turning traffic is removed. Gluck and Levinson (2000) indicated that the capacity of highways with shared left turning lanes is lower than the capacity of highways with exclusive left turning lanes, as shown in Table 3-1. The table shows that the capacity of a two-lane roadway with a shared left is from 425 to 650 vehicles per hour (vph) per approach. When left turns are removed, capacity increases to 840 vph.

Table 3-1. Capacity with different left-turn configurations (Gluck and Levinson 2000)

	Capacity vph per approach Two-lane roadway	Four-lane roadway
No left turns	840	1,600
Shared left (50 to 150 left-turns/hour)	425–650	900–1,000
Exclusive left turn	750–960	1,100–1,460

In another study, Gluck et al. (1999) indicated that when more than six left turns per cycle are present, almost all thru vehicles in a shared lane are blocked by the left-turners.

3.2.2. Traffic Flow Impacts Case Studies

A case study for US 69/Grand Avenue in Ames, Iowa, was described in section 2.2.2 of this report. The case study compared the traffic flow impacts of the existing corridor, which has no left-turn lanes and split phasing at the main intersection of 13th Street and Grand Avenue. Using VISSIM, the existing scenario was optimized and used as one alternative and then compared to two other alternatives. One alternative included the addition of left-turn lanes and optimized signal timing at the signal and progression along the corridor. The other alternative was to implement a roundabout at 13th Street and Grand Avenue.

Results indicate that both the addition of left-turn lanes and the use of a roundabout resulted in significantly lower average delays, stopped delays, or travel times than the existing scenario. For the northbound direction of travel, the roundabout alternative had lower average delays and stopped delays than the alternative with signals and left-turn lanes, but both of these alternatives have almost identical travel times. The alternative with signals and left-turn lanes had lower average delays, stopped delays, and travel times for the southbound direction of travel than the roundabout alternative.

Overall, both the signal with left-turn lanes and the roundabout alternatives produce similar results, suggesting that the roundabout does not provide a significant advantage in terms of traffic operations through the corridor. The safety benefits, right-of-way, and air quality impacts of a roundabout alternative were not considered in this analysis.

3.3. Safety Impacts of Left Turns

In general left-turn lanes have been demonstrated to have a positive safety impact. McCoy and Malone (1989) compared multi-vehicle accidents on approaches with left-turn lanes to similar approaches without left-turn lanes. The results of a chi-squared test indicated that left-turn lanes on urban four-lane roadways significantly reduced rear-end, sideswipe, and left-turn accidents. However, the authors found that right-angle crashes increased.

Harwood et al. (2002) cited a study by Foody and Richardson (1973) that reported a 38% reduction in crashes at signalized intersections with the addition of a left-turn lane. Harwood et al. (2002) also cited a 1988 report that indicated that using a left-turn signal phase and a left-turn lane reduced accidents by 36%. When a left-turn signal phase was not provided, the authors reported only a 15% decrease.

Harwood et al. (2002) also reported results of their own research, in which they compared the impact of adding left- and/or right-turn lanes. They evaluated a total of 43 projects for which only left-turn lanes were added at existing signalized intersections. The authors compared sites where improvements were made to similar sites that were not improved during the study period. They analyzed the data using empirical Bayes and two other comparison methods. At four-approach signalized intersections, they reported a 10.0% (± 0.8%) reduction in total intersection accidents and a 34% (± 0.8%) reduction in intersection approach accidents for projects where left-turn lanes were added. They also found a 9% (± 1.3%) reduction in total fatal and injury intersection accidents and a 35% (±1.3%) reduction in fatal and injury approach accidents. At intersections with three approaches, the authors only reported results describing the reduction in intersection approach accidents. They reported a reduction in all intersection approach accidents of 49% (± 13.9%) and a 48% (± 23.4%) reduction in fatal and injury accidents. Sites where both left- and right-turn lanes were added experienced a reduction of 7% (± 1.2%) in total intersection accidents at signalized intersections with four approaches. The authors also found a 12% (± 1.7%) reduction in fatal and injury crashes with just the addition of both left- and right-turn lanes. They reported a 16% (± 1.1%) decrease in intersection approach accidents and a 27% (± 1.5%) reduction in fatal and injury intersection approach accidents when both left- and right-turn lanes were added to the project. They also developed accident modification factors to characterize the installation of left-turn lanes, as shown in Table 3-2.

Table 3-2. Accident modification factors for installation of left-turn lane (Harwood et al. 2002)

		Number of major-road approaches on which left-turn lanes are installed	
Intersection Type	**Control**	**One approach**	**Both approaches**
T-intersection	Stop sign on minor	0.67	----
	Signal	0.93	---
Four-approach	Stop sign on minor	0.73	0.53
	Signal	0.90	0.81

Maze et al. (1994) also reported a reduction in crashes with the installation of left-turn lanes. The authors developed a model that predicted a 6% reduction in crash rate when a permitted signal phase was used and a 35% reduction when installation was accompanied by protected/permitted left-turn phasing.

The FHWA (2007a; 2007b) produced a toolbox describing intersection countermeasures and their potential effectiveness. The toolbox suggests the following CRF for all crashes when left-turn lanes are added at urban intersections:

- CRF of 7 when adding left-turn lanes at a T-intersection with a signal
- CRF of 33 when adding left-turn lanes at a T-intersection with stop control
- CRF of 10 when adding left-turn lanes at one approach of a four-leg intersection with signal control
- CRF of 19 when adding left-turn lanes at two approaches of a four-leg intersection with signal control
- CRF of 27 when adding left-turn lanes at one approach of a four-leg intersection with stop control
- CRF of 47 when adding left-turn lanes at two approaches of a four-leg intersection with stop control

The toolbox suggests the following CRF for fatal/injury crashes when left-turn lanes are added at urban intersections:

- CRF of 9 when adding left-turn lanes at one approach of a four-leg intersection with signal control
- CRF of 17 when adding left-turn lanes at two approaches of a four-leg intersection with signal control
- CRF of 29 when adding left-turn lanes at one approach of a four-leg intersection with stop control
- CRF of 50 when adding left-turn lanes at two approaches of a four-leg intersection with stop control

Several other studies have suggested little safety improvement with the addition of left-turn lanes. Campbell and Knapp (2005) did a simple comparison of geometric characteristics at urban intersections in Wisconsin. The authors compared intersections with and without left-turn lanes and found that both types of intersections had similar crash rates, suggesting that the provision of left-turn lanes did not improve safety.

Abdel-Aty and Keller (2005) evaluated crashes at signalized intersections in Florida. The authors analyzed intersection crashes using two different statistical methods, ordered probit and hierarchical tree-based regression. Both were used to evaluate various intersection characteristics. The authors analyzed a number of intersection variables, including the number of left-turn lanes. However, the number of left-turn lanes was not a significant variable in either model.

3.4. Fuel Consumption and Air Quality Impacts of Left-turn Lanes

3.4.1. Summary of Information from Other Sources

Little information was available that measured the air quality benefits of left-turn lanes. In general, left-turn lanes can be expected to improve air quality by decreasing delay, since left turning vehicles are removed from the traffic stream. Since no information was available, one case study was conducted as described in the following sections.

3.4.2. Air Quality Impacts Case Study

The air quality impacts of the different alternatives for the US 69 corridor case study, described in sections 3.2.2 and 2.2.2, were evaluated. Many analyses that compare air quality at the project level use the USEPA’s mobile source emission factor model, MOBILE, or other models that aggregate emissions based on average travel speed. However, a number of studies have shown a direct correlation between vehicle mode and emissions. The USEPA is in the process of finalizing the next mobile source emission rate model, MOVES, which will be able to estimate emissions based on vehicle mode. However, MOVES has not yet been released. In the interim, the University of California-Riverside’s CMEM is the only model based on testing of a large number of vehicles, and it is the only model that can predict second-by-second tailpipe emissions for a wide variety of light-duty vehicles available based on instantaneous vehicle operating mode (Barth et al. 2006).

VISSIM has the capacity to output second-by-second speed, acceleration, position, and other characteristics for individual vehicles modeled during the traffic simulation. These types of data were output for the intersection alternatives presented in the US 69/Grand Avenue case study in section 2.2.2. Since heavy-duty vehicle volumes were low, only light-duty vehicles were used in the model. Moreover, since no information was available about the types of light-duty vehicles that make up the case study fleet, the fleet mix for Riverside, California, used in the CMEM model was used. Vehicle traces for 25% of the vehicles were output, and vehicle traces were input into CMEM to estimate emissions. Emissions were then normalized to reflect actual volumes. As indicated in section 2.2.2, only vehicles traveling through the system were modeled.

Of the three alternatives modeled, the existing signalized alternative within a coordinated set of signals produced the highest emissions for all pollutants and the largest amount of fuel consumption for both northbound and southbound traffic. Compared to the roundabout alternative, the signalized alternative with the addition of left-turn lanes resulted in lower fuel consumption and lower emissions for all pollutants. Table 3-3 summarizes these results.

Table 3-3. Summary of effectiveness of left-turn lanes

Traffic flow	Safety	Fuel consumption/Air quality
• Removing left turns increases capacity (Gluck and Levinson 2000) • Addition of left turn lanes resulted in significantly less average delay, stopped delay, and travel time (Ames, IA Case Study)	• Significantly reduced rear-end, sideswipe, and left-turn accidents while right angle crashes increased (McCoy and Malone 1998) • Reduced crashes by 38% (Foody and Richardson 1973) • Reduced crashes by 36% when used with left turn signal phase (Hauer et al. 1988) • Addition of left turn lanes reduced crashes by between 9% and 49%, depending on site characteristics (Harwood et al. 2002) • Reduced crashes by 35% when used with protected/permitted left-turn phasing (Maze et al. 1994) • CRF for all crashes ranges from 7 to 47 when left turn lanes are added at urban intersections (FHWA 2007a; 2007b) • CRF for fatal/injury crashes ranges from 9 to 50 when left turn lanes are added at urban intersections (FHWA 2007a; 2007b) • Other studies (Campbell and Knapp 2005; Abdel-Aty and Keller 2005) found that left turn lanes did not improve safety	• Little information available but decreasing delay should be expected to improve air quality • The signalized alternative with addition of left turn lanes resulted in lower fuel consumption and lower emissions for all pollutants (Ankeny, IA Case Study)

4. MEDIANS

Medians separate opposing traffic. The two most common treatments on urban and suburban arterials are two-way left-turn lanes (TWLTL) and raised medians, though in some cases depressed center medians are also used. The following sections summarize the use of TWLTLs and raised medians.

Several other excellent resources are available for comparing the use of different median types. Saito and Cox (2004) completed an in-depth literature review and summarized a number of factors to consider in selecting a median type in their report, "Evaluation of Four Recent Traffic and Safety Initiatives: Volume 1. Developing a Guide for Evaluating the Need for Raised Medians." In Appendix A of their report, the authors provide a guide for evaluating the need for raised medians. Other resources include NCHRP 395, Capacity and Operational Effects of Midblock Left-turn Lanes (Bonnenson and McCoy 1997); the Transportation Research Board's (TRB) *Access Management Manual* (TRB 2003); and NCHRP 420, Impacts of Access Management Techniques (Gluck et al. 1999).

4.1. Median Treatments as Part of Access Management

The following briefly summarizes the impacts of median treatments on access management. The TRB *Access Management Manual* (2003) provides an excellent resource. It includes general information on median treatments, as well as information on selecting a median type, selecting median width, and selecting and placing median openings.

4.1.1. Two-Way Left-turn Lanes

TWLTLs provide a median separation between oncoming lanes of traffic and provide a center turn lane that vehicles can use to turn into or out of adjacent land uses. These medians remove left turning vehicles from the thru traffic stream and provide a refuge island for vehicles turning into the opposing direction of traffic from a driveway. The TWLTLs also provide a refuge for pedestrians. They are typically used in areas of moderate to intense roadside development with a high existing or expected demand for midblock left turns. Access is provided at any point, so the TWLTLs are not an impediment to frequent or randomly organized access points. The main advantage of TWLTLs is that they provide a storage area for left turning vehicles to wait for gaps in the opposing traffic streams. This improves traffic flow because left turning vehicles are removed from the traffic stream, thus reducing the potential for rear-end crashes. Because drivers can directly exit and enter adjacent properties, drivers and property owners generally prefer TWLTLs over raised medians. When installed on two-lane undivided roadways, they have been shown to decrease crashes by 35% in suburban areas (ITE 2008).

TWLTLs may be most effective as access management solutions when used with other techniques, such as driveway consolidation and corner clearance. One source (Mn/DOT 2008) suggested that TWLTLs work best when volume and driveway density is low, commercial driveways make up the majority of total driveways, and the proportion of left turning vehicles is high (20% or greater at peak hour).

However, research has indicated that when commercial driveway density is greater than 24 per mile (both directions), crash rates increase significantly. TWLTLs are also not recommended when traffic volumes are over 28,000 ADT. Mn/DOT (2008) found that with high volumes, raised medians were 25% safer than multilane divided sections and 15% safer than TWLTLs. Mn/DOT also suggested that TWLTLs are not appropriate when there are more than four thru lanes (Mn/DOT 2008). The National Highway Institute (NHI) course “Access Management: Location and Design” suggests a planning guideline of 24,000 ADT for replacement of TWLTL cross sections with non-traversable median cross sections due to the safety and traffic flow benefits of non-traversable medians.

ITE (2008) indicated that the advantages of TWLTLs are that they allow more maneuverability and flexibility than raised medians or divided highways, and drivers do not have to worry about striking them. ITE also suggest that TWTLs would not increase the number of U-turns at intersections, as raised or divided medians may. TWLTLs also provide storage area for left turning vehicles out of the traffic stream and provide access for adjacent properties.

Saito and Cox (2004) also summarized the findings of other researchers, who indicated that TWLTL are preferred by firefighters over raised medians. A raised median forces traffic to travel behind other vehicles, since vehicles cannot use adjacent lanes, and slow emergency response.

A summary by Dixon et al. (1999) suggested that TWLTLs provide good access to adjacent property but may result in excessive driveway development. Additionally, if traffic volumes are greater than 28,000 vehicles per day, vehicles in the TWLTL may find it difficult to find acceptable gaps in the opposing direction of travel to make a left turn.

The TRB *Access Management Manual* (2003) suggests that TWLTLs have the potential for overlapping left turn movements. This can be mitigated by site planning and controlling the placement of driveways.

4.1.2. Raised (Non-traversable) Medians

A raised median is a non-traversable device that separates oncoming directions of travel. Non-traversable raised medians may be continuous between intersections or provide midblock openings for left turns or other movements. Gluck et al. (1999) indicated that physically separating opposing directions of travel results in fewer conflicts, but cautions that the benefit may be offset by increased left turns at nearby intersections. The main advantage of raised medians is that left turning traffic is concentrated at established median openings. Raised medians also provide a better pedestrian refuge than TWLTLs.

The primary disadvantage of raised medians is that they increase travel time and delay for left turning vehicles, which are forced to travel circuitous routes to reach their destinations. This can result in undesirable turning movements, such as U-turns or neighborhood cut-through. The median can also pose a safety hazard if a vehicle strikes it and may also be difficult to see at night without overhead lighting (ITE 2008).

Saito and Cox (2004) suggest that traffic operations in general are better with raised medians than with undivided roadways, since left turning traffic, which migrates to intersections or median openings, does not block traffic. The authors caution, however, that the delay to traffic attempting to turn into or out of midblock properties can be increased. They summarized a list of advantages and disadvantages of raised medians found in other literature:

- Speed control
- Decrease in conflicts
- Increase in capacity
- Enhanced traffic flow
- Regulation of traffic
- Clearer indications of travel lanes at intersections
- Favoring of predominant movements
- Additional area for traffic control devices
- Additional area for pedestrian refuge
- Encouragement of development of alternative access roads
- Concentration of left turns at midblock openings or intersections
- Discouragement of strip development
- Controlled land use

4.2. Traffic Flow Impacts of Medians

In general, studies agree that traffic operations improve with the implementation of a TWLTL or raised median. However, little information is available about whether TWLTLs or raised medians perform better.

Gluck et al. (1999) found that using TWLTLs and raised medians in general reduce delay and improve traffic operation. The authors indicated that a few studies had evaluated traffic operations before and after installation of a TWLTL and had reported reduced delay. Bonneson and McCoy (1998) indicated that raised medians and TWLTLs had similar delays on arterials.

The results of several Iowa studies indicate that TWLTLs can improve LOS by one grade and lane capacity by 36% (FHWA 2003). An earlier CTRE study of US 67 in Bettendorf, Iowa, evaluated a site that was converted from a four-lane undivided roadway with over 60 access points per mile to a five-lane roadway with a TWLTL to help remove left turning traffic from thru traffic. The study’s authors evaluated operations before and after and found that LOS along the corridor had increased from C to B, even though traffic volume had increased by 8% (Maze et al. 1999). Another location, Iowa Highway 28 in Des Moines, within the same study was also reported. The roadway was originally an undivided four-lane facility. Full raised medians and left-turn bays at intersections were added, and LOS increased from B to A (Maze et al. 1999).

Another CTRE study evaluated US 69 (Duff Avenue) in Ames, Iowa. A TWLTL was added along the entire study corridor, along with driveway consolidation and closure at strategic locations. Signal upgrades were also made at two intersections. During the study period, AADT increased from 20,500 to 22,000 vehicles per day, while LOS improved from C to B (Maze and Plazak 1997). The same study evaluated Highway 18/71 in Spencer, Iowa, where a TWLTL was added to a highly developed commercial business activity location. Although no significant improvements in operations were noted, an LOS of B was retained over time (Maze and Plazak 1997).

A 1998 CTRE study of US 6 in Coralville, Iowa, evaluated the impact of raised medians and other treatments. Before access management was implemented, the corridor was a four-lane undivided roadway with no curb and gutter. A continuous TWLTL was implemented along the corridor, along with a driveway consolidation that reduced the number of driveways from 17 to 9. Left-turn lanes were also added at the intersection. The corridor's LOS went from D to C (Maze et al. 1998).

King et al. (2003) evaluated access management treatments along a four-lane suburban road. The treatments included a raised median, signalized and redesigned intersections, and the addition of curbs. The treatments narrowed the roadway from 64 ft to 53 ft. The signals were retimed signals to maintain a 45 mph speed. Evaluation before and after the treatments were installed showed that both the average and 85th percentile speeds decreased by 2 to 3 mph.

Eisele and Frawley (2005) evaluated three actual and three theoretical corridors in VISSIM to evaluate the operational effects of access management. The authors compared operational effects by median type (raised or TWLTL). They found that replacing a TWLTL with a raised median generally increased travel time. They also found that results were case specific, but travel time differences are based on traffic level and the location and number of raised median openings.

4.3. Safety Impacts of Left Turns

Some information on the safety impacts of medians is provided in section 4.1 of this report. This section covers the more general impacts of left turns.

TWLTLs provide the safety advantage of removing left turning vehicles from the traffic stream and allowing them time to select a gap in the opposing traffic stream. However, TWLTLs still allow uncontrolled turning movements, resulting in more potential conflict points than a raised median. Raised medians reduce conflicts and have the advantage of providing a refuge area for pedestrians, allowing them to cross a roadway in two steps rather than one. That is, pedestrians can cross the first half of the roadway without having to determine whether an oncoming vehicle will attempt to turn left, while an undivided or TWLTL facility forces pedestrians to watch for left turning vehicles. ITE (2004) found that raised medians can reduce crashes by 25% to 40% and provide a pedestrian refuge. However, raised medians can be dangerous if a vehicle strikes them at high speed and can be difficult to see at night unless they are lighted (ITE 2004). Additionally, some studies have suggested that with a raised median crashes migrate from the corridor to downstream intersections. For instance, Dixon et al. (1999) studied improvements on four-lane roadways in Cobb County, Georgia. Two roadways had TWLTLs and one had a raised median implemented. The authors found that the number of right-angle and total crashes increased after installation of both raised medians and TWLTLs. Rear-end crashes decreased for all three corridors, left-turn thru crashes decreased at the raised median corridor and one of the TWLTL corridors, and left-turn thru crashes stayed the same at the second TWLTL corridor.

Eisele and Frawley (2005) studied 11 corridors to evaluate the relationships between crash rate and access point density and median type (raised or TWLTL). The authors found that crash rate increases with increased access point density. They found that this was the cases for both raised medians and TLWTLs, but the increase was more marked for raised medians.

Both median types are reported to be safer than undivided medians. A CTRE of US 67 in Bettendorf, Iowa, evaluated a site that was converted from a four-lane undivided roadway with over 60 access points per mile to a five-lane roadway with a TWLTL to help remove left turning traffic from thru traffic. The study's authors evaluated crashes before and after improvements and found that total crashes had decreased by 50%, with a 91% reduction in broadside left-turn crashes. Another location in the same study, Iowa Highway 28 in Des Moines, was also examined. The roadway was originally a four-lane undivided roadway. After full raised medians and left-turn bays at intersections were added, the number of crashes decreased by about 51% (Maze et al. 1999).

Another CTRE study evaluated US 69 (Duff Avenue) in Ames, Iowa. A TWLTL was added along the entire study corridor, along with driveway consolidation and closure at strategic locations. Signal upgrades were also made at two intersections. During the study period, AADT increased from 20,500 to 22,000 vehicles, while crashes decreased by 70%. Another location evaluated in the same study was Highway 18/71 in Spencer, Iowa, where a TWLTL was added to a highly developed commercial business activity location. Crashes decreased by 13% in that corridor. Highway 65/69 in Des Moines, Iowa, was also included in the study. Before treatment, the roadway was a four-lane undivided roadway. A raised median was added, resulting in a 50% decrease in crashes (Maze and Plazak 1997).

In another CTRE study, US 6 in Coralville, Iowa, was evaluated. Before access management was implemented, the corridor was a four-lane undivided roadway with no curb and gutter. A continuous TWLTL was implemented along the corridor, as well as driveway consolidation, which reduced the number from 17 to 9. Left-turn lanes were also added at the intersection. Crashes decreased along the corridor by 34% (Maze et al. 1998).

The FHWA (2003) evaluated data from seven states and suggested that raised medians reduced crashes over 40% in urban areas. A study of corridors in Iowa found that the use of TWLTLs reduced crashes by 70%.

Parsonson et al. (2000), evaluating Memorial Drive in Georgia, reported a 37% drop in the total crash rate and a 48% drop in the injury crash rate after installation of a raised median.

Saito and Cox (2004) evaluated four corridors where raised medians had been installed. Both midblock and intersection crashes were evaluated, and the results are shown in Table 4-1 (rear-end and right-angle crashes include both midblock and intersection crashes).

Table 4-1. Change in crashes with installation of median (Saito and Cox 2004)

Corridor	Change in midblock crashes	Change in intersection crashes	Change in rear-end crashes	Change in right-angle crashes
1	+ 10%	-10%	- 26%	- 50%
2	+ 50%		+ 93%	- 87%
3	- 123%	+ 88%	+ 35%	- 59%
4	+ 14%		+ 44%	- 50%

Overall, Saito and Cox (2004) concluded that right-angle and rear-end collisions decreased in rate and percentage at midblock, while right-angle collisions decreased or stayed the same at signalized intersections. Rear-end crashes increased or stayed the same at signalized intersections, and severity of crashes decreased both midblock and at signalized intersections.

The majority of studies have suggested that, while both TWLTL and raised medians are safer than undivided roadways, raised medians usually have a lower crash rate than TWLTLs. For instance, a summary of several studies by Gluck and Levinson (2000) reported that highways with non-traversable medians had an average crash rate of 5.6 per million vehicle miles traveled (VMT), highways with TWLTLs had a crash rate of 6.9 per million VMT, and undivided facilities had a crash rate of 9.0 per million VMT.

Margiotta and Chatterjee (1995) evaluated 25 segments in Tennessee that were four-lane roadways, had adjacent commercial land use, were in suburban areas, and had non-traversable medians or TWLTLs . The authors used analysis of covariance (ANOCOVA) to consider the effects of different variables on crashes. They found that driveway density is an important contributor to crashes for segments with non-traversable medians, but not for segments with TWLTLs. Additionally, when driveway densities are high and when low to medium traffic volumes are present, TWLTLs were found to have a lower expected number of accidents per mile than non-traversable medians. The authors suggest that non-traversable medians are generally safer than TWLTLs when ADT is less than or equal to 32,500 vehicles per day, which is the maximum volume included in the study.

A study of median treatments in Georgia reported that raised medians reduce pedestrian-involved crashes by 45% and fatalities by 78% when compared to TWLTLs (FHWA 2003).

Bonneson and McCoy (1997) evaluated the relationship between access points and median type. Table 4-2 shows the results, expressed in crashes per 100 million vehicle miles (MVM). The authors found that, for all access point densities, raised medians had a lower crash rate than either undivided medians or TWLTLs.

Table 4-2. Crash rate per 100 MVM by number of access points per mile (Bonneson and McCoy 1997)

Access points/mile	Undivided	TWLTL	Raised median
< 20	3.8	3.4	2.9
20-40	7.3	5.9	5.1
40-60	9.4	7.4	6.5
> 60	10.6	9.2	8.2

Citing a study by Oregon State University that evaluated midblock and pedestrian crashes, CTRE (2008) reported that both midblock and intersection pedestrian crash rates were significantly lower for raised medians than for TWLTLs or undivided roadways (Table 4-3).

Table 4-3. Midblock and pedestrian crashes by roadway/median type (CTRE 2008)

Roadway/median type	Mid-block pedestrian crash rate per MVM	Intersection pedestrian crash rate per MVM
Undivided	**6.69**	**2.32**
Five-lane painted TWLTL	**6.66**	**2.49**
Divided four-lane with raised	**3.86**	**0.97**

Bowman and Vecellio (1994a; 1994b) evaluated sites that had raised medians, TWLTLs, or undivided cross sections in central business districts and suburban areas. The authors reported that arterials with TWLTL medians in central business districts had lower accident rates than undivided arterials and found no statistically significant difference between TWLTLs and raised medians. Pedestrian crash rates in central business districts were lowest when a raised median was present. In suburban settings, corridors with a raised median curb had significantly lower crash rates than corridors with TWLTLs or undivided corridors. Arterials with raised medians had lower pedestrian crash rates than arterials with undivided medians. No significant difference was found between pedestrian crash rates with raised medians and TWLTLs.

4.4. Fuel Consumption and Air Quality Impacts of Medians

No literature was available that discussed whether a particular type of median resulted in lower fuel consumption or emissions. In general, any improvements that smooth traffic flow will have air quality benefits. However, increasing travel distance will negatively impact air quality.

4.5. Economic Impacts of Medians

Levinson and Gluck (2000) presented a method to quantify the economic impacts of installing a raised median based on the number of vehicles that turn left into a roadside business, the proportion of those turns that represent pass-by traffic, and the estimated annual sales of the business. According to the model, economic impact depends on the extent to which access to the business increases or decreases, the type of activity, the background economic conditions (those that rely on pass-by traffics), changes in business conditions and traffic volumes, and the development of competitive business sites.

Saito and Cox (2004), Gluck et al. (1999), and Eisele and Frawley (2001) have also published studies on the economic impacts of different median treatments.

Table 4-4. Summary of effectiveness of TWLTLs and raised medians

Median type	Advantages	Disadvantages	Traffic flow	Fuel consumption/ air quality
Two-way left turn lanes (TWLTL)	• Midblock access • Separates traffic • Removes left turning traffic from main traffic • Flexible • Vehicles can utilize during emergency response	• Difficult for left turning vehicles to find gap when opposing volumes are high • May result in excessive driveway development (Dixon et al. 1999)	• Generally reduce delay and improve operation (Gluck et al. 1999) • Similar delay as raised median (Bonneson and McCoy 1998) • Improved LOS by 1 grade (Maze et al. 1999)	• Little information available but improvement in operation and speeds by removing left turning vehicles from traffic should have positive impact
Raised (non-traversable)	• Separates traffic • Focuses left turns at intersections • Decreased conflict • Regulation of traffic • Pedestrian refuge • Access control	• May increase U-turns • May increase neighborhood cut thru traffic • Safety hazard if struck • May be difficult to see in dark	• Similar delay as TWLTL (Bonneson and McCoy 1998) • Improved average and 85ht percentile speeds by 2–3 mph (Maze et al. 1999)	• Little information available but improvement in operation and speeds should have positive impact • Increased travel distance for left turning vehicles could have negative impact

Table 4-5. Summary of effectiveness of TWLTL and raised medians

Type	Safety impacts	Recommendations
Two-way left turn lanes (TWLTL)	• Reduced crashes by 13-70% over undivided (Maze and Plazak 1997; Maze et al. 1998) • Crash rate of 6.9 per million VMT compared to 9.0 for undivided and 5.6 for raised median (Gluck and Levinson, 2000) • Have lower crash rate than raised with high driveway density and low-medium traffic volume (Margiotta and Chatterjee 1995) • Similar crash rate as raised median in CBD (Bowman and Vecellio 1994) • Similar pedestrian crash rate as raised in suburbans (Bowman and Vecellio 1994) • Decreased rear-end crashes and left-turn decreased or stayed the same (Dixon et al. 1999) • Increased right angle and total crashes (Dixon et al. 1999) • Lower crash rate than undivided in CBD (Bowman and Vecellio 1994)	• May work best with low volume and driveway density, when the majority of driveways are commercial, and proportion of left turning vehicles >= 20% during peak hours (MnDOT 2008) • Not appropriate when there are more than 4 through lanes (MnDOT 2008)
Raised (non-traversable)	• Reduce crashes by 25 to 40% (ITE 2004) • Reduced total crashes by 50% over undivided roadway (Maze et al. 1999) • Crash rate of 5.6 per million VMT compared to 9.0 for undivided and 6.9 for raised median (Gluck and Levinson 2000) • Usually safer than TWLTL when ADT <= 32,500 vpd (Margiotta and Chatterjee 1995) • Reduced crashes by 40% in urban areas (FHWA 2003) • Reduced pedestrian-involved crashes by 45% and fatalities by 78% compared to TWLTLs (FHWA 2003) • Increased right angle and left turn crashes (Dixon et al. 1999) • Decreased rear-end crashes (Dixon et al. 1999) • Decreased total crash rate by 37% and injury crash rate by 48% (Parsonson et al. 2000) • Decreased right angle midblock and at intersection (Saito and Cox 2004) • Decreased rear end at midblock and increased or stayed same at intersections (Saito and Cox 2004) • Decreased severity midblock and at intersection (Saito and Cox 2004) • Lower pedestrian crash rates than undivided or TLWL in CBD (Bowman and Vecellio 1994) • Lower crash rate than undivided or TWLTL in suburban (Bowman and Vecellio 1994)	• Consider over TWLTL when ADT is > 24,000–28,000 vpd (TRB 2003; Dixon et al. 1999) • Safety benefit may be offset by increased left turns at intersections (Gluck et al. 1999)

5. DRIVEWAY CONSOLIDATION

5.1. Driveway Consolidation as Part of Access Management

According to the TRB *Access Management Manual* (2003), providing appropriate locations for access points is critical for safety and roadway efficiency. Driveways are necessary to provide access, but each driveway adds a new set of conflicts points that can affect safety and traffic flow. Reducing access points and driveways reduces conflicts and can improve capacity. Vehicles turning into and out of driveways slow thru traffic and provide points of conflict, while driveway consolidation reduces conflict points and maintains mobility.

5.2. Traffic Flow Impacts of Driveway Consolidation

Fewer interruptions in the traffic stream should result in less slowing of the traffic flow and improved operations. However, no information was available that quantified the positive traffic flow impacts of reducing the number of driveways.

The *Highway Capacity Manuel* (TRB 2000) indicates that, for multilane facilities, speeds are reduced by 0.25 mph for every access point, up to a 10 mph reduction for 40 access points per mile.

Gluck et al. (1999), studying operations, evaluated the impact of right turns at driveways. The authors developed a relationship between the total number of vehicles and the number of thru vehicles impacted while turning right at a single driveway (Table 5-1).

Table 5-1. Impact of turning vehicles on thru traffic (Gluck et al. 1999)

Right-turn volume	% of right-lane through vehicles impacted at a single driveway
<= 30	2
31-60	7
61-90	12
> 90	22

5.3. Safety Impacts of Consolidated Driveways

Access points create additional conflict points and friction in the traffic stream. Gluck et al. (1999) evaluated a number of studies and indicated that increasing the number of driveways and streets increases the number of accidents. The exact relationship depends on road geometry, operating speeds, and intersection and driveway volumes. The authors evaluated 240 roadway segments and created an index (Table 5-2) correlating accident rate with access density (using accident rate for 10 access points per mile as a base). The index suggests that doubling access points from 10 to 20 per mile increases accident rate by 40%.

Table 5-2. Relationship between crashes and crash rate (Gluck et al. 1999)

Total access points per mile in both directions	Crash rate index
10	1.0
20	1.4
30	1.8
40	2.1
50	2.5
60	3.0
70	3.5

Margiotta and Chatterjee (1995) evaluated 25 segments in Tennessee that were four-lane roadways, had adjacent commercial land use, were in suburban areas, and had non-traversable medians or TWLTLs . Using ANOCOVA to consider the effects of different variables on crashes, the authors found that driveway density is an important contributor to crashes for segments with non-traversable medians but not for segments with TWLTLs.

Mn/DOT (2000) randomly sampled 25 segments with different level of access and found a strong positive relationship between increasing access density and increased crash rate.

A CTRE study of US 6 in Coralville, Iowa, evaluated the impact of raised medians and other treatments. Before access management was implemented, the corridor was a four-lane undivided roadway with no curb and gutter. A continuous TWLTL was implemented along the corridor, driveways were consolidated from 17 to 9. Left-turn lanes were also added at the intersection. The corridor went from an LOS of D to an LOS of C (Maze et al. 1998).

A separate CTRE study evaluated US 69 (Duff Avenue) in Ames, Iowa. A TWLTL was added along the entire study corridor, along with driveway consolidation and closure at strategic locations. Signal upgrades were also made at two intersections. During the study period, AADT increased from 20,500 to 22,000 vehicles, and LOS improved from C to B (Maze and Plazak 1997).

Another CTRE study evaluated US 34 in Fairfield, Iowa, before and after access management improvements. Before the improvements, the corridor had driveways approximately every 100 ft. Access management included driveway consolidation of (eight local driveways were closed) and the provision of alternative access from side streets. Signals were also installed at two intersections. After the improvements, crashes decreased by 38% while LOS remained the same (Maze and Plazak 1997)

5. 4. Fuel Consumption and Air Quality Impacts of Driveway Consolidation

No studies were found that evaluated the impact of driveway consolidation on fuel consumption and air quality. However, improved traffic flow usually results in higher travel speeds. Removing turning traffic can also help reduce the slowing and accelerating of vehicles caught behind turning vehicles.

Table 5-3. Summary of effectiveness of driveway consolidation

Traffic flow	Safety	Fuel consumption/ air quality
• Little information available, but should result in less slowing and improved operations • Speeds are reduced by 0.25 mph for every access point up to a 10 mph reduction for 40 access points per mile for multilane facilities (TRB 2000) • Percentage of right lane through vehicles impacted at a single driveway increases as right turn volume increases (Gluck et al. 1999)	• Increased number of driveways and streets increase the number of accidents (Gluck et al. 1999) • Doubling access points from 10 to 20 per mile increases accident rate by 40% (Gluck et al. 1999) • Driveway density is an important contributor to crashes for segments with non-traversable medians (Margiotta and Chatterjee 1995) • There is a strong positive relationship between increased crash rate and increasing access density (MnDOT 2000) • Consolidated driveways led to a 38% decrease in crashes decreased while LOS remained the same (Maze and Plazak 1997)	• Little information available, but improved traffic flow usually results in higher travel speeds and reduces slowing and acceleration which should decrease fuel consumption

6 . U-TURNS

6.1. U-turns as Part of Access Management

U-turns are used to facilitate access when left turning movements are prohibited. Indirect left turns can be safer and contribute to improved traffic flow, although the travel distance required for turning increases, thus increasing overall travel.

6.2. Traffic Flow Impacts of U-turns

The traffic flow impacts of U-turns have not been well documented.

6.3. Safety Impacts of U-turns

Several studies have examined the safety impacts of U-turns. For more than 40 years, the Michigan Department of Transportation has used U-turn crossovers along wide median-divided highways that have intersections with prohibited left turns. The U-turns accommodate left turns that would otherwise happen at the intersections. The study found that prohibiting left turns allows two-phase traffic control, which increases capacity. The study reported a 61% reduction in the average number of crashes on one corridor (Grand River Avenue) and estimated a 14% to 18% increase in capacity over conventional dual left-turn lane designs (Levinson et al. 2000).

Summarizing research on U-turns, Gluck and Levinson (2000) found a 20% accident rate reduction when left turns are eliminated from driveways and a 35% reduction when the U-turn is signalized. The authors also reported that roadways with U-turn crossovers and wide medians have half the accident rate of roads with TWLTLs, and they estimated that use of U-turns in conjunction with two-phase traffic signal control results in a 15% to 20% gain in capacity over intersections with dual left-turn lanes and a multi-phase traffic signal.

6.4. Fuel Consumption and Air Quality Impacts of U-turns

No information was found that quantified the air quality impacts of U-turns.

Table 6-1. Summary of effectiveness of U-turns

Traffic flow	Safety	Fuel consumption/ air quality
• No information available	• 61% reduction in average number of crashes on one corridor where left turns are prohibited and u-turn crossovers are used (Levinson et al. 2000) • 14 to 18% increase in capacity over conventional dual left-turn lane designs (Levinson et al. 2000). • Roadways with U-turn crossovers and wide medians have half the accident rate of roads with TWLTLs (Gluck and Levinson 2000)	• No information available

7. SIGNALIZATION AND TRAFFIC SIGNAL SPACING

7.1. Signalization as Part of Access Management

Although not always considered as an access management technique, signalization is often used to improve traffic operations and reduce crashes.

7.2. Traffic Flow Impacts of Signalization

7.2.1. Summary of Information from Other Sources

The traffic flow impacts of signalization are directly dependent on traffic volumes, turning movements, distances between intersections, and traffic signal phasing. A series of signalized intersections can be coordinated, which can result in improved traffic flow. However, closely spaced intersections can have a significant negative impact on operations. The TRB *Access Management Manual* (2003) indicates that it is virtually impossible to maintain a progression speed of 40 mph or more when the traffic signal spacing drops below one-half mile.

Signals are increasingly being compared to roundabouts. Studies have found that signals perform better under some situations, but that roundabouts perform better under others. Bared and Edara (2005) used VISSIM to evaluate the performance of a roundabout within a coordinated set of signals. The authors used a corridor with three intersections, each separated by one-fourth mile. Initially, they evaluated the corridor with all three intersections signalized. Signal coordination was optimized using TRANSYT-7F. Next, they replaced the middle intersection with a roundabout. VISSIM results indicated that when the system was operating below capacity, the roundabout scenario resulted in less delay. When the corridor approached capacity, they found that the coordinated signals scenario resulted in slightly lower overall delay.

Bergh et al. (2005) evaluated traffic flow for 10 signalized intersections in northern Virginia that were determined to be good candidates for a roundabout based on volume and intersection geometry. The authors evaluated performance for the existing control and then, using aaSIDRA, compared that performance with the hypothetical situation of replacing the existing control with a roundabout. The analysis was based on data collected during peak periods for two days. The authors determined that overall average vehicle delay would be 17% to 92% lower for the roundabout alternatives than for signalization.

Also using aaSIDRA, Sisiopiku and Oh (2001) compared roundabouts with yield, two-way stop, and four-way stop control using different variations in volumes, turning volume splits, number of approach lanes, and lane width. The authors found that roundabouts were the best alternative for two-lane approaches that carry heavy thru or left turning volumes. They suggest that two-way stop and yield control can be effective with light demand. All-way stop control resulted in greater delays under both light and heavy traffic when compared to roundabouts and signalization. The authors found that roundabouts performed better at intersections with two-lane approaches and heavy volumes, while intersections with signals performed better with heavy volumes and heavy left-turns.

Roundabouts and signalized intersections were compared on South Golden Road in Golden, Colorado, which is a corridor with a series of strip malls, grocery stores, fast food restaurants, and other businesses. The one-half mile corridor has an ADT over 20,000. Two alternatives were considered for the corridor: (1) signalized intersections with center medians and restricted left turns and (2) roundabouts at the junctions and center medians to restrict left turns. The city determined that the roundabout alternative provided better access to businesses and was more pedestrian friendly, so this alternative was selected (Hartman 2004).

During the Golden, Colorado, study, traffic operations were compared before and after the roundabouts were installed, as well as with the alternative to add a third signal to the corridor. With the roundabouts, travel time decreased by 10 seconds while the 85th percentile speed decreased from 47 to 33 mph. The queues in the parking lots were nearly eliminated because the vehicles did not have to wait to make left turns. Instead, they made right turns and used the roundabouts for U-turns. Safety also improved along the corridor. Prior to construction of the roundabouts, there were 10 injury crashes per year, but in the four years after the roundabout was constructed only one injury crash was reported (Hartman 2004).

7.2.2. Traffic Flow Impacts Case Study

A case study for the intersection of Northwest Ash Street and Prairie Ridge Drive in Ankeny, Iowa, was used to study the traffic flow impacts of signalization. The case studied was described in section 2.2.2, and complete details about the analysis are provided in section 9.3. The intersection is located near an urban residential area, a park/baseball/public pool complex, a middle school, a church, and a public library. During drop-off/pick-up times and peak-hours, the intersection, which is currently four-way stop controlled, becomes congested and causes queues of up to 25 vehicles. The current intersection conditions were compared with three other alternatives:

- Two-way stop control
- Single-lane roundabout
- Signalization (Due to heavy left turning vehicles, a split phase was the only timing option.)

The existing geometry was maintained for all alternatives. The intersection alternatives were modeled in VISSIM for the morning peak period (7:00 to 8:00 a.m.). Several measures of effectiveness were output for each alternative. In all cases, the split-phase signal performed worst for delay and queue lengths. The roundabout overall resulted in the least amount of delay for northbound and southbound traffic, while the two-way stop control alternative performed best for eastbound and westbound traffic, which was the dominant direction of travel for the analysis period.

7.3. Safety Impacts of Signalization

The FHWA (2007b) produced a toolbox of intersection countermeasures and their potential effectiveness for improving safety. The FHWA suggests the following crash CRF for signalization:

- CRF of 7 when adding left-turn lanes at a T-intersection with a signal
- CRF of 24–67 (depending on crash type) when installing signals and channelization
- CRF of 28–43 for all crashes when converting two-way stop control to signal control, and CRF of 74 for right-angle crashes
- CRF of 36–43 for all crashes when converting two-way stop control to signal control and installing a left-turn lane, 8 for rear-end crashes, and 74 for right-angle crashes

A study by Gluck and Levinson (2000) found a relationship between signal density and crash rate. The authors report that increasing signal density from two to four per mile resulted in a 40% increase in crashes along roadways in Georgia and a 150% increase along US 41 in Florida. Table 7-1 shows the relationship between crashes and signal density as reported by ITE (2004).

Table 7-1. Relationship between crash rate and signal density (ITE 2004)

Signal per mile	Crashes per MVMT
Under 2	3.53
2 to 4	6.89
4 to 6	7.49
6+	9.11

7.4. Fuel Consumption and Air Quality Impacts of Signalization

The impact of signalization on fuel consumption and air quality depends on a number of factors, including signal density. The FHWA (2003) reported that, when more than two signals per mile are installed, travel time increases by over 6% for each additional signal beyond two per mile. The FHWA also reported the results of a study in Texas along a 10 mile corridor; that study found a significant decrease in fuel consumption when half-mile spacing is used rather than quarter-mile spacing.

Table 7-2. Summary of effectiveness of signalization

Traffic flow	Safety	Fuel consumption/ air quality
• Impacts are directly dependent on traffic volumes, turning movements, distance between intersections, and traffic signal phasing • Overall average vehicle delay would be 17% to 92% lower for the roundabout alternatives than for signalization (Bergh et al. 2005) • Performs better with heavy volumes and heavy left-turns (Sisiopiku and Oh 2001) • Split phase signal performed worst in all cases for delay and queue lengths (Ankeny, IA Case Study)	• CRF of 74 for right angle turns when converting from two-way control (FHWA 2007a) • With less than 2 signals per mile, only 3.53 crashes per MVMT (ITE 2004) • With six or more signals per mile, over 9 crashes per MVMT (ITE 2004) • Increasing signal density from 2 to 4 per mile resulted in a 40% increase in crashes along roadways in Georgia and a 150% increase along US 41 in FL (Gluck and Levinson 2000)	• Travel time increases by over 6% for each additional signal greater than two per mile (FHWA 2003)

8. ALTERNATIVE ACCESS ROADS

8.1. Alternative Access Roads as Part of Access Management

Alternative access roads, which include, frontage and backage roads, are used to provide alternate access around access-controlled corridors. This helps keeps traffic that accesses adjacent or nearby properties off of major roadways.

Alternative access roads provide access directly to adjacent properties, removing the traffic from the main traffic lanes and segregating local and thru traffic. Although not quantified, removing turning traffic usually results in fewer conflicts and, as a result, fewer crashes and improved traffic flow and operations, which generally leads to lower fuel consumption and lower emissions. Traffic attempting to access adjacent land use, however, may end up traveling longer paths (Gluck et al. 1999).

Chapter 10 of the TRB *Access Management Manual* (2003) discusses implementing and designing alternative access roads.

8.2. Traffic Flow Impacts of Alternative Access Roads

8.2.1. Summary of Information from Other Sources

The traffic flow impacts of alternative access roads are unknown. If short trips into and out of adjacent or nearby properties are removed from the main traffic flow, traffic operations should improve. Delay to those vehicles making short trips, however, may increase.

8.2.2. Traffic Flow Impacts Case Study—US 69 in Ankeny, Iowa

Since little information was available about the traffic flow impacts of alternative access roads, the research team used VISSIM to evaluate the operational impacts of including backage roads and other access management strategies in a signalized corridor. The analysis compared average corridor travel time, delay, stop time, and travel speeds. Section 10.2 describes the case study in detail. The following sections provide a summary of the results.

US 69 is the major north/south arterial through Ankeny, Iowa. It is signal controlled, with many local retail businesses and residential areas located adjacent to the corridor. The south section of the corridor was the focus of the study. During peak hours, the south section of the corridor operates at near capacity due to commuter traffic. Adding to the congestion are vehicles entering and exiting businesses, making this intersection an excellent candidate for access management improvements.

This section of the corridor is bounded by 1st Street, which extends south to Southeast 9th Street. This section is approximately 0.72 miles long and runs parallel to Interstate 35, serving as Ankeny's second primary commuting route to the Des Moines metropolitan area. The majority of the corridor is commercial development, including such businesses as food and recreational sales establishments, with dense residential areas adjacent to the commercial properties. The three signalized intersections are at 1st Street, South 3rd Street, and Southeast 8th Street. The Iowa Department of Transportation reports a vehicular volume of 17,275 to 22,000 ADT within the study area, with its highest turning movement in the morning and evening peak hours. The study corridor consists of a four-lane curb–and-gutter arterial with no two-way left turning lane into multiple business driveways. The north section of the corridor (north of 1st Street) had access management strategies implemented in the 1990s, including backage roads, a raised center median, and driveway consolidation. Both sections of the corridor are shown in Figure 8-1.

The south corridor was evaluated, and the best access management plan for the corridor was selected. The access management plan consists of installing a non-traversable median along the corridor, consolidating driveways, developing a set of backage roads, and realigning the geometry of several intersections, as shown in Figure 8-2.

The existing network was drawn in AutoCAD, and then adjustments were made for the proposed alternative. The network was output from AutoCAD into a format suitable for VISSIM. Intersection volumes, including turning movements, were available for the existing signalized intersections, but no information was available for turning movements into and out of driveways along the corridor. This information was necessary because driveway activity can have a significant influence on traffic operation.

A field investigation was performed to determine which businesses were located along the study corridor, how many useable driveways each business had on site, the area of the building for each business, and the building's proximity to the nearest signalized intersection or collector street. Once this data was collected, trip generation was determined using the ITE *Trip Generation Handbook* (1997). The total number of trips was allocated among available driveways.

South section of US 69 with no access control

North section of US 69 with access control

Figure 8-1. US 69 corridor

Figure 8-2. Proposed access management plan for US 69

Information was coded into VISSIM, and the model was calibrated. Evaluations of the two models were performed using VISSIM's evaluation tools, including those that investigate corridor travel time, delay, and stopped delay. Data collection points were added to the model at both ends of the corridor for each direction of travel. Information was extracted for vehicles that only traveled the entire length of the corridor from the start point to the end point. The afternoon peak (5:00 to 6:00 p.m.) was used for the evaluation.

Results are provided in Figures 8-3 and 8-4. As shown, the corridor travel time increased in both directions for the access-managed alternative. This may be due to the fact that the proposed model diverts most of the business traffic to signalized intersections. That is, the signals are running on the maximum green times for the minor streets, allowing a larger volume of vehicles to enter the corridor. As the figures also show, the corridor's stopped delay for the proposed model is slightly lower in both directions, and the average delay is slightly lower in the southbound direction but slightly longer than the existing model in the northbound direction. Although travel time, corridor delay, and stopped delay were not greatly affected by the access management strategies implemented, the case study shows that, by implementing these strategies, safety has increased while travel conditions have not decreased.

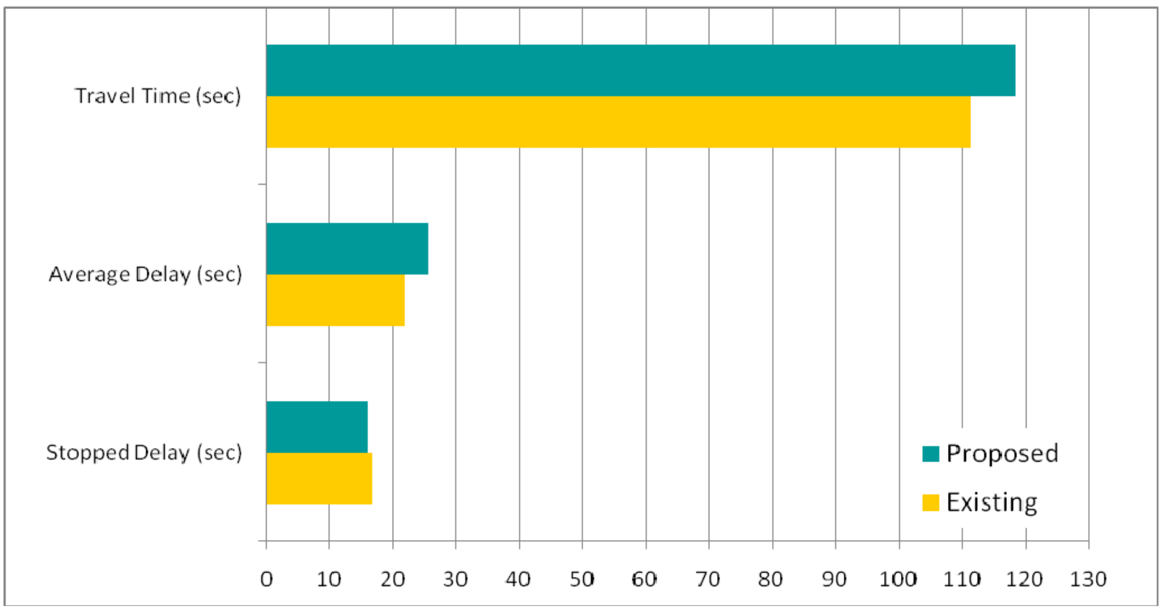


Figure 8-3. Results for northbound vehicles through the corridor

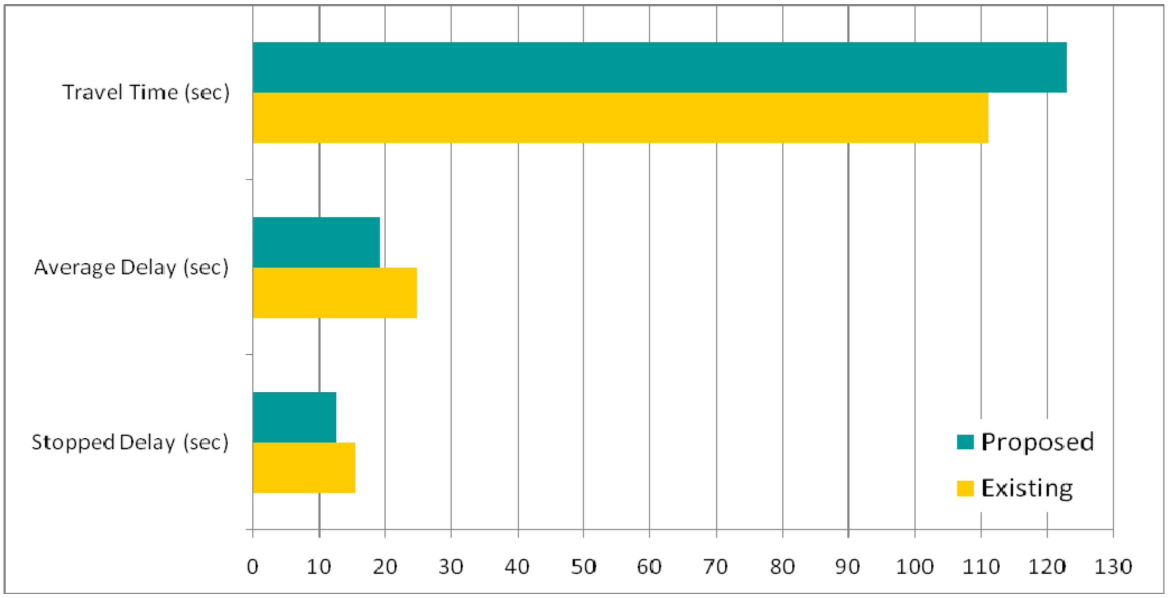


Figure 8-4. Results for southbound vehicles through the corridor

8.3. Safety of Alternative Access Roadways

Though alternative access roads can reduce conflicts, no information was found that quantified the safety impact.

8.4. Fuel Consumption and Air Quality Impacts of Alternative Access Roadways

No information was found that quantified the fuel consumption or air quality impacts of alternative access roads.

Table 8-1. Summary of effectiveness of alternative access roadways

Traffic flow	Safety	Fuel consumption/ air quality
• Little information available; however main flow of traffic should improve while those making short trips may experience increased delays • Travel time increased while stopped delays decreased (Ankeny, IA Case Study)	• Little information available, but conflicts should be reduced	• No information available

9. CASE STUDIES

The following three case studies were conducted to evaluate the trade-offs between different access management strategies.

9.1. US 69 in Ames, Iowa Corridor Study

9.1.1. Background

The city of Ames, Iowa, is located in Story County near the center of the state, 28 miles north of Des Moines. Ames is also conveniently located at the intersection of US 30 and Interstate 35. A city of just over 51,000 people while Iowa State University is in session, Ames is the home of Iowa State University, the Iowa Department of Transportation, and the United State Department of Agriculture animal laboratory. In addition to the city's size and location, these three institutions make Ames an important commercial, transportation, and research hub for the state of Iowa. Ames is the largest population and economic center within Story County. Between 1990 and 2006, the population of Ames increased by only 9.24% (RM Planning Group 2006). This is slightly higher than the population growth rate for both Story County and the entire state of Iowa. During that same period, the population of Ankeny, Altoona, and other northern suburbs of Des Moines approximately doubled.

Today, US 69 is a major arterial that is signal controlled through the city, as shown in Figure 9.1, and many retail and commercial business are located adjacent to the route. During all three peak hours of the day, the corridor is at or near capacity. This study investigated the possible improvements to a rather unique intersection at US 69 (Grand Avenue) and 13th Street.

Figure 9-1. Present day US 69 (Grand Avenue) and 13th Street

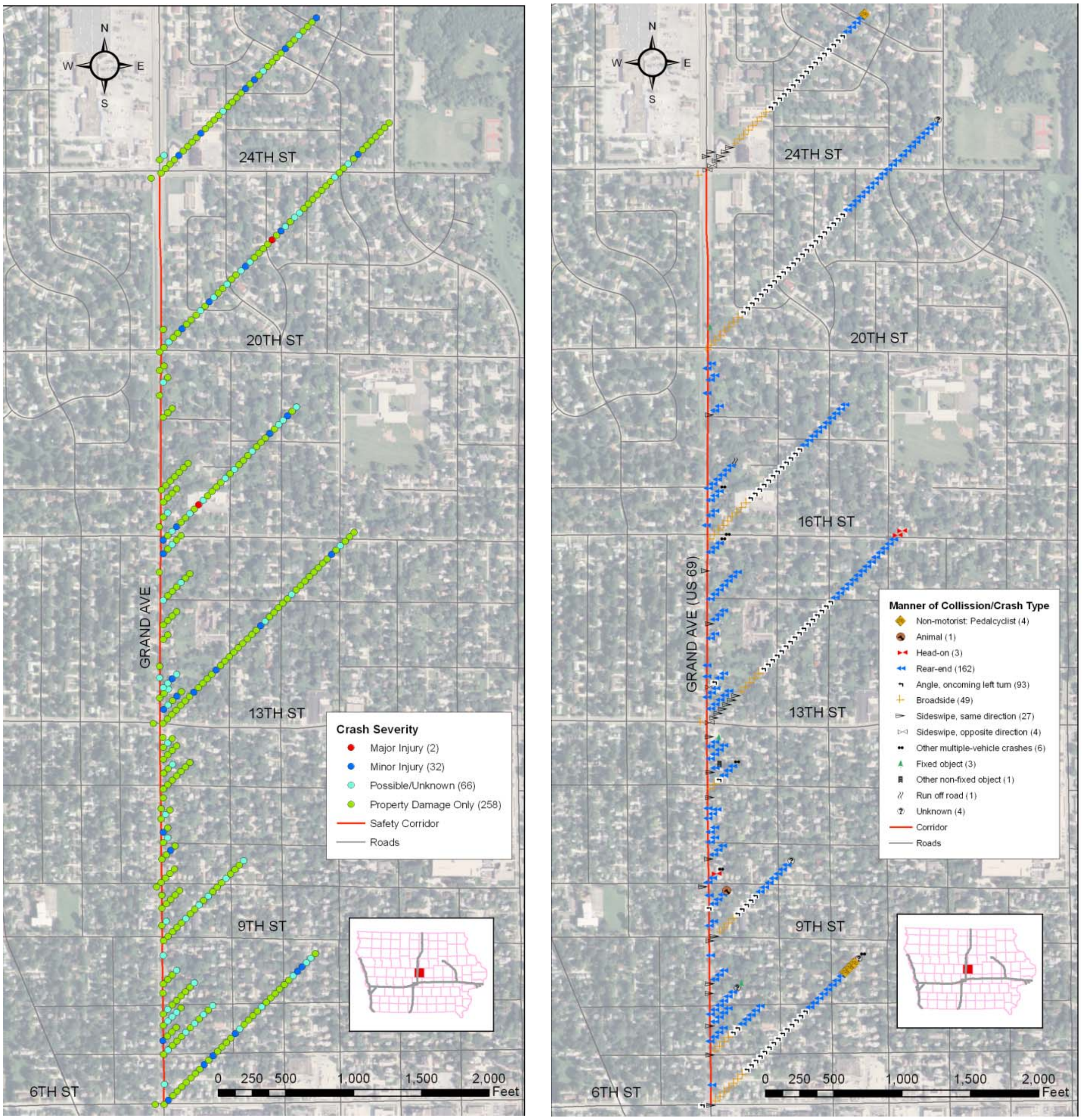
9.1.2. Study Area

The area of focus for this case study is the section of US 69 (Grand Avenue) bounded by 6th Street on the south and 24th Street to the north. This section is approximately 1.6 miles long and runs from the city's historic main street district to the North Grand Mall. The majority of the corridor is residential, with the exception of the area surrounding North Grand Mall, which also includes a Wal-Mart, Cub Foods, and various small retail establishments. US 69 throughout the study area is an undivided paved four-lane curb-and-gutter arterial street with residential driveways, local streets, and neighborhood collector streets directly intersecting the highway. There are sidewalks on both sides of the street and at least 15 ft of clear zone on each side. The Iowa Department of Transportation reports that the average daily traffic for the study area ranges from 15,600 to 18,400, with the highest traffic level at the intersection of Grand and 13th Street. The vast majority of traffic (over 97%) consists of passenger vehicles, including cars, vans, and heavy vehicles.

9.1.3. Crash Experience

Crashes by severity and type along the study corridor are shown in Figure 9-2. As illustrated, the highest number of recorded crashes occurred at intersections where US 69 intersected a local neighborhood street. A majority of these crashes involved angles or oncoming left turning movements. This is understandable, since drivers may not be able to judge the gap time turning onto Grand Avenue. Also looking at the crash type map in Figure 9-2, it can be seen that most of the total numbers of crashes were due to rear-end collisions, most of these happening midblock south and just north of 13th Street.

A possible reason for the high number of signalized intersection midblock rear-end crashes could be drivers wanting to make a left turn onto a local street or driveway without the aid of a two way left turning lane on Grand Avenue. Furthermore, the manner of crash type map shows a relatively high number of pedestrian-vehicle crashes at the signalized intersections. Possible reasons for this could be pedestrians misunderstanding the split signal phase at 13th Street and Grand Avenue, limited sight distance, crosswalks that are not well defined, or the relatively high number of bicyclists in the city. Drivers may not be able to see the bicyclists or recognize their intentions at the intersection.



Crash Severity **Crash Type**

Figure 9-2. Crashes for the Ames corridor

9.1.4. Signalized Intersections

6th Street and Grand Avenue

The intersection of 6th Street and Grand Avenue is the southernmost signalized intersection along the corridor. In early 2001, the signalized intersection south of this intersection was reconstructed and the geometry was changed slightly, including adding a raised median and extending the northbound permitted and protected left turning lane. The 6th Street intersection is located between the downtown cultural district of Ames and adjacent residential areas. On the southeast corner of the intersection is a local bank, and on the southwest side is a small retail business. On the north side of the intersection are multi-resident housing units and private homes, as shown in Figure 9-3. This intersection is actuated-controlled and uncoordinated (offset), and the signal timing is presented in Table 9-1.

Figure 9-3. 6th Street and Grand Avenue northbound view (left) and layout (right)

Table 9-1. Grand Avenue and 6th Street existing signal timing

	Northbound			Southbound			Eastbound			Westbound		
NEMA Phasing	5	2	2	1	6	6	4	4	4	8	8	8
Lane Config.	Left	Thru	Right	Left	Thru	Right	Shrd.	Thru	Right	Left	Thru	Right
Volume (veh./hr.)	21	971	68	168	553	34	16	79	33	21	971	58
Cycle length	100	100	100	100	100	100	100	100	100	100	100	100
Offset	13	13	13	13	13	13	13	13	13	13	13	13
Passage	3	3	3	3	3	3	3	3	3	3	3	3
All-red clearance	0	1	1	0	1	1	0	1	1	0	1	1
Amber phase	4	5	5	4	5	5	3	3	3	5	5	5
Min green	3	3	3	3	3	3	3	3	3	3	3	3
Max green	14	30	30	26	42	42	30	30	30	30	30	30
Total split	18	36	36	30	48	48	34	34	34	34	34	34

9th Street and Grand Avenue

The intersection of 9th Street and Grand Avenue is the second signalized intersection in the study corridor (Figure 9-4). Two neighborhood collector streets intersect Grand Avenue, and an elementary school is located a few blocks west of the intersection. Heavy pedestrian traffic travels east-west, and there is a crossing guard at the intersection in the mornings and afternoons. Residential areas surround the intersection, and there is a regular bus route that travels on both eastbound 9th Street and northbound and southbound Grand Avenue. The intersection is located two blocks north of 6th Street, and the signal timing (actuated-controlled, offset) is presented in Table 9-2.

Figure 9-4. 9th Street and Grand Avenue northbound view (left) and layout (right)

Table 9-2. 9th Street existing signal timing

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
NEMA Phasing	2	2	2	6	6	6	8	8	8	4	4	4
Lane Config.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.
Volume (veh./hr.)	19	1101	29	9	695	3	10	10	20	34	16	46
Cycle length	100	100	100	100	100	100	100	100	100	100	100	100
Offset	96	96	96	96	96	96	96	96	96	96	96	96
Passage	3	3	3	3	3	3	3	3	3	3	3	3
All-red clearance	1	1	1	1	1	1	1	1	1	1	1	1
Amber phase	5	5	5	5	5	5	3	3	3	3	3	3
Min green	3	3	3	3	3	3	3	3	3	3	3	3
Max green	59	59	59	59	59	59	31	31	31	31	31	31
Total split	65	65	65	65	65	65	35	35	35	35	35	35

13th Street and Grand Avenue

The intersection of 13th Street and Grand Avenue (Figure 9-5) is one of the most complicated and, recently, politically driven intersections in Ames. This intersection is the third signalized intersection in the study corridor and is a split-phase signalized intersection with no left or right turning lanes and an absence of traffic signals over the travel lanes. The intersection serves the city as a cross point for two major arterials, which lead to either Iowa State University heading westbound or Mary Greeley Medical complex heading eastbound. The intersection is surrounded by private residences, a local church on the northwest side of the intersection, and a small business on the southeast side. The split-phase, actuated-controlled signal timing is presented in Table 9-3.

Figure 9-5. 13th Street and Grand Avenue northbound view (left) and layout (right)

Table 9-3. 13th Street existing signal timing

	Northbound			Southbound			Eastbound			Westbound		
NEMA Phasing	2	2	2	1	1	1	3	3	3	4	4	4
Lane Config.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.
Volume (veh./hr.)	165	879	56	104	620	54	38	249	67	28	417	191
Cycle length	150	150	150	150	150	150	150	150	150	150	150	150
Offset	88	88	88	88	88	88	88	88	88	88	88	88
Passage	3	3	3	3	3	3	3	3	3	3	3	3
All-red clearance	1	1	1	1	1	1	1	1	1	1	1	1
Amber phase	5	5	5	5	5	5	3	3	3	3	3	3
Min green	10	10	10	10	10	10	15	15	15	15	15	15
Max green	43	43	43	31	31	31	23	23	23	29	29	29
Total split	49	49	49	37	37	37	29	29	29	35	35	35

20th Street and Grand Avenue

The intersection of 20th Street and Grand Avenue (Figure 9-6) is the fourth signalized intersection in the study corridor. Two local streets intersect the intersection, and both local streets lead to two elementary schools. Similar to 9th Street and Grand Avenue, this intersection experiences heavy east-west pedestrian traffic. However, the minor street volumes are quite low. The intersection is surrounded by private residences with a limited right-of-way on each side of Grand Avenue. Similar to 13th Street and Grand Avenue, signal heads are not located above each travel lane. The signal timing (offset, fixed) is presented in Table 9-4.

Figure 9-6. 20th Street and Grand Avenue northbound view (left) and layout (right)

Table 9-4. 20th Street existing signal timing

	Northbound			Southbound			Eastbound			Westbound		
NEMA Phasing	1	1	1	2	2	2	3	3	3	4	4	4
Lane Config.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.
Volume (veh./hr.)	69	951	26	41	694	44	22	16	56	28	40	38
Cycle length	100	100	100	100	100	100	100	100	100	100	100	100
Offset	88	88	88	88	88	88	88	88	88	88	88	88
Passage	3	3	3	3	3	3	3	3	3	3	3	3
All-red clearance	1	1	1	1	1	1	1	1	1	1	1	1
Amber phase	5	5	5	5	5	5	3	3	3	3	3	3
Min green	24	24	24	24	24	24	24	24	24	24	24	24
Max green	60	60	60	60	60	60	34	34	34	34	34	34
Total split	66	66	66	66	66	66	34	34	34	34	34	34

24th Street and Grand Avenue

The intersection of 24th Street and Grand Avenue (Figure 9-7) is the last signalized intersection in the study corridor. Similar to 13th Street, 24th Street serves as a major collector street for the city of Ames. The actuated intersection has northbound and southbound permitted and protected left turning lanes, and the east and west legs have shared turning and thru lanes. On the southeast side of the intersection is a local school, on the southwest side of the intersection are multi-family dwellings, on the northeast side of the intersection are a bank and an ACE hardware store, and on the northwest side of the intersection is North Grand Mall. Directly northwest of the intersection is a gas station. The signal timing (offset, actuated-coordinated) for the 24th Street and Grand Avenue intersection is presented in Table 9-5.

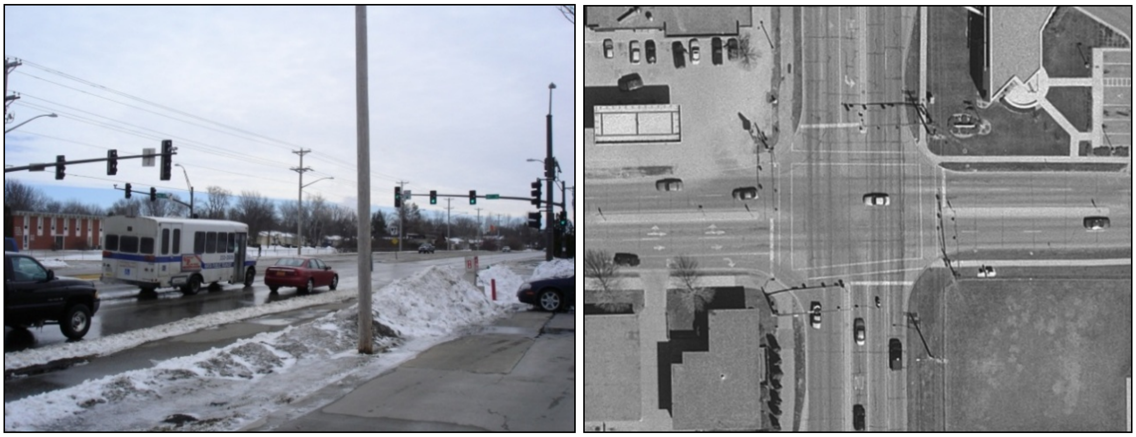


Figure 9-7. 24th Street and Grand Avenue northbound view (left) and layout (right)

Table 9-5. 24th Street existing signal timing

	Northbound			Southbound			Eastbound			Westbound		
NEMA Phasing	1	1	1	2	2	2	3	3	3	4	4	4
Lane Config.	Left	Thru	R. Shrd.	Left	Thru	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.	L Shrd.	T. Shrd.	R. Shrd.
Volume (veh./hr.)	114	858	38	30	483	30	31	103	220	43	97	47
Cycle length	100	100	100	100	100	100	100	100	100	100	100	100
Offset	78	78	78	78	78	78	78	78	78	78	78	78
Passage	3	3	3	3	3	3	3	3	3	3	3	3
All-red clearance	1	1	1	1	1	1	1	1	1	1	1	1
Amber phase	3	3	3	3	3	3	3	3	3	3	3	3
Min green	3	3	3	3	3	3	3	3	3	3	3	3
Max green	18	39	39	13	34	34	34	34	34	34	34	34
Total split	22	45	45	17	40	40	38	38	38	38	38	38

In July 2007, the City of Ames requested that a feasibility study be performed on the intersection of 13th Street and Grand Avenue to investigate possible alternatives to improve travel time through the corridor and to improve safety. The city reported that this intersection performed at LOS F, with an average peak-hour delay of 207 seconds. A private engineering firm came up with eight alternatives that included multiple engineering improvements for each alternative. Recommended improvements included such items as widening the lanes, installing additional traffic signals, signalizing nearby intersections, adding left turning lanes, widening 13th Street, or installing a modern roundabout. For this case study, three realistic alternatives were selected to model in the microsimulation suite VISSIM 4.30. The alternatives selected included (1) doing nothing, (2) installing a two-lane modern roundabout, and (3) adding protected and permitted left turning lanes on all approaches. The following two sections describe the model structure for the roundabout and the left turning permitted and protected scenarios, but not the model for existing conditions. However, all three alternatives will be compared in the analysis section of this report.

9.1.4. Modeling Ames US 69 Corridor in VISSIM

Microscopic simulation has become an almost standard tool for traffic engineering when comparing multiple design alternatives. One of the most flexible simulation packages, invented in the early 1990s, is VISSIM, which can model and analyze roundabouts. Unlike modeling a stop controlled or signalized intersection, roundabouts are based on drivers accepting or denying gaps; this type of modeling invokes driver behavior. One of VISSIM's strengths is it is a discrete, stochastic, time-step–based program that follows many of the same principles described by Wiedemann and Reiter (1992).

Similarly for all three studied models, links and connectors were drawn into the model at full scale using aerial imagery obtained from Story County, Iowa. Vehicle volumes were obtained from the City of Ames and were loaded into each signalized approach, where the model terminated. Unlike other traffic simulation programs, VISSIM uses routing decisions to determine where vehicles travel based on the turning movement volume percentage; this will be explained later in this section. Vehicle compositions were also input into the model, which were based on a percentage as well. It was determined that only 1% of the total number of vehicles were either buses or heavy vehicles, while 99% of the vehicles in the simulation were various passenger cars. VISSIM also applies a speed distribution to each vehicle when it enters the network. Depending on vehicle build, network geometry, or driver characteristics the vehicle encounters, each vehicle's continuous speed always tries to lie within the distribution. The specified vehicle distribution in the initial calibration can easily be adjusted, although the default speed distribution for the posted speed limit of 35 was used. Speed distribution was between 29.8 to 36 miles per hour (Figure 9-8).

Lastly, the signal timing and vehicle detectors described in the previous section were input into the NEMA virtual signal controller that is part of VISSIM. Since the City of Ames created an existing complex Synchro timing file for the corridor that was not compatible with VISSIM, raw data was input into VISSIM and the signal timing was slightly adjusted to maximize the coordination and optimization between the various types of intersections studied in this corridor in order to mimic real world scenarios.

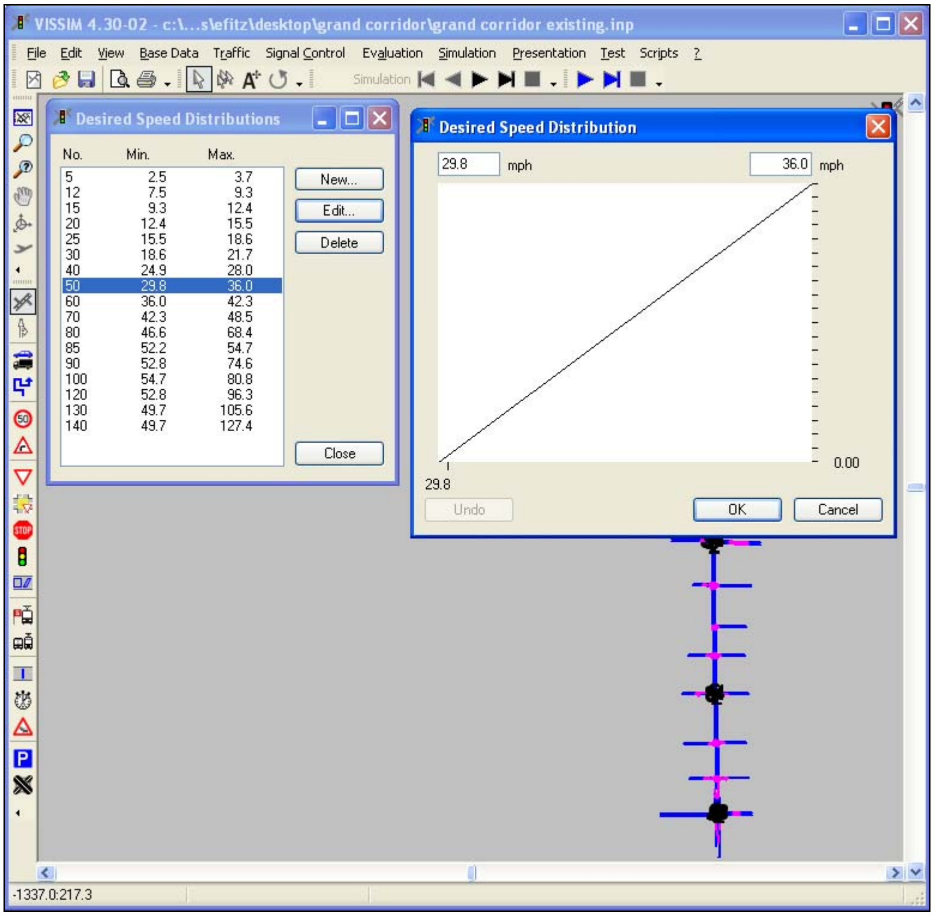


Figure 9-8. Vehicle speed distribution

Roundabout Model Structure

In addition to the car following and driver behavior models built into the program, VISSIM reacts to road geometry. Figure 9-9 shows the result of one of the alternatives from the City of Ames feasibility study, a two-lane roundabout. As the figure shows, the design consisted of four approach legs consisting of two lanes and two circulating lanes inside the roundabout, which would encroach on multiple private properties around the intersection.

Using the city-proposed roundabout illustrated in Figure 9-10, a more robust design was created using Land Desktop 4 and the FHWA's *Roundabouts: An Informational Guide* (Robinson et al. 2000). As the figure illustrates, an outside radius of 170 ft with two 18 ft travel lanes and a 12 ft truck apron was created. However, because of the geometry of 13th Street (east-west) a 90 degree roundabout was skewed on the east leg and the placement was moved north of the intersection slightly to minimize property impact.

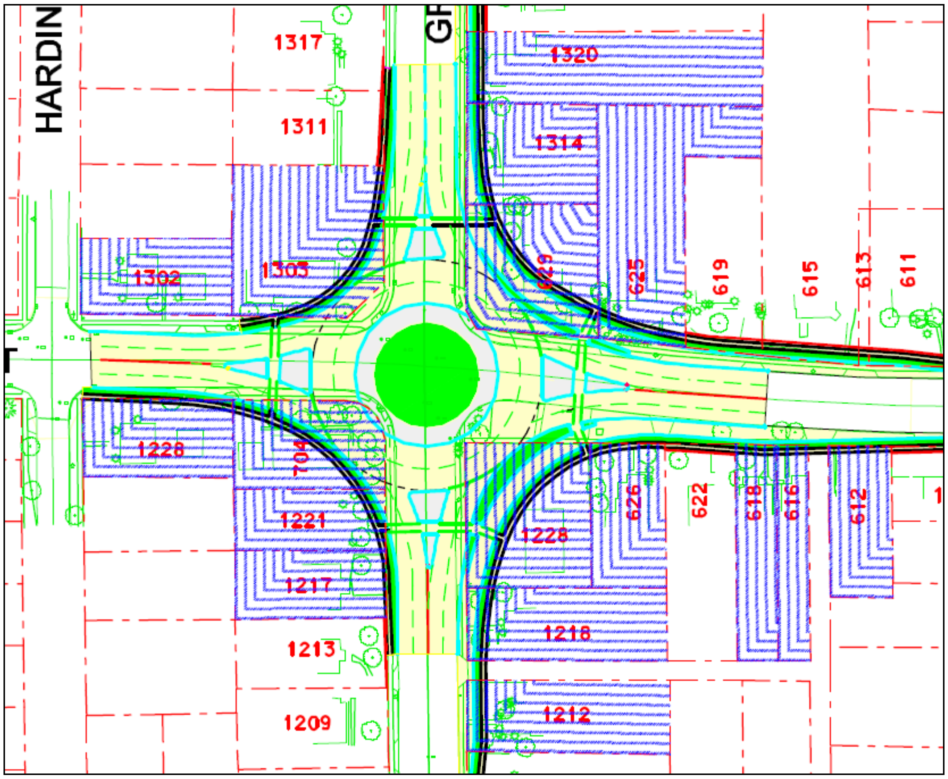


Figure 9-9. Roundabout design

Figure 9-10. AutoCAD model used for simulation building

To accurately use a microsimulation package to evaluate the impact of a roundabout, two models were created. The first model consisted of the existing conditions (split-phase signal at 13th Street) and the proposed roundabout (two-lane unsignalized at 13th Street). In both models, calibration tools included the following, each of which will be explained below:

- Links and connectors
- Priority rules
- Reduced speed zones
- Driver behavior
- Routing decisions

Links and Connectors. Using a process similar to that used to create a signalized intersection or urban road, the roundabout geometry was created using links and connectors. A link is a defined length of road with an unlimited number of lanes with any dimensions; in this case, the link was two lanes at specified lengths depending on the design. Similar to the link, the link connector connects links together. The advantage of using a connector is that it can adjust to different lane widths and provides vehicles a place to weave if necessary. Unlike AutoCAD or other simulation programs, there are no options for adding curved links or connectors, and thus multiple points must be added to each link or connector and then adjusted to make a horizontal curve. The link and connector set for the proposed roundabout is shown in Figure 9-11.

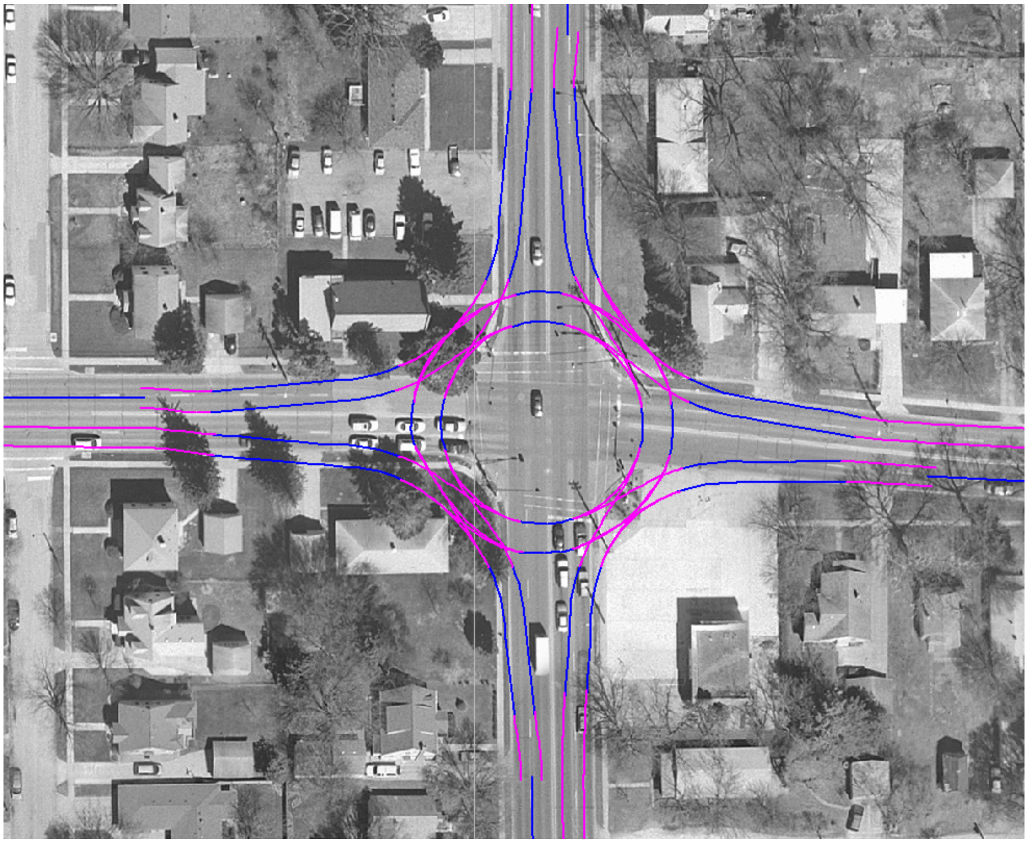


Figure 9-11. Roundabout link and connectors

As shown in each approach leg in Figure 9-11, two sets of links and connectors were created that represent individual lanes because this was the easiest way to specify which lane a vehicle needed to be in to either make a left turning, thru, or right turning movement. Away from the roundabout on each exit, the two separate links and connectors merge into a single link, which gives the vehicle a chance to merge into the left or right lane.

Priority Rules. To simulate safe vehicle travel through the roundabout, acceptable gaps called priority rules must be coded into VISSIM at the end of each approach leg. Priority rules consist of a red bar located at the yield point and multiple green conflict markers associated with the red stop line. Separate priority rules were coded into the Grand Avenue model roundabout for both passenger cars and heavy vehicles because of the differences in vehicle design and acceleration. Additionally, a yield point (or red bar) was placed on each of the approach lanes. As a vehicle approaches the red stop line, two separate conditions must be met for the vehicle to proceed into the roundabout, including minimum headway and minimum gap time, both of which are specified when coding these into the model. Illustrated in Figure 9-12 are the priority rules coded for each approach leg.

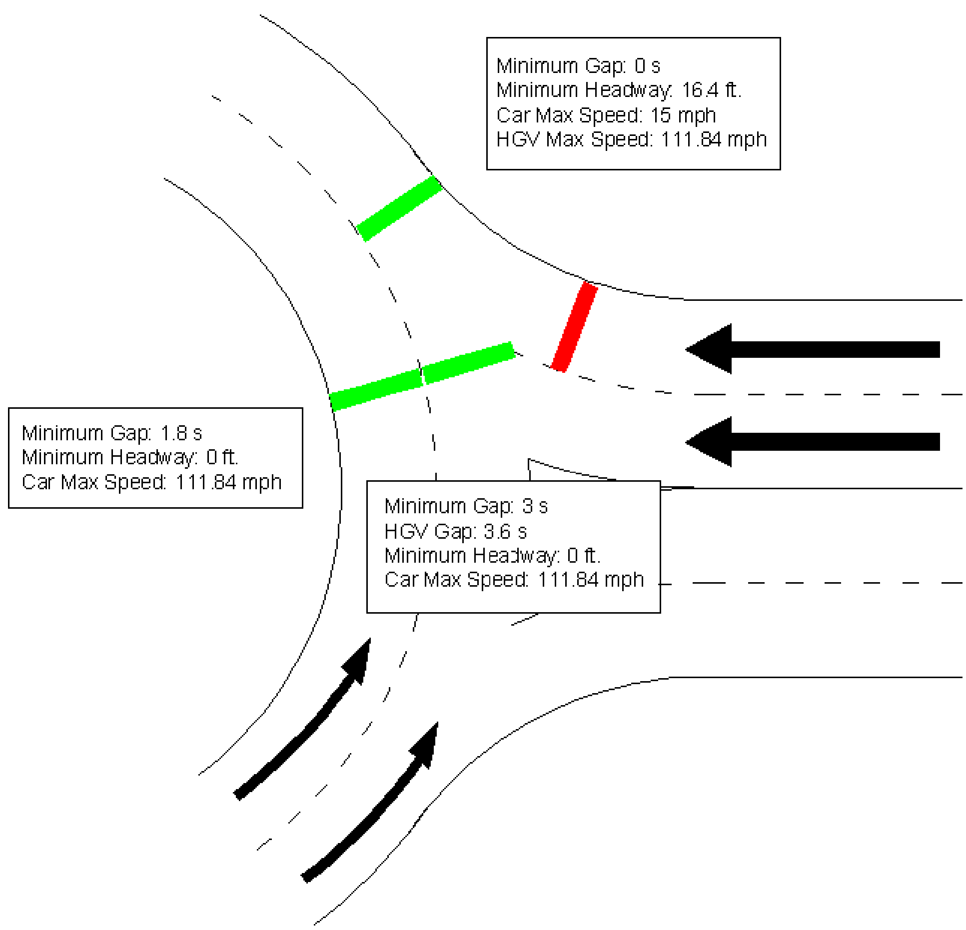


Figure 9-12. Roundabout priority rules

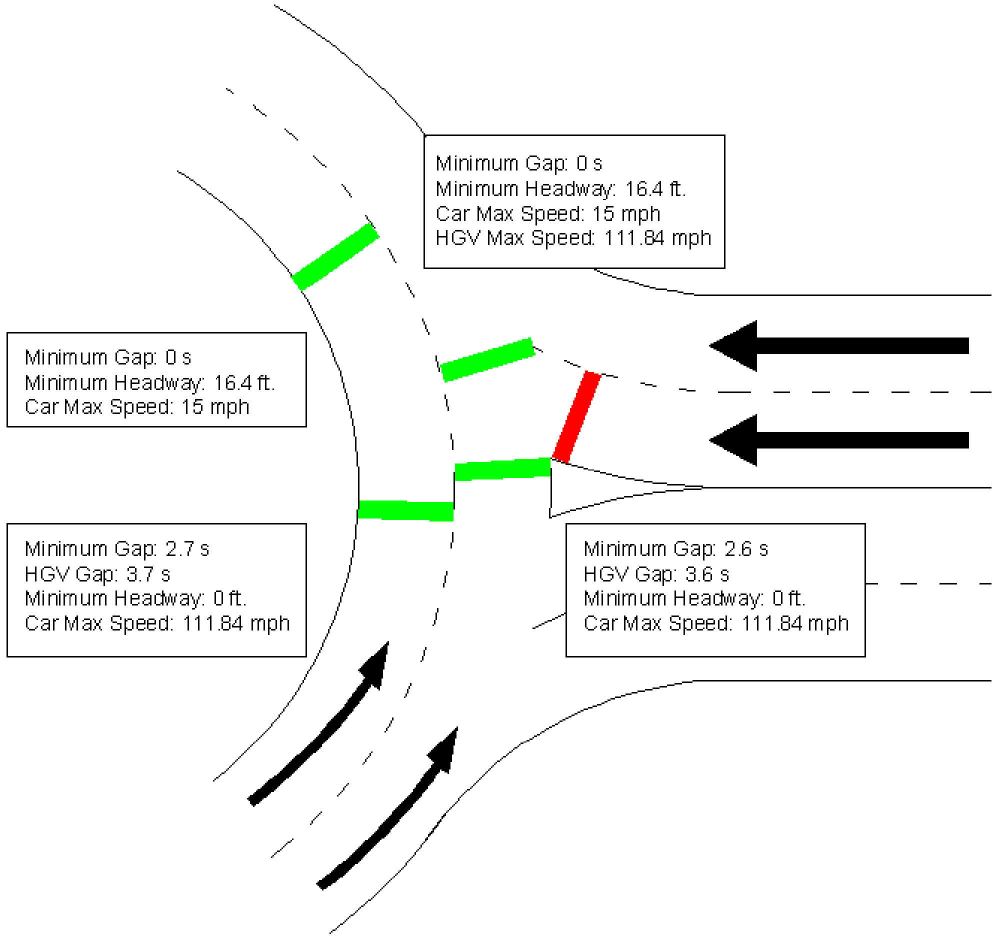


Figure 9-12. Roundabout priority rules (continued)

For the proposed roundabout, typical gap time included the following times: 0, 1.8, 2.6, 2.7, 3.6, and 3.7, as shown in Figure 9-13. The gap time depended on whether the conflict area was downstream or upstream of the red stop line and on which lane the yielding vehicle was in. Additionally, the minimum headway for each of the conflict points included both 0 minutes, if the conflict point was upstream, and 16.4 minutes. Finally, the priority vehicle's maximum speed was taken into consideration at these conflict points. If the priority vehicle upstream was traveling slower than 11.84 mph, then the vehicle was taken into consideration. If the priority vehicle was downstream of the red stop line, the vehicle would be taken into consideration if it was traveling slower than 15 mph. To accomplish these rules for both lanes, the priority rules were coded twice for each approach, with distances staggered at conflict points. For priority rules, the red stop line and green conflict point must not intersect or overlap; otherwise, the yielding vehicle will be waiting on itself and unnecessary queues and delays will occur. The end result of applying four sets of priority rules is illustrated in Figure 9-13.

Figure 9-13. Proposed roundabout priority rules

Reduced Speed Areas and Desired Speed Decisions. To simulate existing field speed conditions, VISSIM allows for speed control through the roundabout, since most drivers slow down while in the roundabout usually due to its smaller radius. Since the program tries to have vehicles travel at the desired speed distribution, it would be unrealistic to have vehicles traveling through the roundabout at 28.6 to 38.2 mph. The reduced speed areas were placed before the yield point on the approach leg, allowing vehicles to slow as they approach the priority rules. Additionally, reduced speed areas were placed within the roundabout, forcing vehicles to traverse the roundabout at a much slower speed. As shown in Figure 9-14, green boxes highlight links and connectors where the reduced speed zone is forced. Additionally, the "20,20,20" label presents the default reduced speed for all vehicles (cars, heavy vehicles, buses), which is 12.4 to 15.5 mph.

Opposite a reduced speed area are speed decision points, illustrated in Figure 9-14 by pink bars. These points were placed on the roundabout exits at a point shortly after a vehicle would exit the roundabout, allowing the vehicle to accelerate to the normal corridor speed distribution of 29.8 to 36 mph.

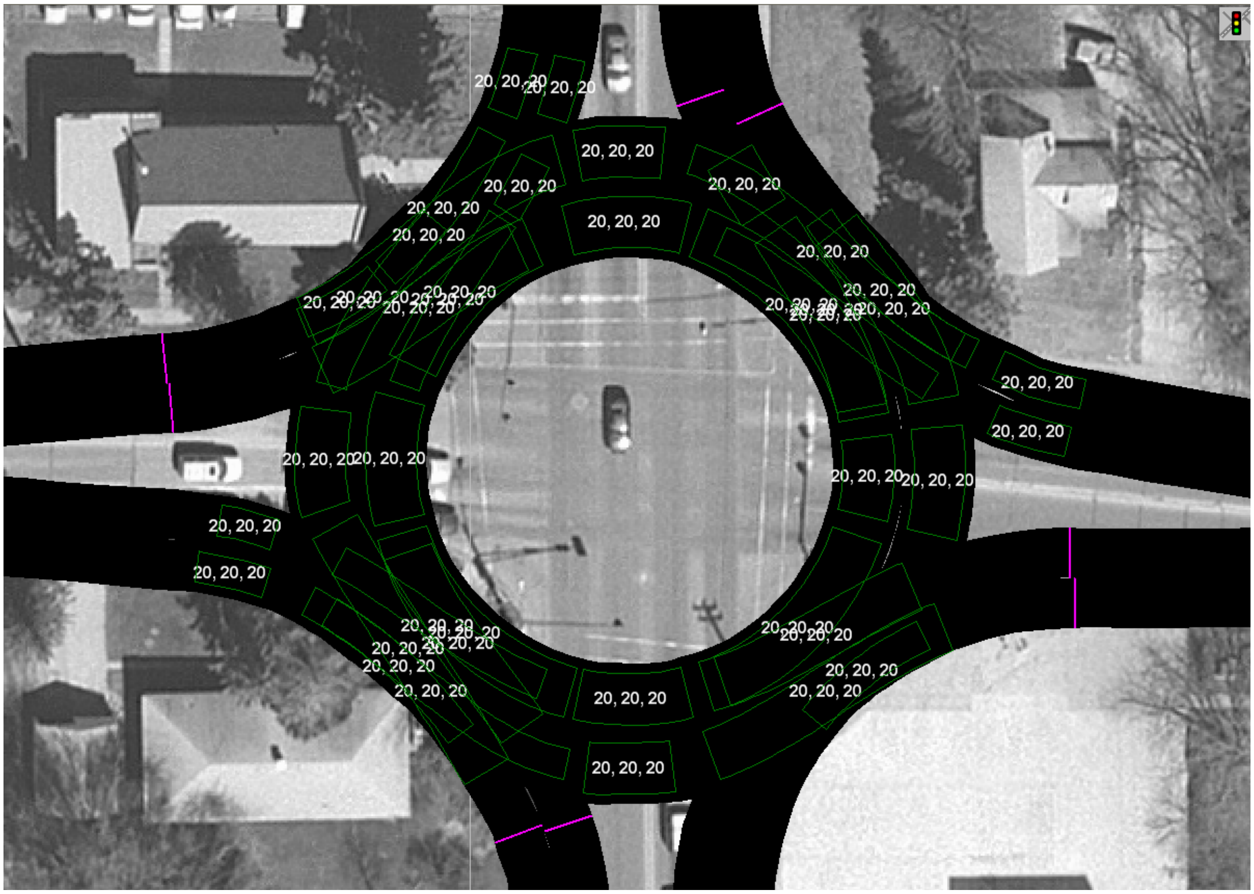


Figure 9-14. Roundabout reduced speed areas

Driver Behavior. Because there is so much happening visually at the proposed roundabout at any given point, the number of observed vehicles (or decisions) that the yielding driver can see at once in the network was increased from two to three after a recommendation from PTV America. Inc. This setting, although it cannot be visualized in the model more accurately, represents field conditions and allows drivers to make quicker and more accurate decisions at the yield point. Furthermore, by changing the driver behavior at the roundabout, an overall decrease in queuing was experienced. This setting was applied to the links within the roundabout and the links directly connecting to the roundabout on each approach lane.

Volume and Routing Decisions. Using the intersection turning movement volume obtained from the City of Ames, entry points were created at the far north and south of the corridor, and east-west entry points were created at every street that included a signalized intersection. Because the intersection volumes were not collected on the same day or time, the unsignalized streets between signalized intersections were used to load or unload vehicles into the corridor to achieve the recorded volumes at each signalized intersection. Furthermore, driveways directly connected to the corridor were not considered in this study.

Once the turning movement volume was coded into the model, routing decisions were created to give VISSIM a percentage or exact volume of how many vehicles per hour made a left turning, thru, or right turning movement. Although VISSIM is based on a stochastic model, there can be some control as to how many vehicles the programmer would like to have travel along a certain direction or path. A routing decision was placed before every possible location where a vehicle would have the option to travel more than one way. Figure 9-15 illustrates how routing decisions work, showing in this case a left turning movement from the south using the inside roundabout lane. The yellow line in the figure shows a possible route for a northbound vehicle. In a typical approach to a signalized intersection, a vehicle would have the option of making a left turning, thru, or right turning movement, depending on how many lanes are available (e.g., double left, triple thru, etc.). Using the dialog window, the number of vehicles for each routing decision was coded in for the evaluation time. Depending on the design of the intersection or roundabout with a corresponding vehicle volume, VISSIM may or may not reach the desired turning movement volume, which could result in an overall bad design or poor signal timing.

Figure 9-15. Roundabout left turning northbound routing decisions

Summary of Findings. Once the routing decisions were put into place, the model was complete. The 3-D view can be seen in Figure 9-16. Before implementing the proposed roundabout, the City of Ames tried to coordinate the corridor with various types of traffic signals, ranging from fixed to fully actuated. Unlike larger metropolitan areas, the city has not coordinated this corridor using fiber optics, but rather uses three signal plans that are coordinated north and south separately, using signal timing offsets ranging from 20 to 80 seconds.

The first model to be evaluated with the City of Ames signal plan was the existing condition model, which had a split-phase traffic signal at 13th Street and Grand Avenue. The city used this intersection as the zero point of offset coordination, and the other four intersections were offset between 20 and 80 seconds. With the Synchro program, which the city uses for signal timing, the offsets were adjusted slightly based on vehicle speed distribution.

Figure 9-16. Roundabout at 13th and Grand Avenue in operation

The second model, which was the model that proposed a roundabout at 13th Street and Grand Avenue, revealed another issue. This model showed that the existing signal coordination allowed platoons of vehicles to arrive at the roundabout at the same time from the north and south, creating pockets of congestion at the intersection. To overcoming this, the signal timing at 20th Street and 9th Street was thrown out of coordination by adjusting the offset and maximum green time so platoons would arrive in sequence instead of at the same time.

The third model that was evaluated involved a signalized intersection with permitted and protected left turning lanes, as described in the following section.

Left Turning Lane Model Structure

In addition to a proposed roundabout at the intersection of 13th Street and Grand Avenue, the city investigated the addition of permitted and protected left turning lanes Figure 9-17 shows one approach (the other three are the same), which shows a left turning lane with 80 ft of storage.

The proposed intersection was created using the same techniques described above for the roundabout model structure (Figure 9-18). Along with the basic link and connector setup and routing decisions, some features were added, including right turn on red, permitted left turning, and vehicle detectors. Similar to the priority rules described above for roundabouts, priority rules were created to stop a left turning vehicle from crashing into an oncoming thru vehicle when it had a green light indicator. The priority rules, as shown in Figure 9-19, made a vehicle wait for the oncoming vehicle if the following conditions were not met: minimum gap time of 6.0 seconds, minimum headway of 16.4 ft, and a maximum speed of 111.8 miles per hour. In addition to the priority rules, right turn on red was coded in to allow vehicles to make a right turn on red if there were no oncoming vehicles in the perpendicular thru flow through the intersection.

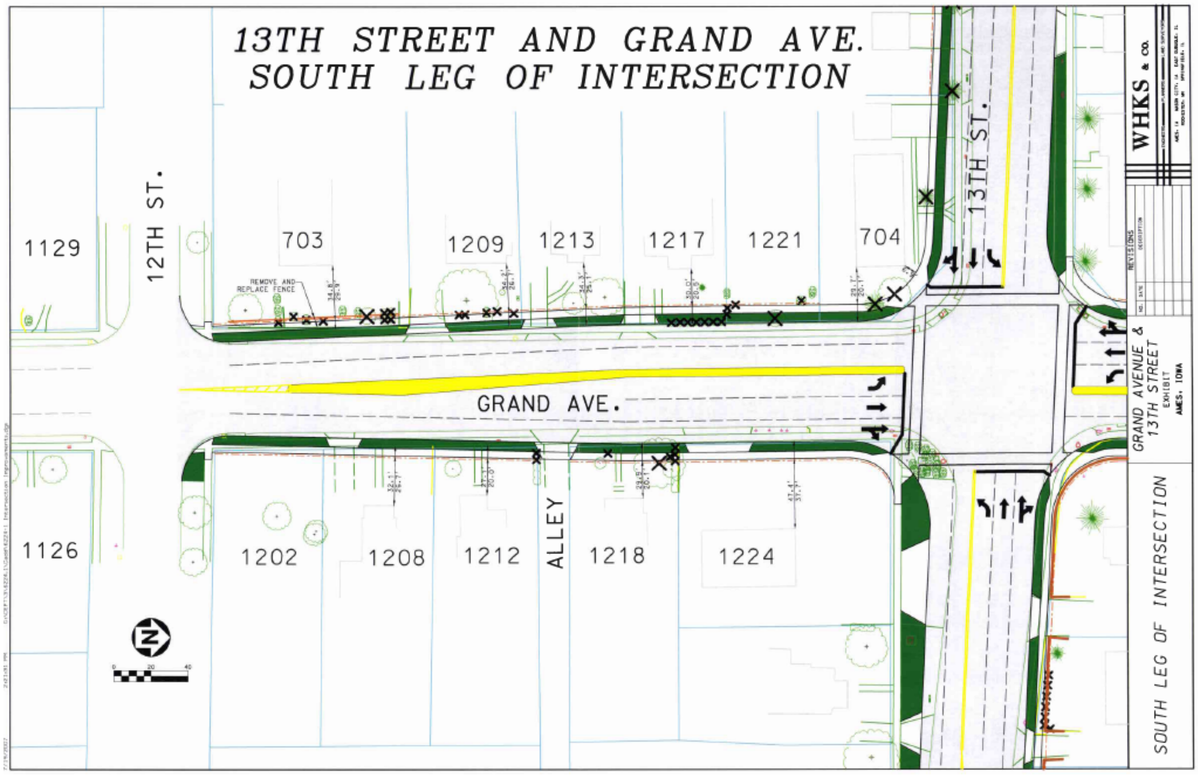


Figure 9-17. Left turning lane, eastbound approach, at 13th Street and Grand Avenue

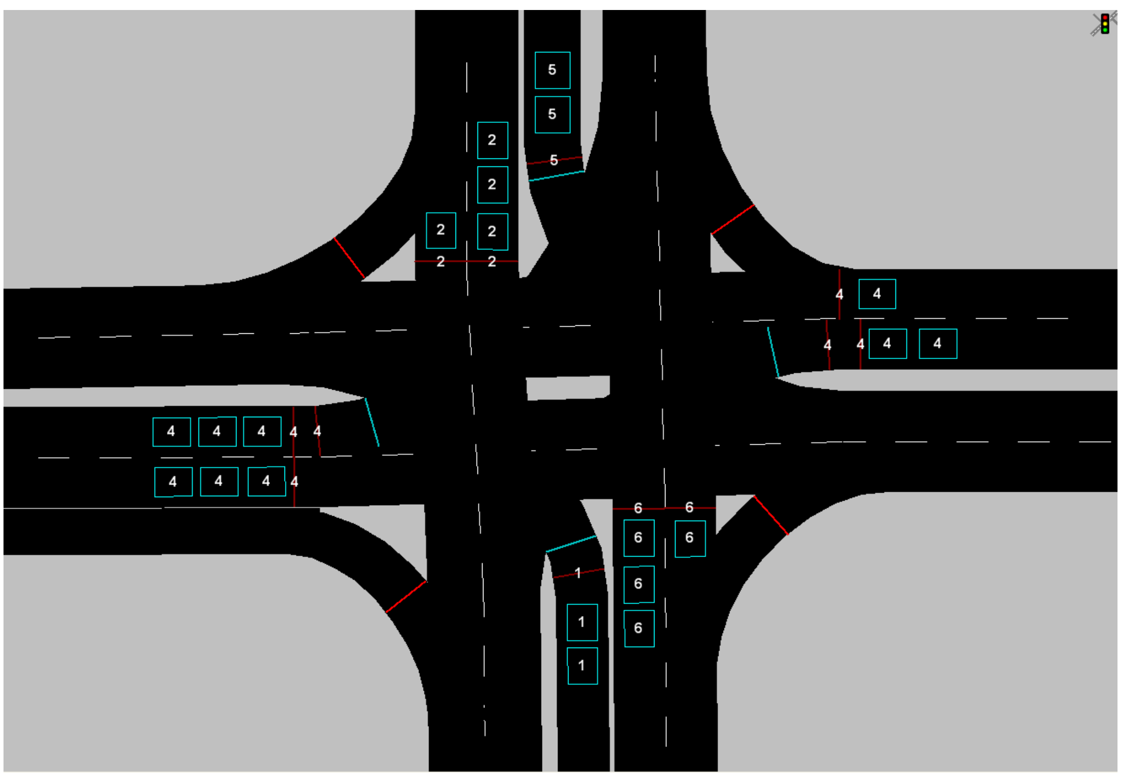


Figure 9-18. Intersection layout, right turn on red, vehicle detectors, and signal bars

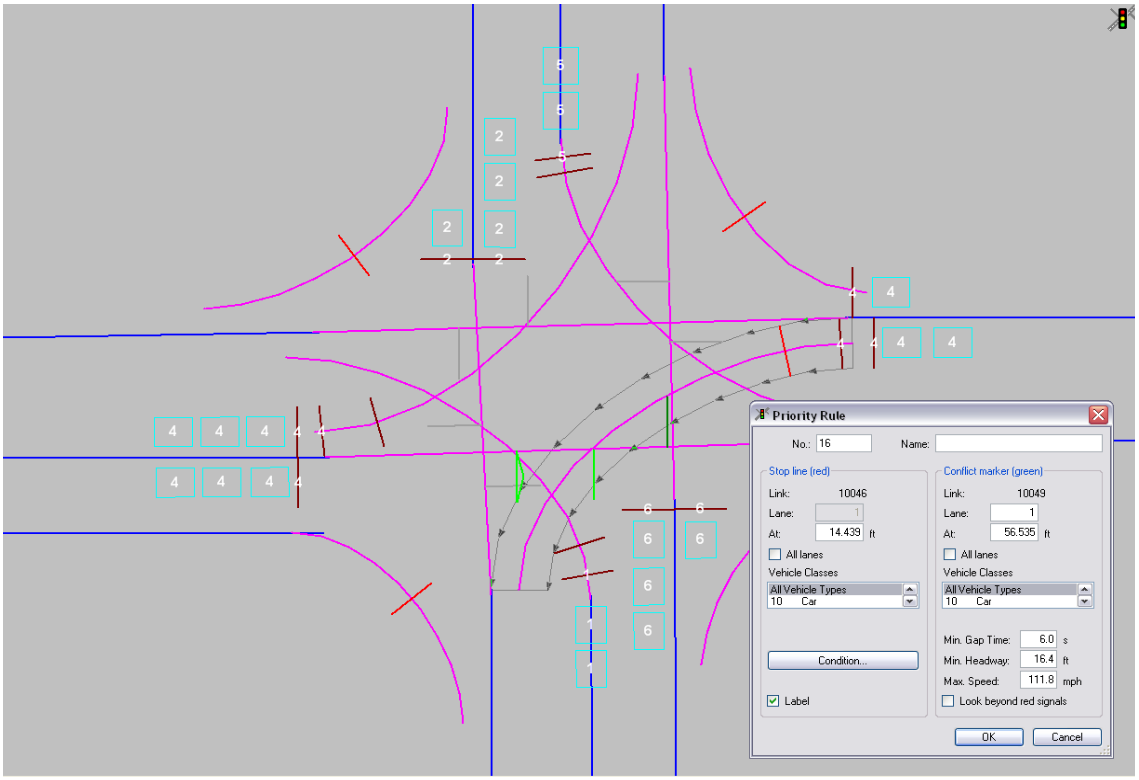


Figure 9-19. Left turn priority rules

Signal Timing. Using the turning movement volumes for the intersection of 13th Street and Grand Avenue, the initial signal timing plan was created in Synchro 6 based on the given evening peak-hour turning movement volumes. The plan was then reproduced in VISSIM's NEMA phasing virtual signal controller, as illustrated in Figure 9-20. The virtual controller, which follows the same principals as a ring and barrier–based intersection traffic controller, is a vital part of the modeling process. It allows vehicles to react to various types of vehicle detectors, multiple signal plans, vehicle recalls, max phasing, overlaps, or signal coordination between intersections. Additionally, VISSIM allows the implementation of right turn on red, depending on the signal phase; U-turns; or even forced red light running.

Once the signal controller was programmed, signal stop bars were placed at the intersection and assigned a number corresponding to the movement NEMA phase in the signal controller. For example, the southbound approach has two NEMA phases, 2 and 5. Typically, all thru movements are even numbers and left turning movements are odd numbers. Also typically, a signalized intersection has eight NEMA phases, unless the intersection has more than four approaches, preemption, or a light rail running through it. Once the stop bars on each lane are in place, signals, arms, and poles are created and added to the model, as shown in Figure 9-21. Figure 9-22 illustrates the new intersection in operation within the program. The pink cars are coded probe vehicles, which will be explained in the analysis section below.

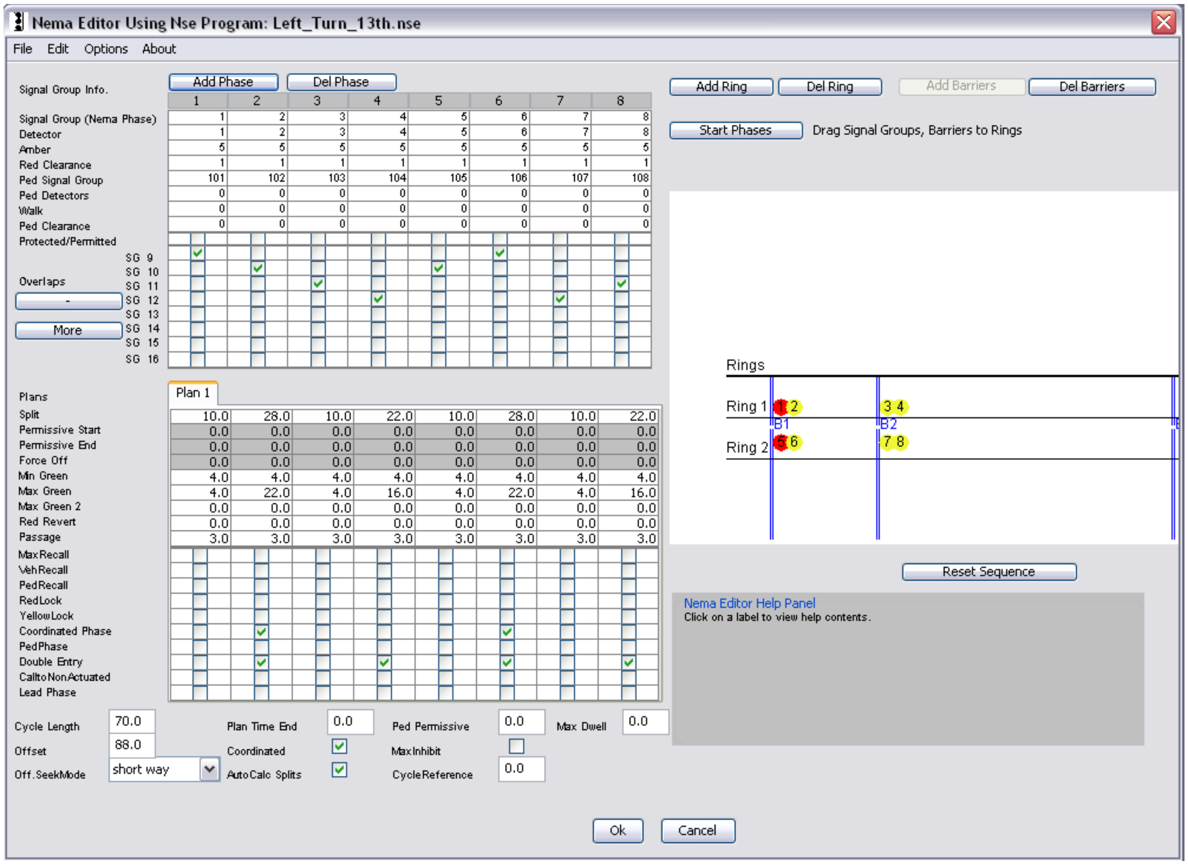


Figure 9-20. Virtual NEMA signal controller

Figure 9-21. Final intersection design for 13th Street and Grand Avenue

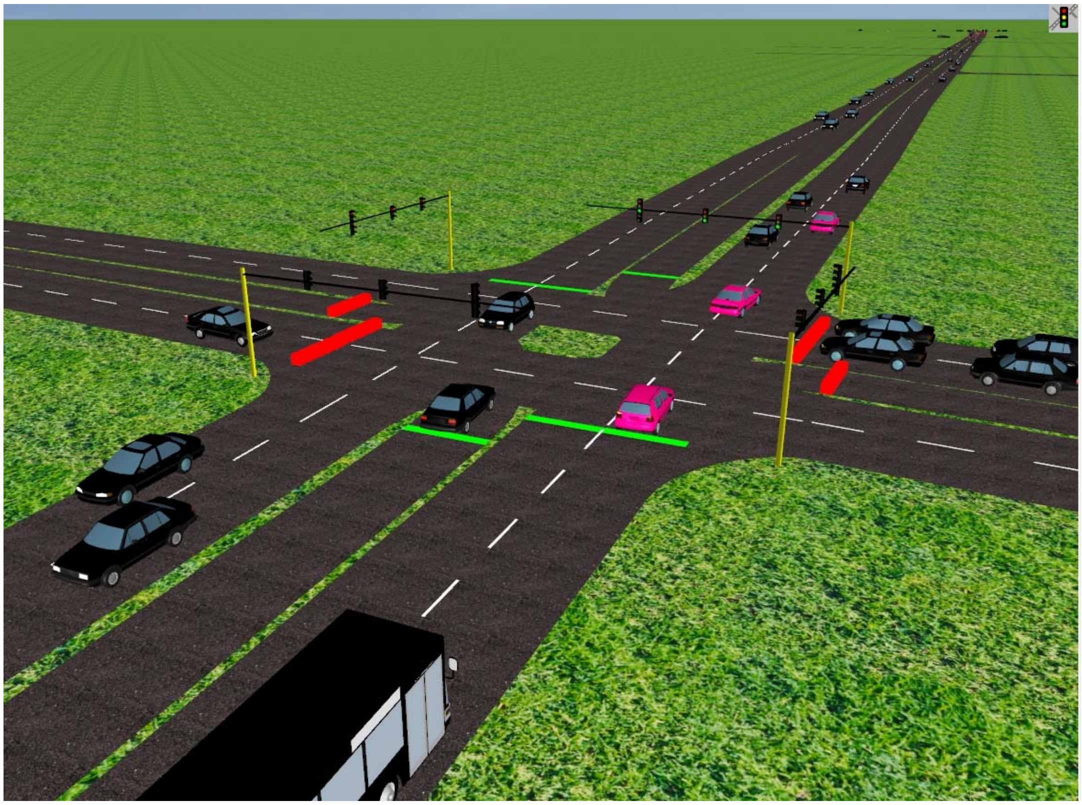


Figure 9-22. 13th Street and Grand Avenue with signals and left turning lanes

9.1.5. Evaluation

VISSIM provides multiple evaluation tools to analyze network models based on time set parameters. For the 13th Street and Grand Avenue model, a 15 minute loading window was allowed before the analysis began for approximately one hour of evening peak-hour traffic. Three types of test were run during this time, including travel time of vehicles traversing the corridor from either the north or south end of the model, average delay and stopped delay of these vehicles, and extrapolation of probe vehicles that entered and exited the network at each end. The data collection points were placed between the two farthest north and south signalized intersections, allowing turning movement vehicles entering the intersection to be recorded.

Coded probe vehicles were implemented in this model to investigate the speed and acceleration of a percentage of the total number of entering vehicles at the farthest southern and northern entry points of the corridor. Probe vehicles, unlike regular input vehicles, were coded to travel the corridor from north to south or south to north, overriding the stochastic turning movements VISSIM allows other vehicles to make. For this investigation, sample sizes of 25% of the total number of entering vehicles at the northernmost or southernmost point were used. Figures 9-23 through 9-30 show VISSIM's evaluation results for each type of vehicle group and each type of network treatment implemented.

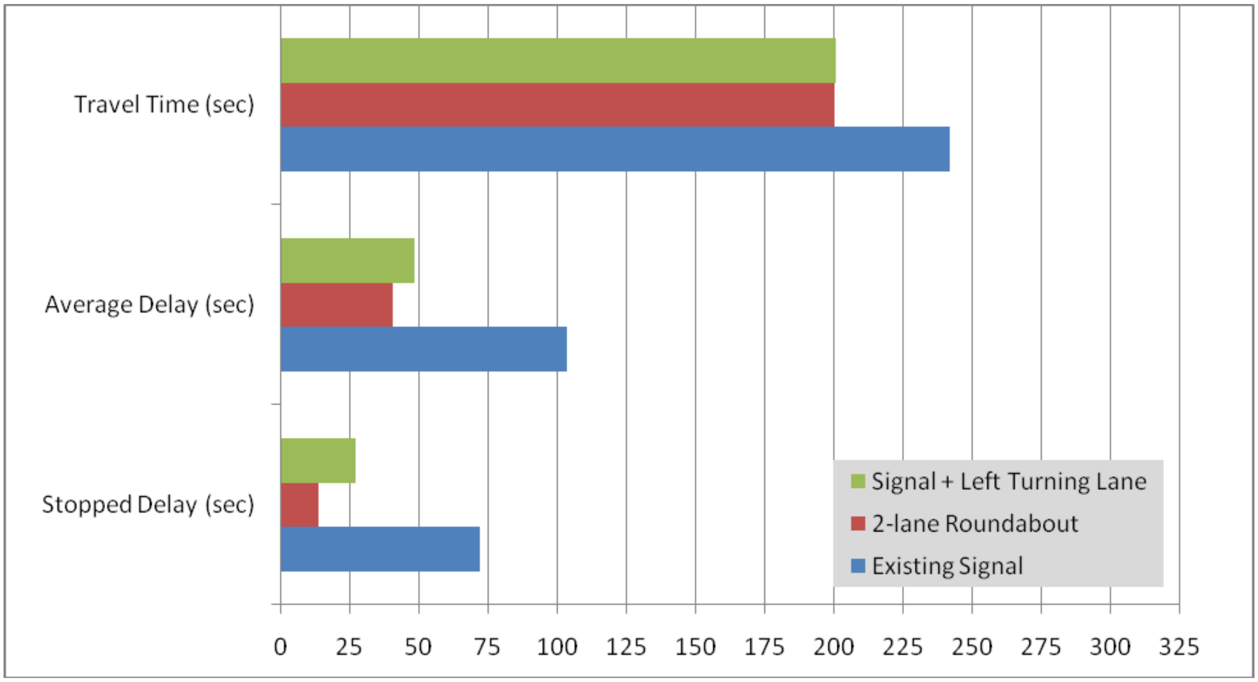


Figure 9-23. Northbound probe vehicles summary

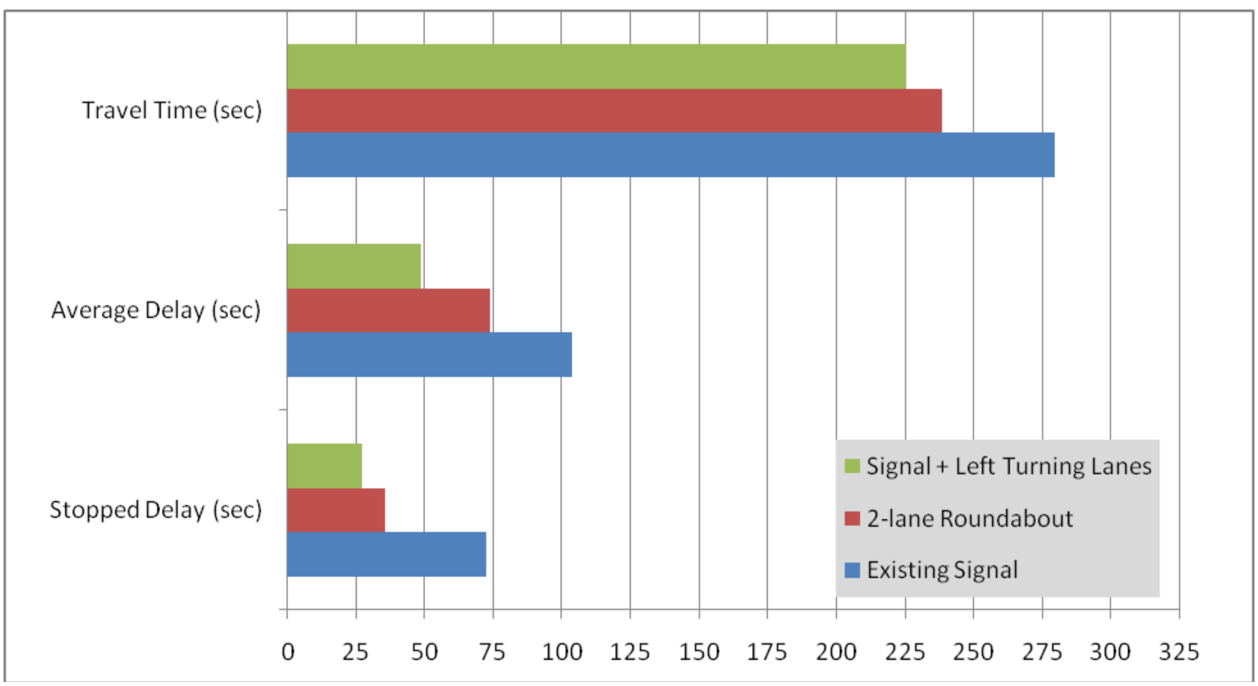


Figure 9-24. Southbound probe vehicles summary

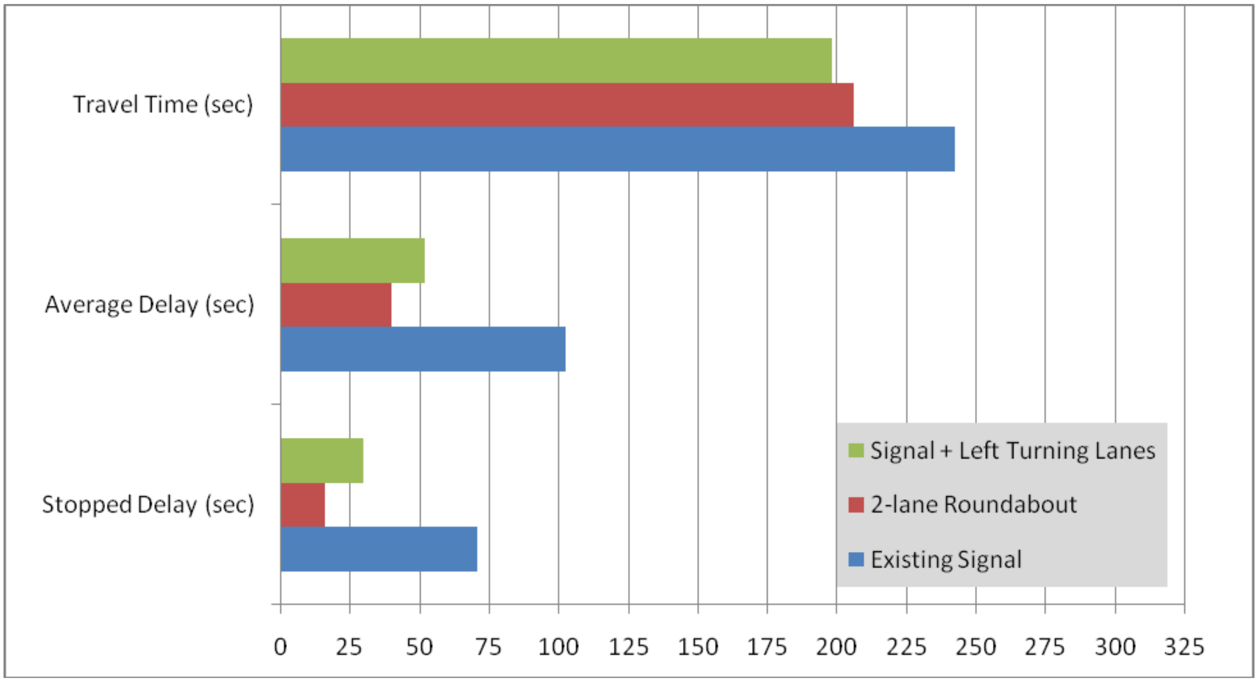


Figure 9-25. Northbound cars summary

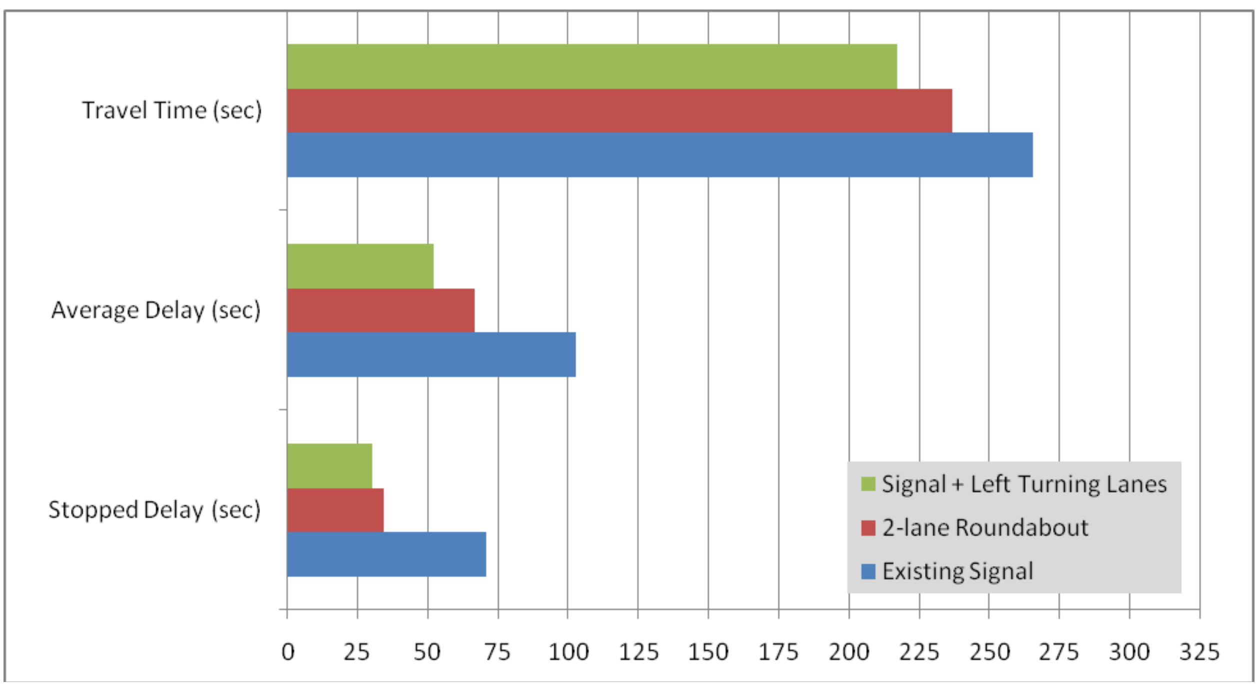


Figure 9-26. Southbound cars summary

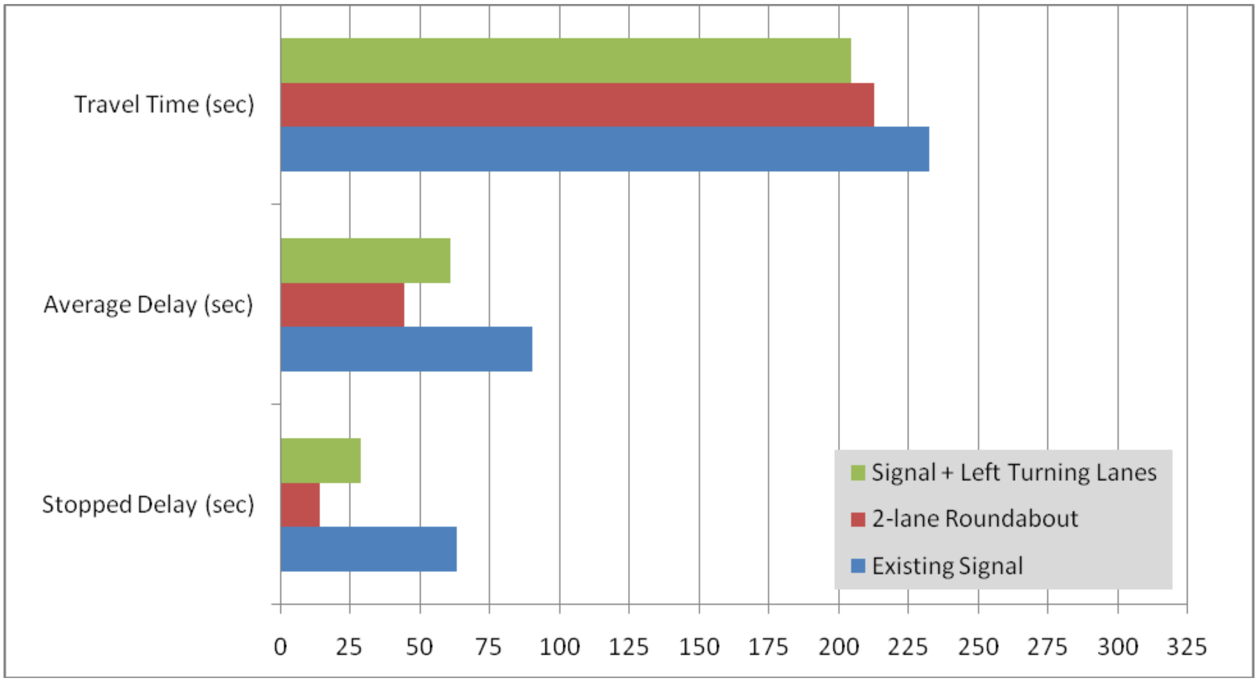


Figure 9-27. Northbound heavy vehicles summary

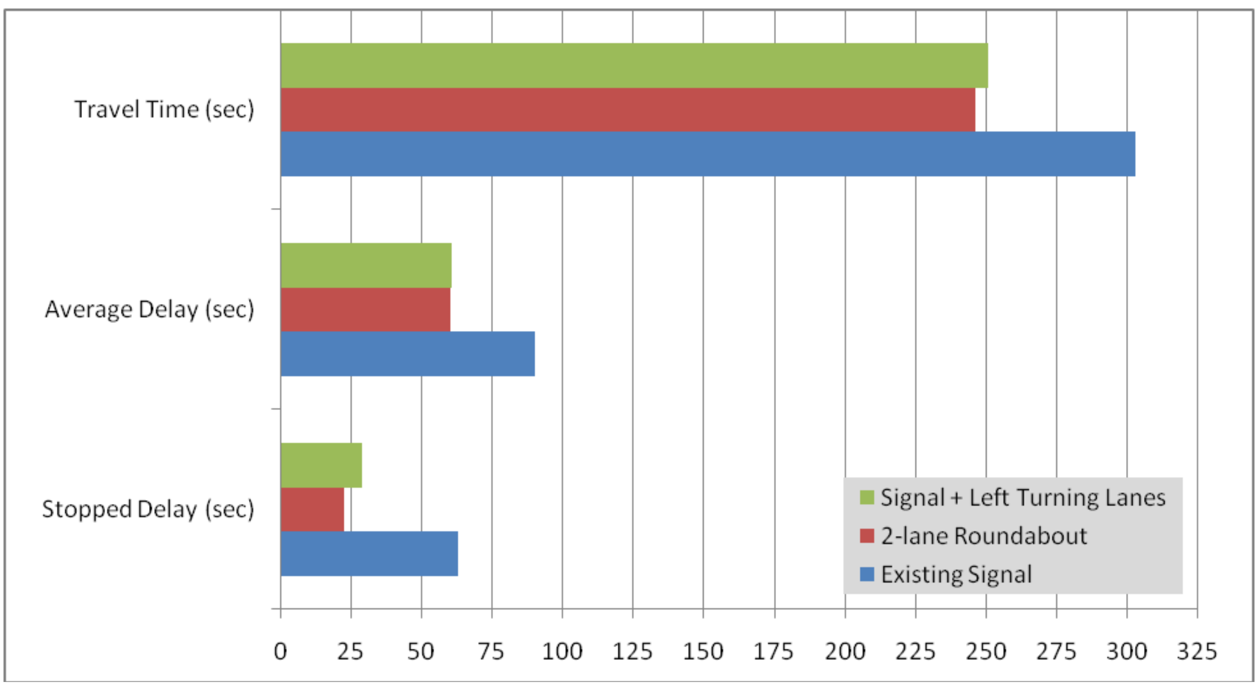


Figure 9-28. Southbound heavy vehicles summary

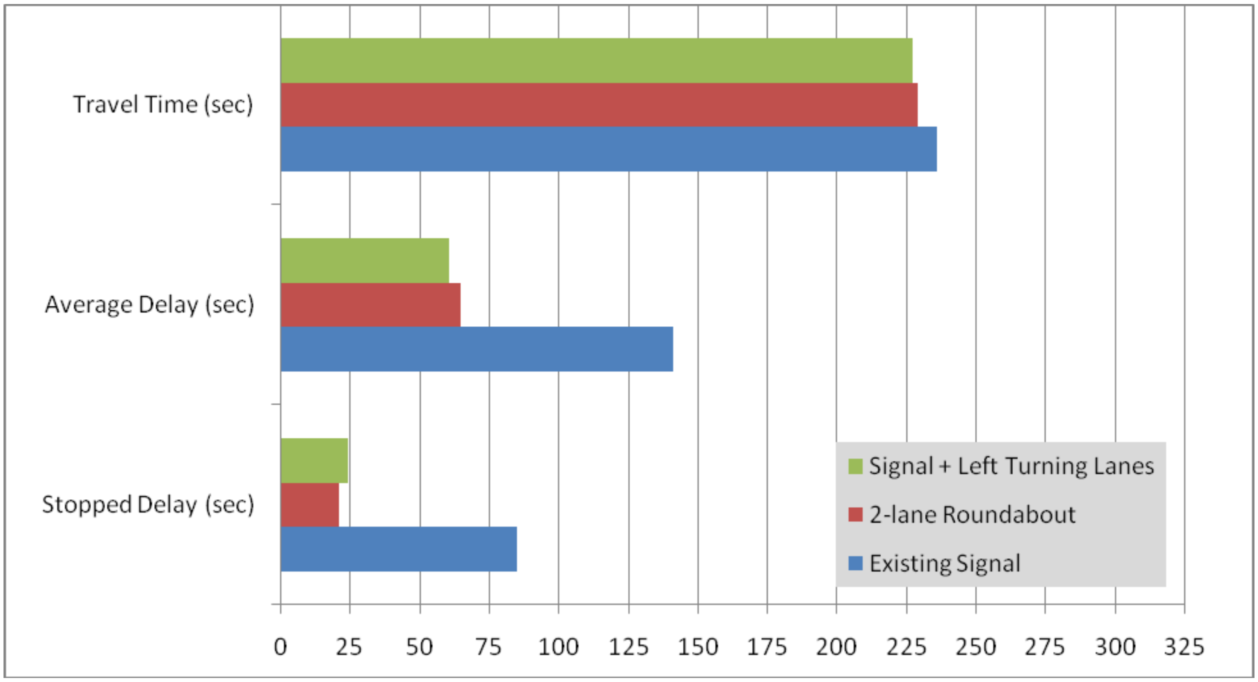


Figure 9-29. Northbound bus summary

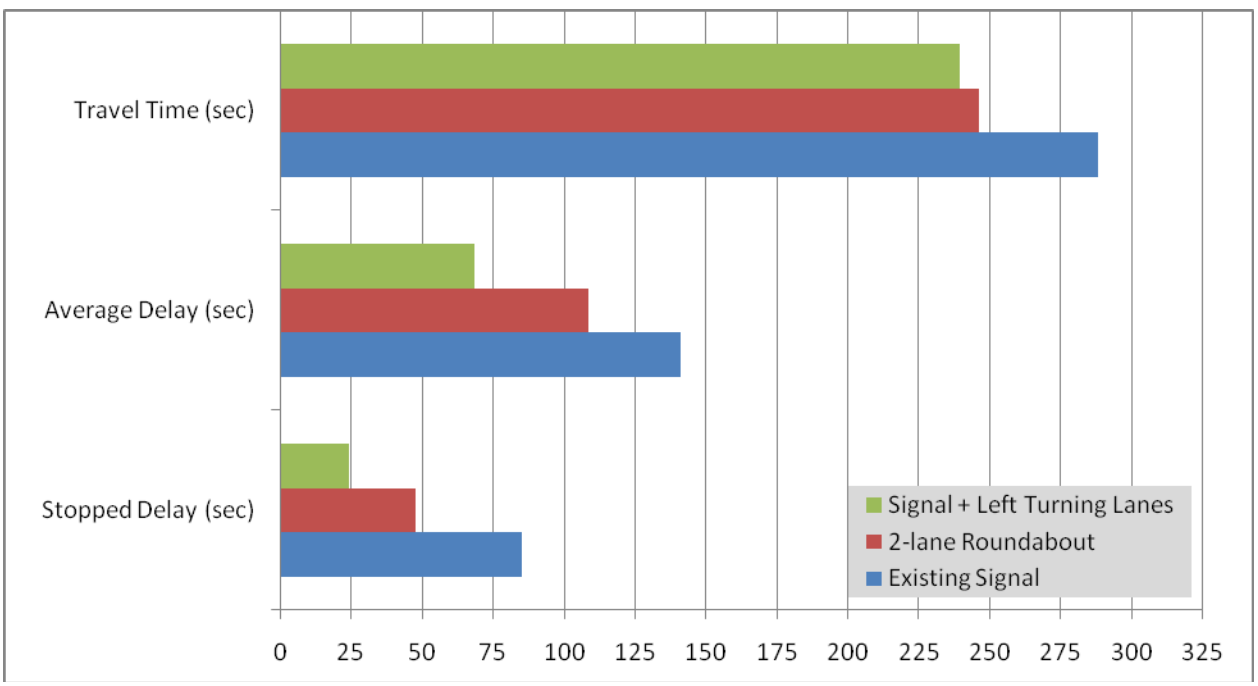


Figure 9-30. Southbound bus summary

9.1.6. Key Findings in Operations

As illustrated in Figures 9-23 through 9-30, southbound traveling vehicles experienced higher travel time, delay, and stopped delay time than the northbound traveling vehicles. It can also be seen that both operational improvements, including installing a two-lane roundabout or an upgraded intersection with better signal timing and a dedicated left turning lane on all approach legs, showed improvements in travel time, average delay, and stopped delay. Due to the nature of the corridor and the geometry of the signalized intersections, coordinating the signals through the corridor may further increase operations. However, this situation was not tested.

9.2. US 69 Ankeny, Iowa Corridor Study

9.2.1. Background

The city of Ankeny, Iowa, is a thriving city, located in Polk County just north of Des Moines, west of Interstate 35, and along US 69. Ankeny is a rapidly growing suburban community with a population growth rate that far exceeds that of the State of Iowa or of Polk County. Between 1990 and 2006, the population of Ankeny more than doubled, increasing from approximately 18,500 to almost 39,000 residents. In addition, Ankeny has historically been a major “bedroom community” for Des Moines, and it is the largest northern suburb of the Des Moines metropolitan area. In addition, the community is home to many commercial businesses and a regional educational instate, including the rapidly growing John Deere assembly plant and a campus of Des Moines Area Community College, just west of US 69 (Ankeny Boulevard).

Today, US 69 through south Ankeny is a major arterial corridor that is signal controlled, with many local retail businesses and residential areas located adjacent to the corridor (Figure 9-31). During peak hours, this section of the corridor operates at near capacity with commuter traffic. Adding to the congestion are vehicles entering and exiting businesses without a two way left turning lane, making this intersection an excellent candidate for access management improvements.

Figure 9-31. Present day South Ankeny Boulevard (US 69)

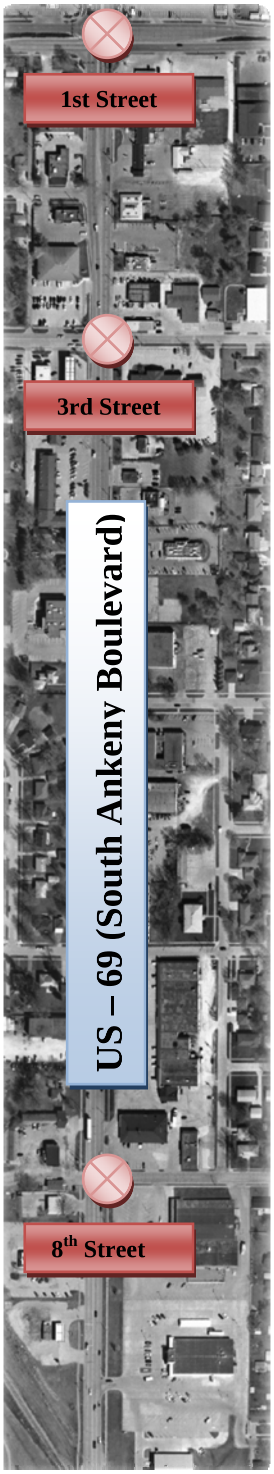


Figure 9-32. South Ankeny Boulevard in Ankeny, Iowa

9.2.2. Study Area

South Ankeny Boulevard

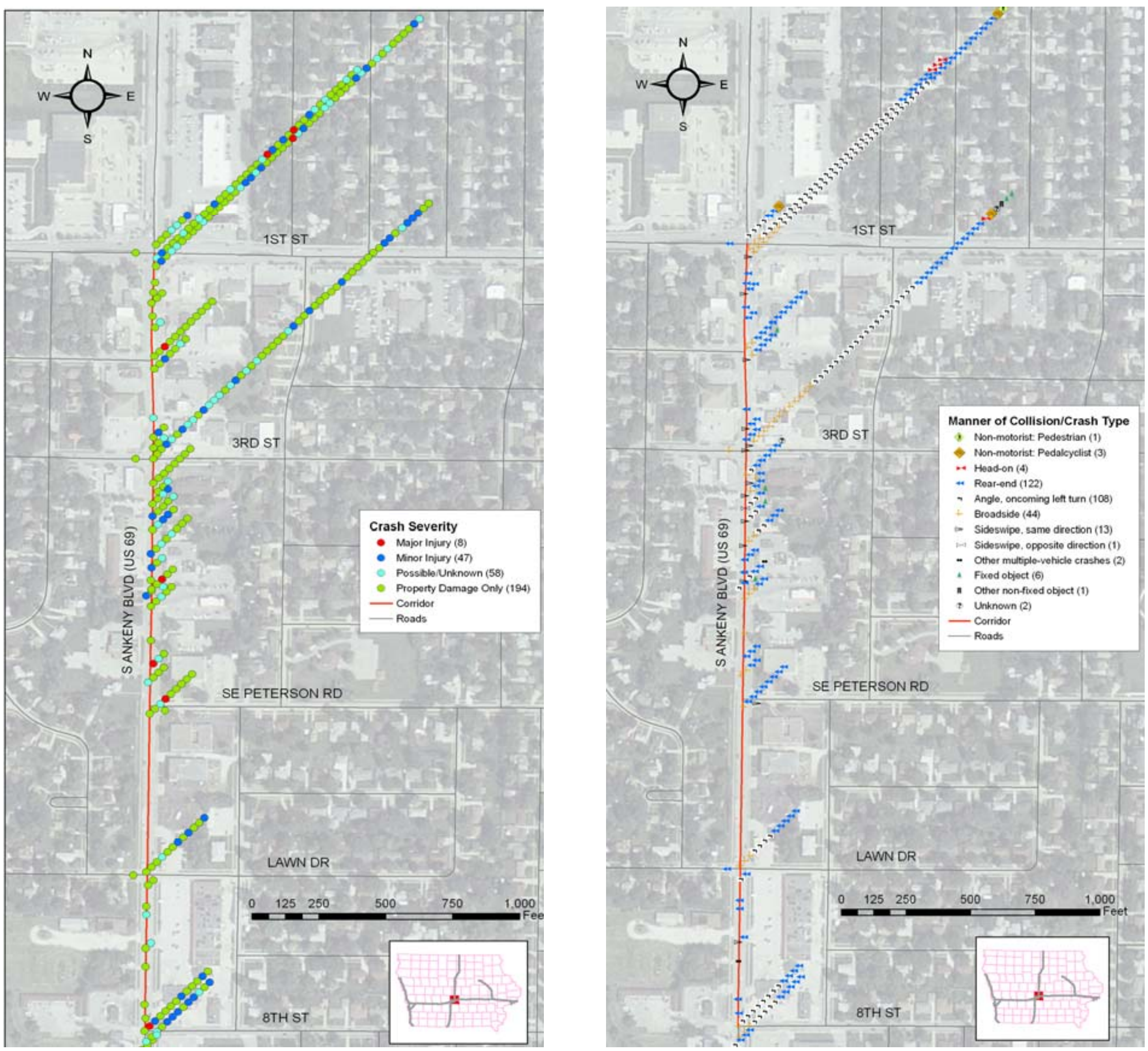
The area of focus for the first study includes the southern section of Ankeny Boulevard (US 69), bounded by 1st Street and extending south to Southeast 9th Street (Figure 9-32). This section is approximately 0.72 miles and runs parallel to Interstate 35, serving as the city's second primary commuting route to the Des Moines metropolitan area. The majority of the corridor has commercial development, including food and recreational sales establishments, with dense residential areas adjacent to the commercial properties. Three signalized intersections are at 1st Street, South 3rd Street, and Southeast 8th Street. The Iowa Department of Transportation reports a vehicular volume of 17,275 to 22,000 ADT within the study area, with its highest turning movements during the morning and evening peak hours. The study corridor consists of a four-lane curb-and-gutter arterial with no two-way left turning lane into multiple business driveways. Along the corridor north of 1st Street (the northern part of the corridor), access management strategies were implanted in the 1990s, including backage roads, a raised center median and driveway consolidation, as shown in Figure 9-33.

North of the study corridor are larger retail businesses and Ankeny High School. The following sections briefly describe the three signalized intersections within the study corridor. The vast majority of traffic consisted of passenger vehicles, including cars, vans, and SUVs.

9.2.3. Crash Experience

Crashes by severity and type along the study corridor are shown in Figure 9-34. As illustrated in the crash severity map, many of the reported crashes occurred at the major intersections along the corridor, with 1st Street and South Ankeny Boulevard experiencing the most. However, it should be noted that three major injury crashes and many minor injury crashes occurred midblock, raising the possibility that lack of access management might have played a role in the crashes. From the crash type map shown in Figure 9-34, it can be seen that these midblock crashes were either rear-end or angle crashes, meaning that these crashes occurred due to vehicles blocking the left lane in either direction and misjudging the oncoming vehicle gap, or they occurred due to a dangerous situation in which the vehicle in behind could not stop while waiting for a gap. Due to the increased numbers of crashes located within the many midblocks of the corridor, this study area is an excellent candidate for multiple access management strategies.

Figure 9-33. North Ankeny Boulevard with implemented access management



Crash Severity — Crash Type

Figure 9-34. Crashes along the Ankeny study corridor

9.2.4. Signalized Intersections

1st Street and Ankeny Boulevard (US 69)

Considered one of the busiest intersections in Ankeny, the intersection of 1st Street and Ankeny Boulevard (Figure 9-35) is an important intersection of two major arterials that run throughout the length of the city. The intersection is located at the furthest point north in the study area. Noticeable peak-hour volumes can be found on all approaches, with a typical queue of around 20 to 25 vehicles. All approaches have permitted/protected left turning lanes, and the westbound approach has two left turning lanes. The intersection is surrounded by commercial development, including a small and large commercial strip mall, a gas station, and a florist. The business developments adjacent to this intersection have multiple driveways located where vehicles might queue. However, all left turning movements on all four approaches are bounded by a raised median so cross-traffic will not get stuck in the opposing traffic lanes. The intersection signal timing is given in Table 9-6.

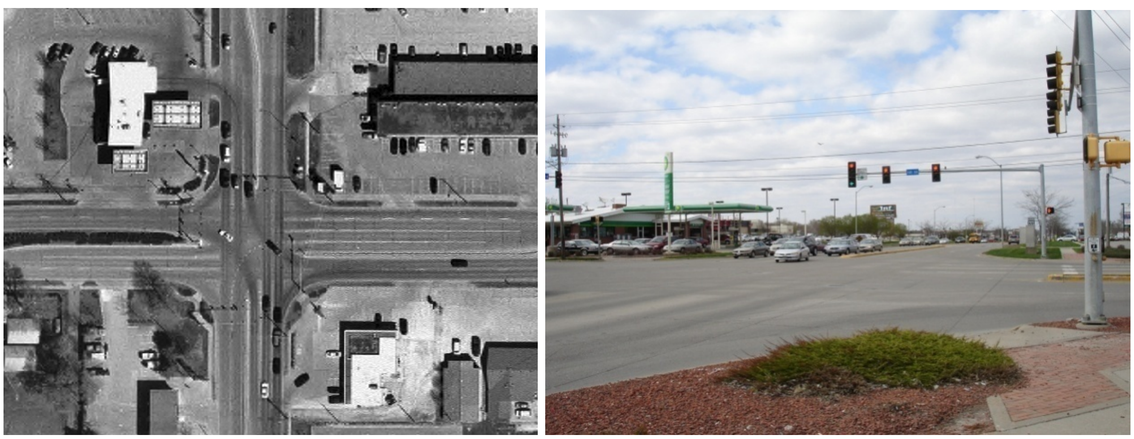


Figure 9-35. 1st Street and Ankeny Boulevard (left) and northbound view (right)

Table 9-6. 1st Street existing signal timing for South Ankeny Boulevard and 1st Street

	Northbound			**Southbound**			**Eastbound**			**Westbound**		
NEMA Phasing	7	4*	4*	3	8*	8*	1	6*	6*	5	2*	2*
Lane Config.	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	2x Left	Thru	Right
Volume (veh./hr.)	260	546	155	211	696	161	195	453	320	183	376	150
Cycle length	160	160	160	160	160	160	160	160	160	160	160	160
Offset	22	22	22	22	22	22	22	22	22	22	22	22
Passage	2	1	1	2	1	1	2	1	1	2	1	1
All-red clearance	1	1	1	1	1	1	1	1	1	1	1	1
Amber phase	3.5	4	4	3	4	4	3	4	4	3	4	4
Min green	7	9	9	7	9	9	7	8	8	7	8	8
Max 1 green	15	30	30	15	30	30	15	30	30	15	30	30
Max 2 green	15	50	50	15	50	50	15	50	50	15	50	50
Total split	19.5	55	55	19	55	55	19	55	55	19	55	55

* Fiber actuated-coordinated

South 3rd Street and South Ankeny Boulevard (US 69)

The intersection of South 3rd Street and South Ankeny Boulevard, illustrated in Figure 9-36, is the second signalized intersection in the corridor study. Two neighborhood collector streets intersect Ankeny Boulevard, with the eastbound approach leading to Ankeny's original city center. Adjacent to this intersection are residential areas with small businesses, including two banks with a drive-through option, a gas station, and an apartment management agency. The intersection is located three blocks south of the signalized intersection of 1st Street and Ankeny Boulevard. The existing signal timing is given in Table 9-7.

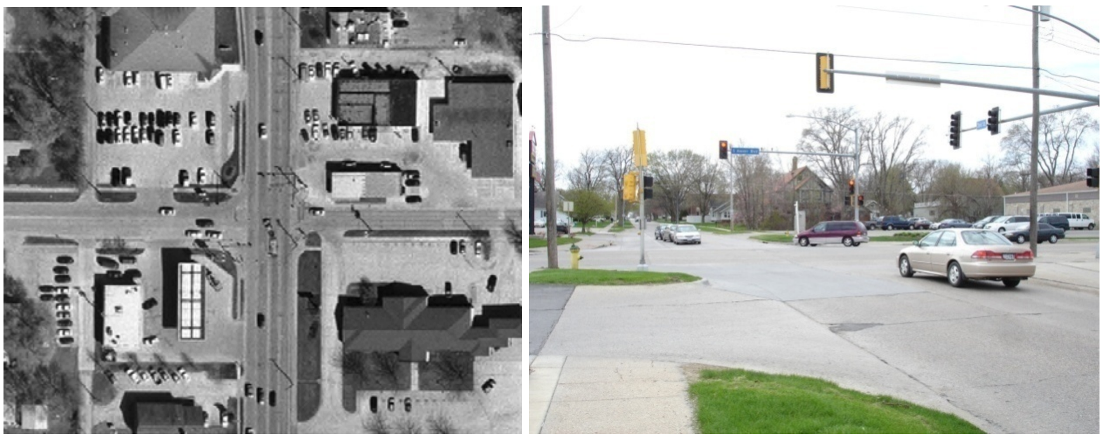


Figure 9-36. South 3rd Street and South Ankeny Boulevard (left) and westbound view (right)

Table 9-7. South 3rd Street existing signal timing at South Ankeny Boulevard and South 3rd Street

	Northbound		Southbound		Eastbound		Westbound	
NEMA Phasing	2*	2*	6*	6*	4	4	8	8
Lane Config.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.
Volume (veh./hr.)	338	368	479	517	123	108	102	144
Cycle length	110	110	110	110	110	110	110	110
Offset	29	29	29	29	29	29	29	29
Passage	4	4	4	4	4	4	4	4
All-red clearance	1	1	1	1	1	1	1	1
Amber phase	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Min green	40	40	40	40	20	20	20	20
Max 1 green	78.5	78.5	78.5	78.5	44.5	44.5	44.5	44.5
Total split	83	83	83	83	49	49	49	49

* Fiber actuated-coordinated

South 8th Street and South Ankeny Boulevard (US 69)

Located 0.5 miles south of 3rd Street, the intersection of South 8th Street and South Ankeny Boulevard (Figure 9-37) provides residents east of the study corridor a safe location to enter. Although this signal might seem insignificant in the field, South 8th street, along with 1st Street, allows a direct connection to Ankeny's other busy parallel running street, Southeast Delaware Avenue. The intersection is surrounded by commercial businesses, including a big box store on the south, multiple restaurants on the north and southwest sides, and a small commercial business on the northwest side. It was noted during a field visit that many of these business driveways are within close proximity of the intersection, with one being less than 20 ft away from the curb radius. Additionally, this intersection does not provide a protected left turning phase for southbound Ankeny Boulevard traffic onto South 8th Street, lending itself to occasional backups during morning and evening peak hours. The existing signal timing is given in Table 9-8.

Figure 9-37. South 8th Street and South Ankeny Boulevard (left) and northbound view (right)

Table 9-8. South 8th Street existing signal timing at South Ankeny Boulevard and South 8th Street

	Northbound		**Southbound**		**Eastbound**		**Westbound**	
NEMA Phasing	2*	2*	6*	6*	4	4	8	8
Lane Config.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.	L Shrd.	. R. Shrd.
Volume (veh./hr.)	490	596	275	312	17	17	5	5
Cycle length	90	90	90	90	90	90	90	90
Offset	59	59	59	59	59	59	59	59
Passage	4	4	4	4	4	4	4	4
All-red clearance	1	1	1	1	1	1	1	1
Amber phase	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Min green	15	15	15	15	6	6	6	6
Max 1 green	71.5	71.5	71.5	71.5	44.5	44.5	44.5	44.5
Total split	76	76	76	76	49	49	49	49

* Fiber actuated-coordinated

9.2.6. VISSIM Models

Design Considerations

Using a 2006 aerial image of the corridor provided by Polk County, a rough sketch was drafted with possible access management strategies (Figure 9-38). This concept drawing was input into AutoCAD to finalize the plan and adjusted to match the existing infrastructure. To continue the access management from the northern section of the corridor, a raised 12 ft non-traversable median with turning lanes at major intersections was specified. Lane widths were adjusted to 12 ft wide, driveway and intersection curb radii were adjusted to match, and backage roads were designed with a 24 ft cross section. Driveways leading to backage roads and backage roads leading to collector streets were controlled by stop signs, giving priority to the larger of the intersection roads. Most businesses, with a few exceptions, continued to have two access points: generally, one on South Ankeny Boulevard and the other connecting to a backage road or a driveway shared with an adjacent business.

Network Setup

Similar to the models created for the Ames study, two separate VISSIM models were created for the US 69 study. The first model was used for calibration, with existing signal timing, geometry, and vehicle counts entered into the program. The second model created was the proposed access management improvements. Both of these models are illustrated in Figure 9-39, with the existing model on the left and the proposed model on the right as links and nodes.

Trip Generation and Redistribution

Explained in the previous section of this report, the three Ames models considered whether a certain adjustment to a single intersection affected operations, based on the number of entering vehicles at all of the signalized intersections and using major side streets as loading and unloading points for extra vehicles. For the Ankeny study, to fully understand the impact that the proposed access management treatments would have on the corridor, driveway and side street vehicle turning movement volumes were needed to calibrate the model. Since the study corridor lies on a state highway, the Iowa Department of Transportation provided p.m. peak-hour turning movement counts recorded in 2004 for each of the three signalized intersections. Due to Ankeny’s population increase over the past four years, a 2% growth factor was applied to each of the turning movement counts, which is reflected in the signalized intersection summary in section 9.2.5.

Once known intersection turning movement volumes were determined, a field investigation was performed to determine which businesses were located along the study corridor, how many useable driveways were on site at each business, the area of each business’ building, and each building’s proximity to the nearest signalized intersection or collector street. Once this data was collected, trip generation was determined using the ITE *Trip Generation Handbook* (ITE 1997), and then the number of trips generated was divided by the number of driveways.

Figure 9-38. Proposed alternatives

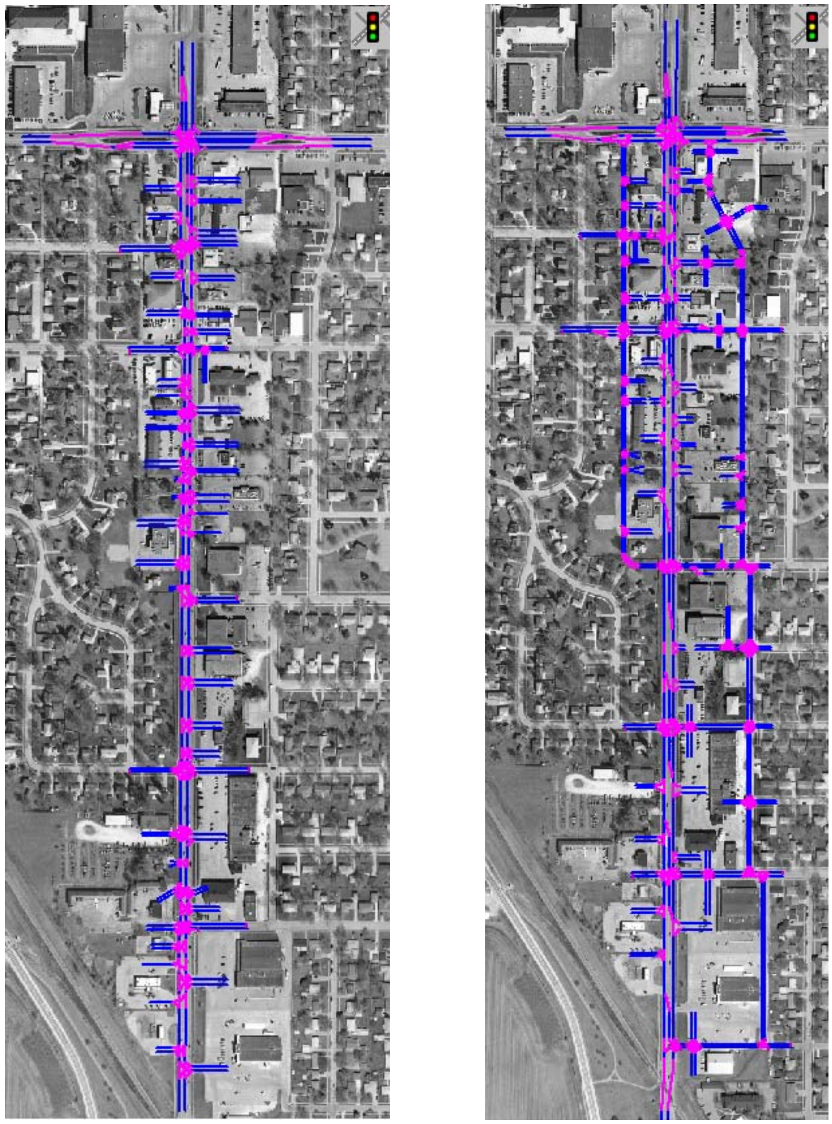


Figure 9-39. Existing (left) and proposed (right) models as link and nodes

To determine the trip generation for the proposed access management plan, engineering judgment was the main factor in assigning trips and their respective routes. The following rules were applied to each business along the corridor:

- The access management plan specified a raised non-traversable median for the entire length of the study corridor, with access points at signalized intersections or major intersections where residential collectors met the corridor. This treatment did not allow vehicles to make a left turn off of the corridor into a business driveway. Instead, vehicles would have to make a left turn at a major intersection and travel along a new backage road, which led to the business driveway, typically at the rear of the business.
- The left turning vehicle count was split 80%/20%. That is, 80% of the vehicles wanted to get to a business using the closest signalized intersection to travel to the backage road, while the other 20% used the farther signalized intersection or a minor collector street to

access the business. This split allowed for human error and for drivers unfamiliar with the area.

- The same rules applied in reverse for vehicles wanting to exit the business to make a left turn onto the corridor. The total number of exiting vehicles wanting to make a left turn was divided 80%/20%. The 80% were routed onto the backage road to the closest signalized intersection. The 20% were routed in the opposite direction, with the assumption that these drivers had never used the backage road, was closer to a network exit point, or had the possibility of traveling to a second destination along the corridor.

Once trip generation values were determined for each entry point in the corridor (including driveways, side streets, and network), routing decisions were applied at each entry point, as discussed for the Ames model in section 9.1.4 of this report. These routing decisions directed traffic based on the given percentage traveling towards a destination, although VISSIM generates vehicles that travel randomly to various destinations. With over 1,000 routing decisions coded into the program, it became extremely complicated for vehicles to make fast decisions in the network, sometimes missing turns or disappearing altogether from the network. To eliminate this problem, the combined routing feature was used, which combined repeated, overlapping, or excessive routing decisions into one or a manageable few decisions. This made it easier for vehicles to make decisions and provided enough time to move into the appropriate travel lane.

Conflict Areas and Intersection Nodes

Conflict areas, much like priority rules used in the Ames roundabout model, are defined when two links or connectors overlap. In the case of the corridor study, this occurs when the driveway meets the corridor road. There are three different types of conflict areas in VISSIM, including crossing, merging, and branching. When a vehicle approaches the conflict area, the driver makes a plan about traversing the conflict area. Generally, if a stop sign is not present, the vehicle interprets the conflict area as a yield point and will wait, slow down, or come to a complete stop for the appropriate gap to cross the conflict point. Vehicles on the corridor will also react to the conflict area by watching the crossing or merging vehicle entering the corridor. However, due to the nature of the simulation, not all drivers make the appropriate judgment when crossing or merging onto the mainline, and thus vehicles on the mainline approaching the conflict area may apply the brake or even come to a complete stop to avoid a potential collision.

Similar to routing decisions described in the previous section, there can thousands of possible conflict points in this corridor study. To make identifying conflict areas easier, VISSIM allows what are called nodes to be drawn around areas that have known conflict points, but that may sometimes be difficult to define with a mouse. Figure 9-40 illustrates node 12 of the existing Ankeny corridor. This node consists of nine driveways with crossing and merging movements.

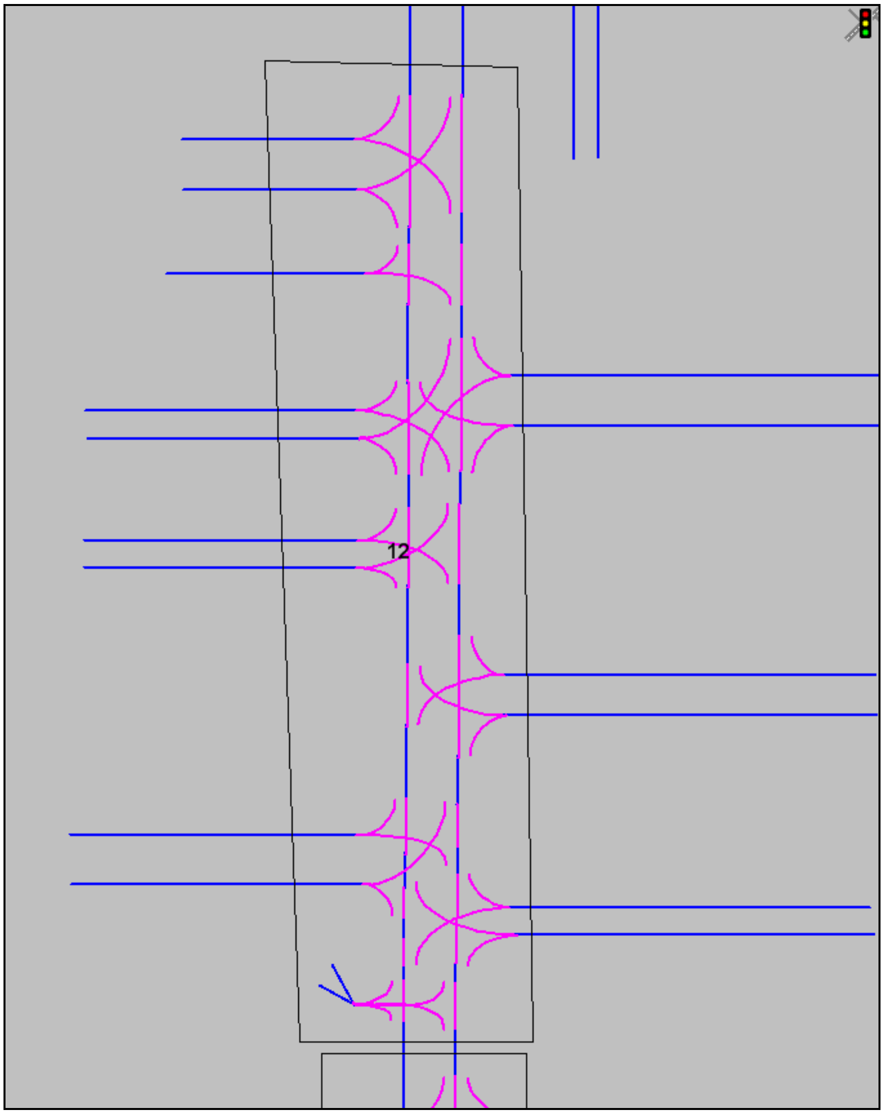


Figure 9-40. Node identification for the Ankeny corridor

Nodes can also be used to evaluate the intersection, including finding lane delay, max queue length, stop delay, and vehicle counts, although the signalized intersections were not evaluated separately in this study. After defining the nodes in the model, conflict points could automatically be found by specifying which node to evaluate. Figure 9-41 illustrates the evaluation of node 12, in which 107 possible conflicts were identified. As the figure shows, two colors represent the movements in the conflict area: green represents priority and red represented yield. Additionally, some conflict areas may show no color in the table. This is due to an identified conflict that may or may not be a realistic conflict area, such as overlapping links and nodes.

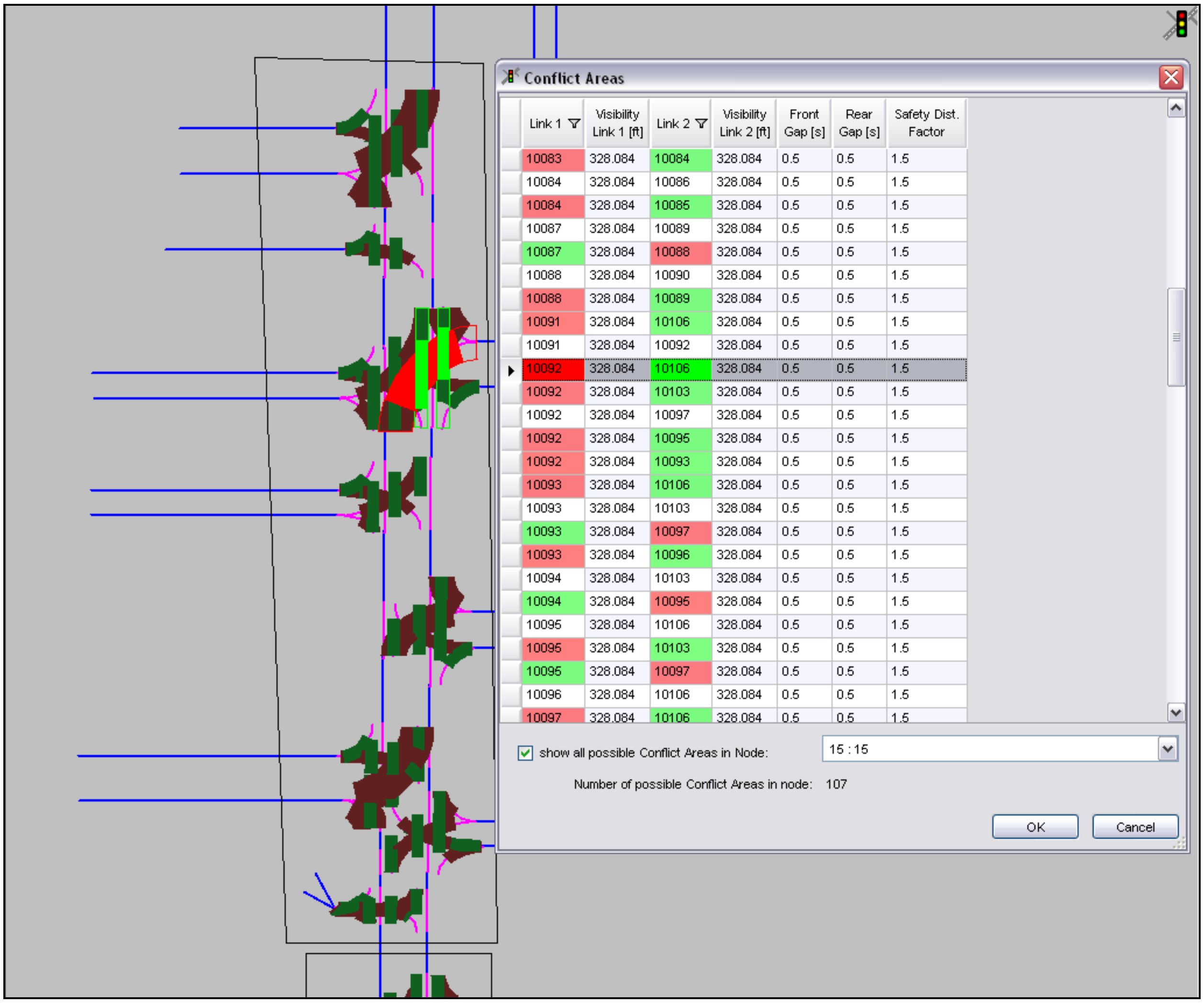


Figure 9-41. Conflict area identification

9.2.7. Evaluation of Alternatives

Once the model was calibrated and the proposed model was created, two working 3-D simulations were created, illustrated in Figures 9-42 and 9-43. The two models were evaluated by VISSIM's evaluation tools, including those that investigate corridor travel time, delay, and stopped delay. Unlike the Ames models, probe vehicles were not included in the evaluation, nor were buses or heavy vehicles due to the small overall percentage of recorded vehicles in those two categories. Two data collection points were added to the model at both ends of the corridor for each direction of travel. Data were collected for vehicles that only traveled the entire length of the corridor from the start point to the end point.

Similar to the Ames models, a loading time was implanted into the model to load the system before the evaluation began. For the two models, a loading time of 30 minutes was implemented, and then an hour of data was analyzed from 5:00 p.m. to 6:00 p.m.

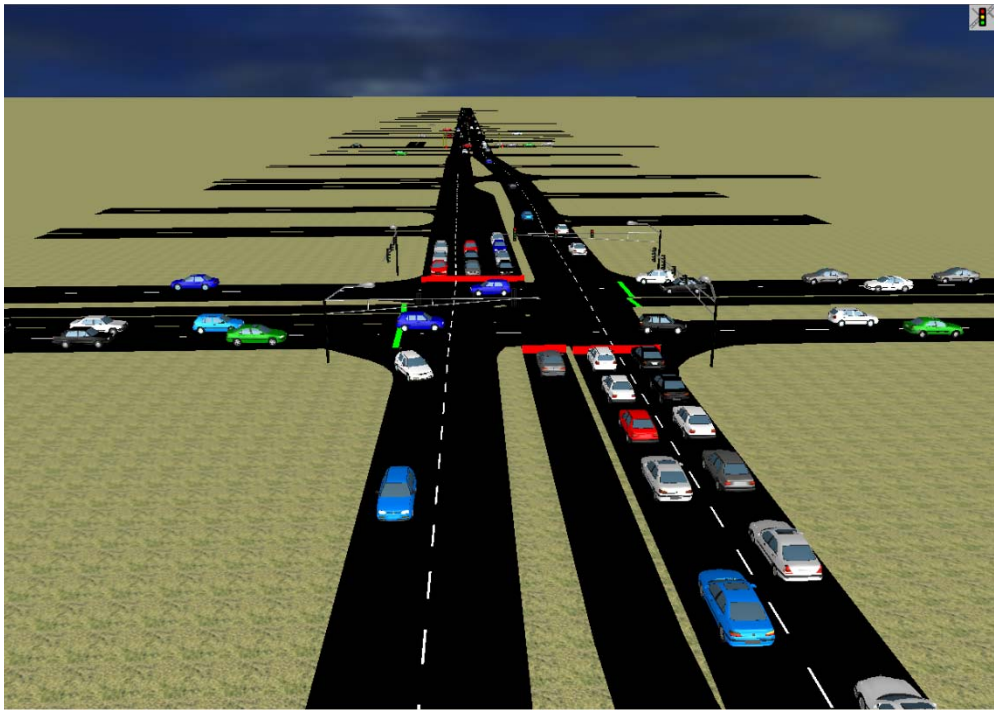


Figure 9-42. Existing South Ankeny Boulevard corridor looking south from 1st Street

Figure 9-43. Proposed South Ankeny Boulevard corridor looking south from 1st Street

9.2.8. Summary of Findings

Figures 9-44 and 9-45 illustrate the results of the hour-long analysis, as reported by VISSIM. As the figures show, the corridor travel time of the proposed model increased in both directions. This may be due to the fact that the proposed model diverts most of the business traffic to signalized intersections: the signals are running on the max green times for the minor streets and thus allowing a larger volume of vehicles to enter the corridor. The figures also show that the corridor stopped delay is slightly lower for the proposed model in both directions, and the average delay is slightly lower in the southbound direction. In contrast, the delay in the proposed northbound direction is slightly greater than in the existing model. Although travel time, corridor delay, and stopped delay were not significantly impacted by the access management strategies implemented, the evaluation shows that, by implementing these strategies, safety has increased while travel conditions have not decreased.

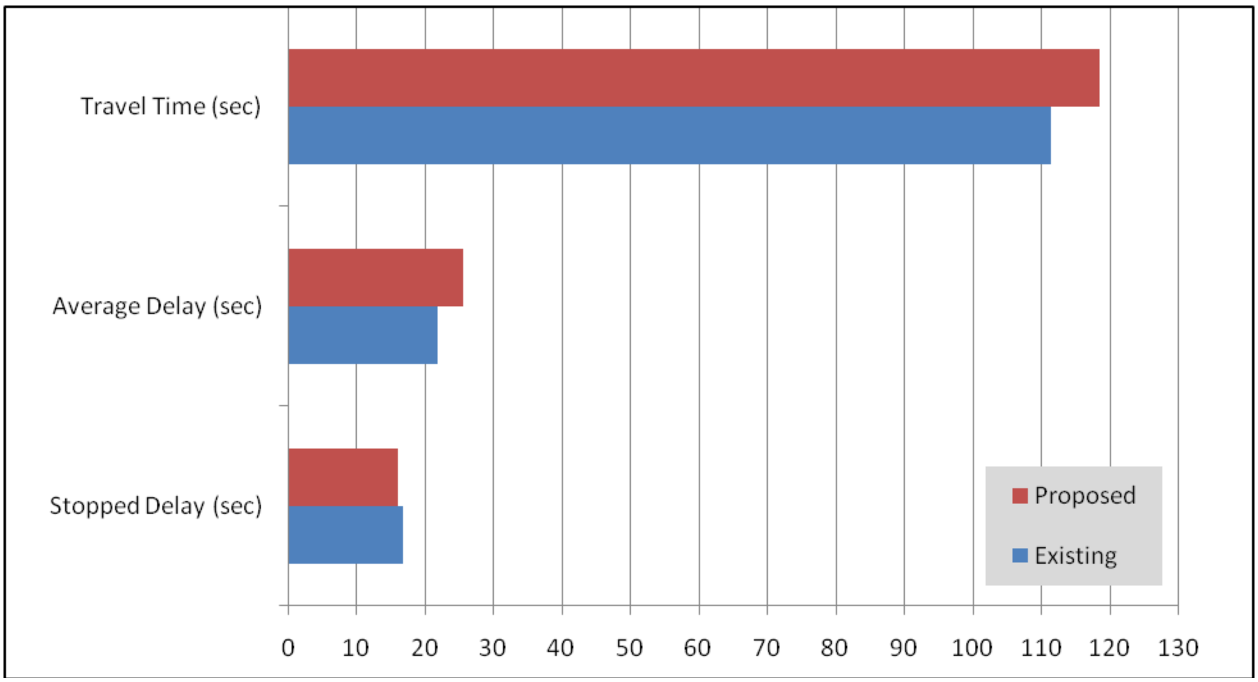


Figure 9-44. Northbound corridor summary

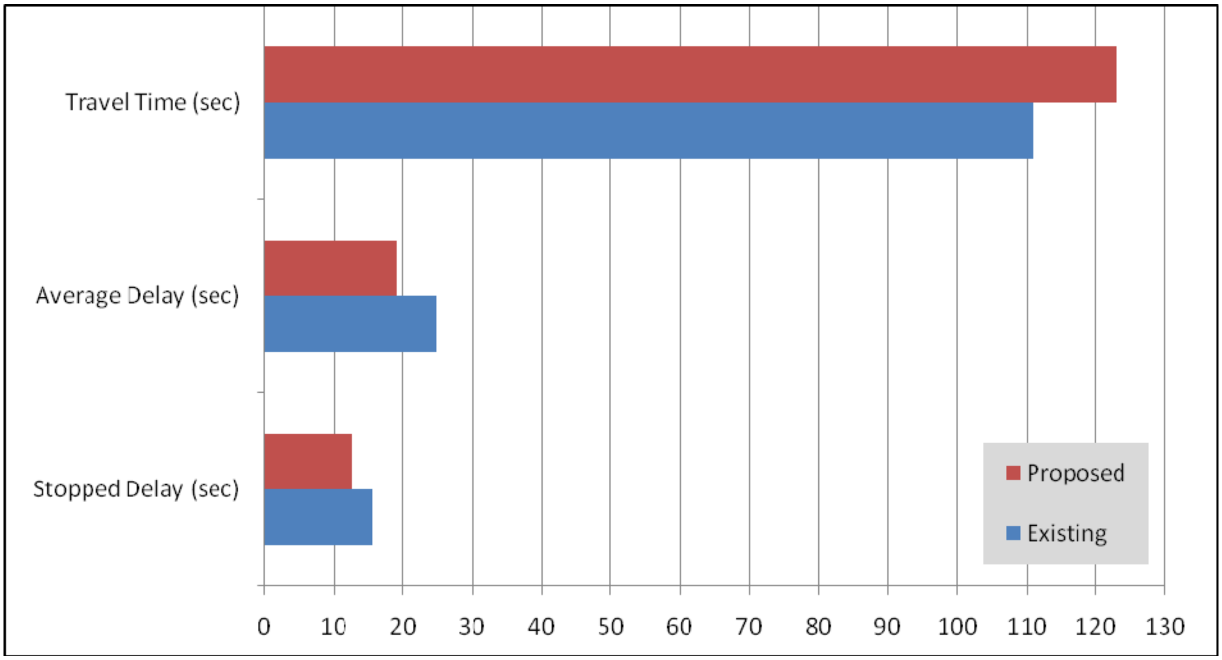


Figure 9-45. Southbound corridor summary

9.3. Intersection of Northwest Ash Street and Prairie Ridge Drive in Ankeny

9.3.1. Background

The intersection of Northwest Ash Street and Prairie Ridge Drive in Ankeny, Iowa, is located less than one mile away from the other Ankeny case study corridor. This intersection, illustrated in Figure 9-46, is located in a mixed-use land area consisting of urban residential lots, the Ankeny park system, and multiple religious properties. The intersection experiences high morning and peak-hour volumes, with two collector streets intersecting. Additionally, during the morning and afternoon peak hours, 10 to 16 school buses from Northview Middle School enter the southbound approach of the intersection, allowing vehicles to queue in the southbound approach up to 25 cars in length. This intersection was selected for investigation and possible intersection operational improvements due to its unique location, limited right of way, and unbalanced turning movement volumes.

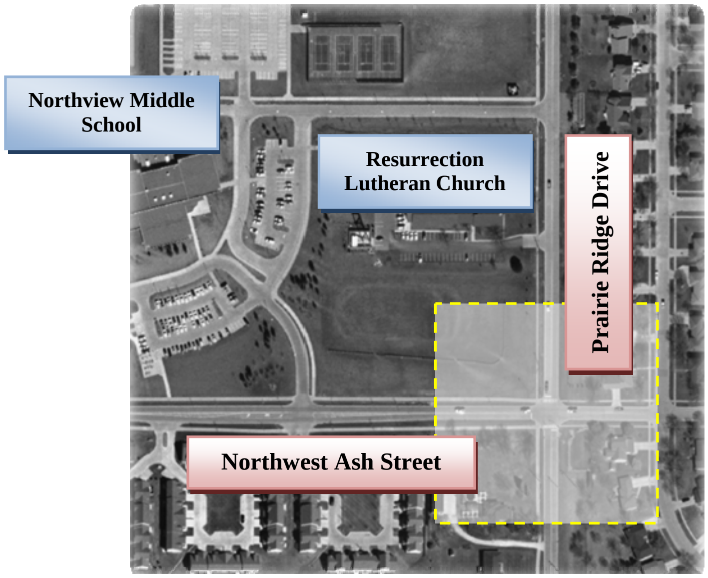


Figure 9-46. Intersection location and adjacent lane use

9.3.2. Crash Experience

Figure 9-47 shows crashes at the intersection from 2001 through 2006. As illustrated, three right-angle crashes occurred at the intersection, two in 2002 and one in 2005. As shown, all of the crashes involved vehicles traveling eastbound, which has the highest turning movement volume for all of the approaches.

9.3.3. Intersection Characteristics and Data Collection

The intersection of Northwest Ash Street and Prairie Ridge Drive consists of four single-lane approaches. Each lane is 13 to 14 ft wide, and lanes in each of the approaches are separated by a double yellow line. There are two crosswalks running east-west, mainly for children walking to school from the residential area east of the intersection to the middle school west of the intersection. The intersection grade is minimal, and there is plenty of sight distance in all directions.

Road geometry involves two collector streets intersecting at 90 degrees (Figure 9-48). However, the geometries on the eastbound and westbound approaches leading up to the intersection are different. On the eastbound approach, Northwest Ash Street becomes a two-lane road less than 500 ft away from the intersection, with a left turning lane into the middle school. The street returns to two lanes prior to the intersection. On the westbound approach, the local roadway Northwest Maple Street, which runs parallel to Prairie Ridge Drive, intersects Northwest Ash Street less than 300 ft away from the intersection.

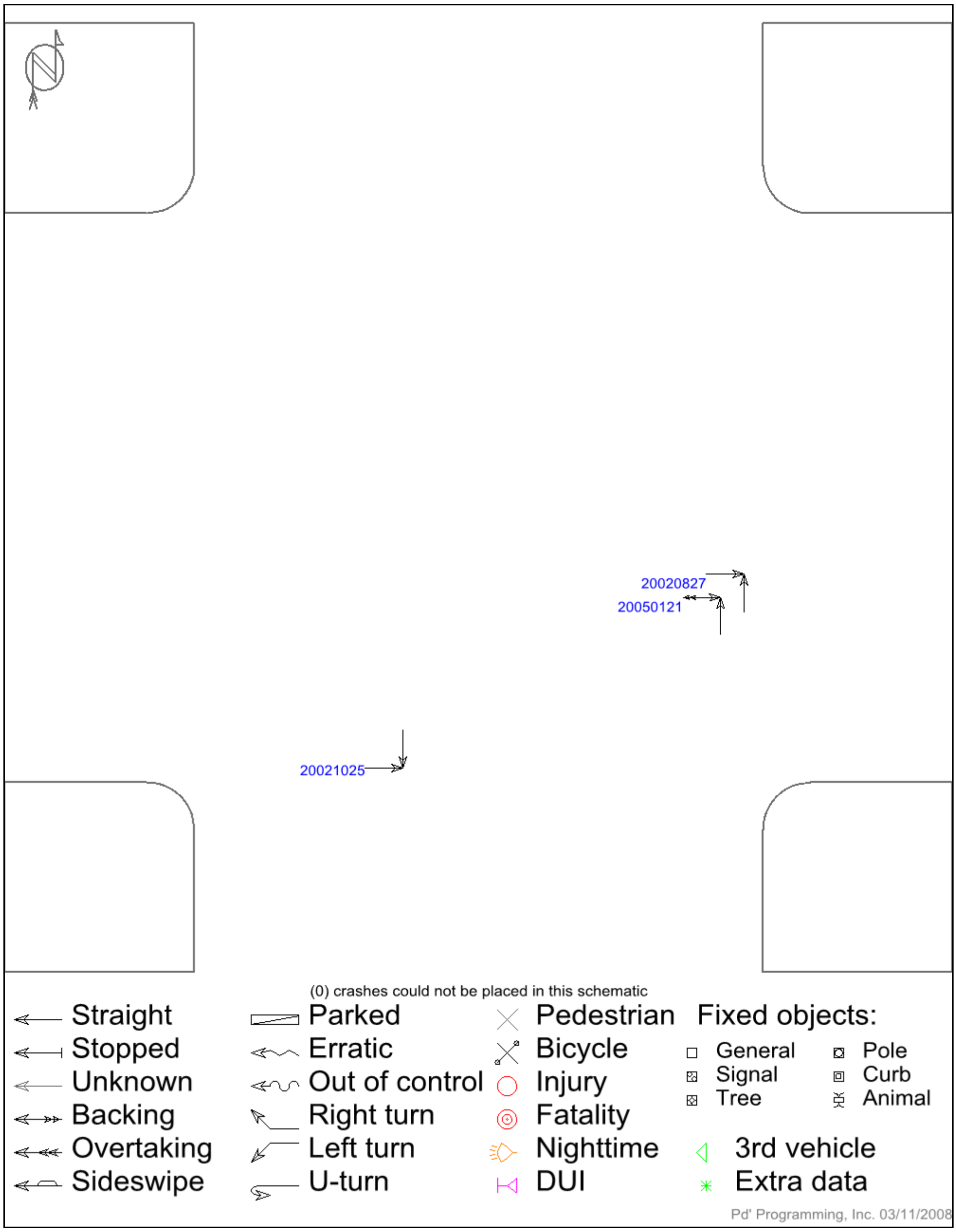


Figure 9-47. Crash diagram of Northwest Ash Street and Prairie Ridge Drive (2001–2006 reportable crashes)

Figure 9-48. Existing four-way stop intersection looking north

Because the intersection is not located on a state route, peak-hour turning movement volume could not be obtained from the Iowa Department of Transportation. Two separate counts were manually performed using a Jamar counting board. Both counts, taken on a random weekdays, are shown in Figure 9-49, with the morning peak hour taken from 7:00 a.m. to 8:00 a.m. and the evening peak hour count taken from 5:00 p.m. to 6:00 p.m. After reviewing the results, the research team decided to investigate possible solutions for the heavier peak hour and heavier left turning movement volumes, which occurred during the morning peak hour.

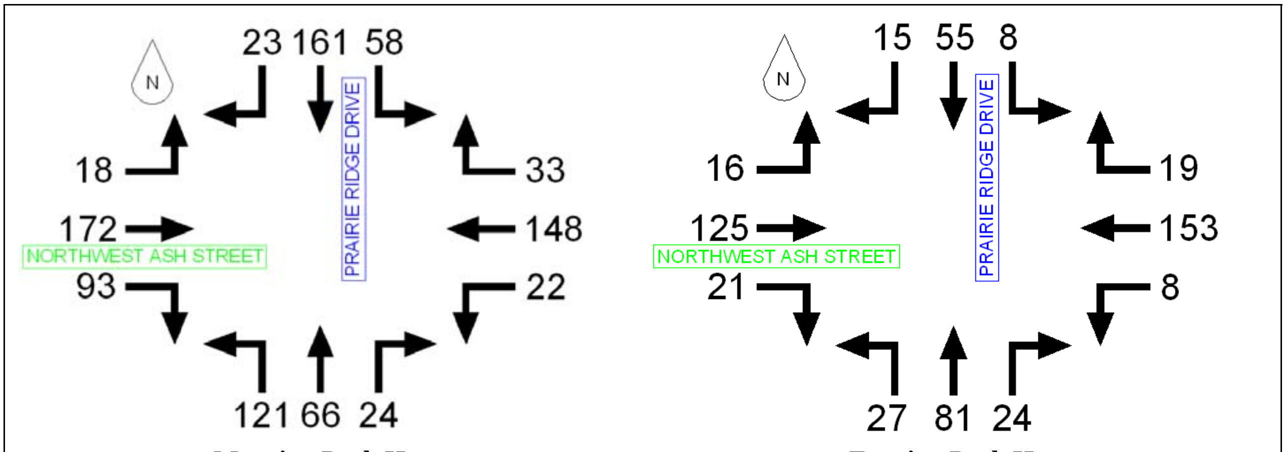


Figure 9-49. Peak hour turning movement volumes

As Figure 9-49 shows, the northbound left and eastbound right turning movement volumes were high due to the adjacent middle school, where parents dropped their children off in the morning.

Due to the nature of the high left turning movement volume, four unique solutions were proposed to improve the operation of the intersection in the morning: removing two stop signs on the major route (Northwest Ash Street), installing a single-lane urban roundabout, adding a full-split intersection, and adding a half-split intersection that gives priority to the major route.

Alternative 1, Two-way Stop

At a typical two-way stop intersection, right of way is given to the two approaches, opposite of each other, with the higher volumes. This keeps traffic moving. For Northwest Ash Street and Prairie Ridge Drive, the eastbound and westbound approaches were considered the major routes in this investigation for the following reasons:

- The highest number of recorded a.m. peak-hour vehicles travel along the eastbound approach
- A high number of right turning vehicles turn to the south.
- Crosswalks run parallel to the selected eastbound-westbound approaches.
- A collector street connects the selected approach to US 69 farther east.

In addition to these reasons, a traffic signal that connects Prairie Ridge Drive to Ankeny's busy east-west corridor is located about one mile south of the intersection.

Using the model of the existing conditions, which included four-way stop signs, a new VISSIM model was created by removing the stop signs from the eastbound and westbound approaches and creating conflict areas (Figure 9-50). To determine which conflict areas needed to be coded into VISSIM, the intersection node tool, described earlier in this report, was used to determine all possible conflict areas. Conflict areas were selected based on giving priority to Northwest Ash Street. In the simulation, vehicles traveling north or south were required to stop at the stop sign and then decide whether enough gap time was available in both directions to make the turning movement.

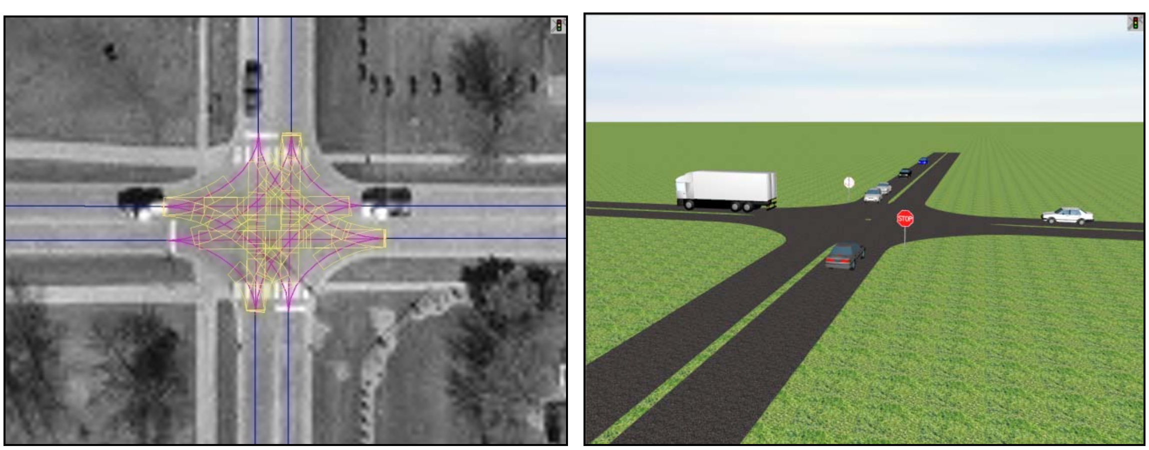


Figure 9-50. Two-way stop VISSIM setup and 3-D model in operation

The simulation was also coded so that if a vehicle traveling northbound arrived at the intersection after another vehicle traveling southbound had already stopped at the intersection, priority would be given to the first vehicle that arrived at the intersection. However, if both vehicles were making a left turn from their respective approach directions, both vehicles were allowed to enter the intersection at the same time, assuming enough gap time was found. In addition to determining the conflict areas, speed reduction areas were implemented for the major route, assuming that vehicles would not traverse a turning movement traveling at the speed limit. The specified speed reduction assumed that turning vehicles making either a left or right turn would execute the movement while traveling between 9 and 15 mph.

Alternative 2, Single-lane Roundabout

Single-lane roundabouts are becoming a popular solution in urban residential areas as an alternative to signalized intersections. Due to entering vehicle volume and right-of-way constraints, it was determined that a single-lane roundabout would be appropriate to investigate at this site. Using the design recommendations found in the FHWA's *Roundabouts: An Informational Guide* (Robinson et al. 2000), a single-lane roundabout, 115 ft in diameter with 18 ft wide circulating lanes, was designed in AutoCAD (Figure 9-51).

Figure 9-51. AutoCAD roundabout design

After design details were finalized, the line work from AutoCAD was brought into VISSIM. Similar to the procedure described in section 9.1.4 for the Ames roundabout model, links, nodes, driver behavior, and reduced speed areas were created. The same values from the Ames roundabout model were used. Since the roundabout consists of one circulatory lane, priority rules were minimal, with a coded gap time of 3.0 seconds for cars and heavy vehicles to enter the roundabout. These setup procedures and the working model are illustrated in Figure 9-52.

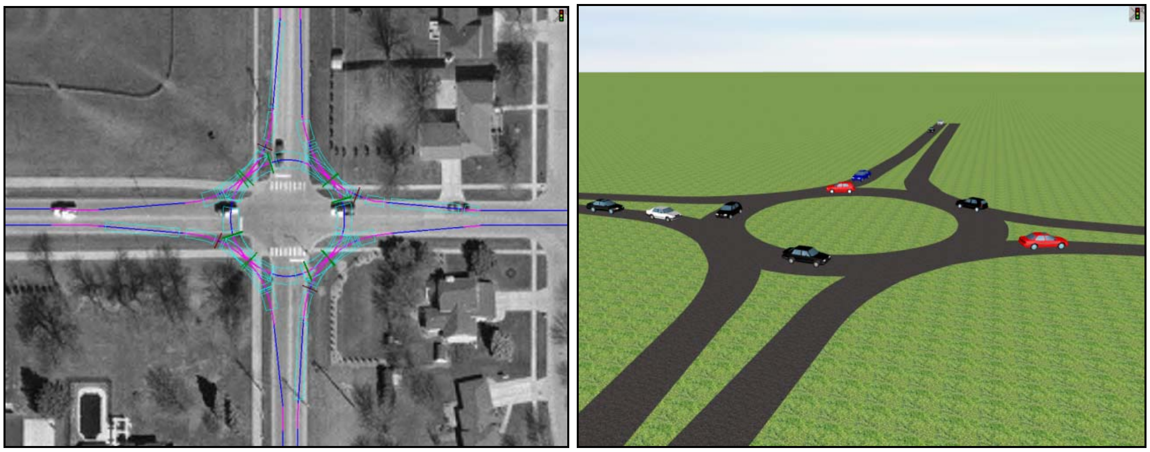


Figure 9-52. Single-lane roundabout setup and 3-D model in operation

9.3.5. Alternative 3 Signal with Split Phasing

Split-phase signal timing operation is mainly used under constrained conditions, including unusual geometry, minimal cross section width for a dedicated left turning lane, right-of-way constraints that would prohibit intersection expansion or reconstruction, or heavy opposing left turning movement that would constrain thru movement vehicles. Split phasing can include splitting two or four approach legs of the intersection, depending on whether the left turning movement volume is equal to or greater than the thru movement volume. If the left turning movement is less than the thru movement volume, split phasing can become inefficient and geometric changes might be recommended.

As described above, the traffic volumes for the intersection of Northwest Ash Street and Prairie Ridge Drive pose a significant signal timing challenge, with limited right of way for possible intersection reconstruction, a heavy morning and afternoon peak hour, and unbalanced left turning movement in one direction. Split phasing was chosen after numerous tries with a conventional signalized intersection. Due to a high left turning movement volume in the northbound approach, the vehicle queue length and the delay time increase to well over the existing conditions to justify installing a traffic signal.

Using the steps described in section 9.1.4, the intersection of Northwest Ash Street and Prairie Ridge Drive was created in VISSIM as an isolated intersection and not as part of a network or corridor (Figure 9-53). Links and nodes were coded into the program using an aerial image of the intersection taken in 2004 by Polk County, Iowa, The intersection was drawn on top of the image, and one mile of roadway was created in all four directions, excluding driveways, parking lots, and additional local roads. Once the intersection was created in VISSIM, conflict areas were identified using the node tool described above in the Ankeny corridor study.

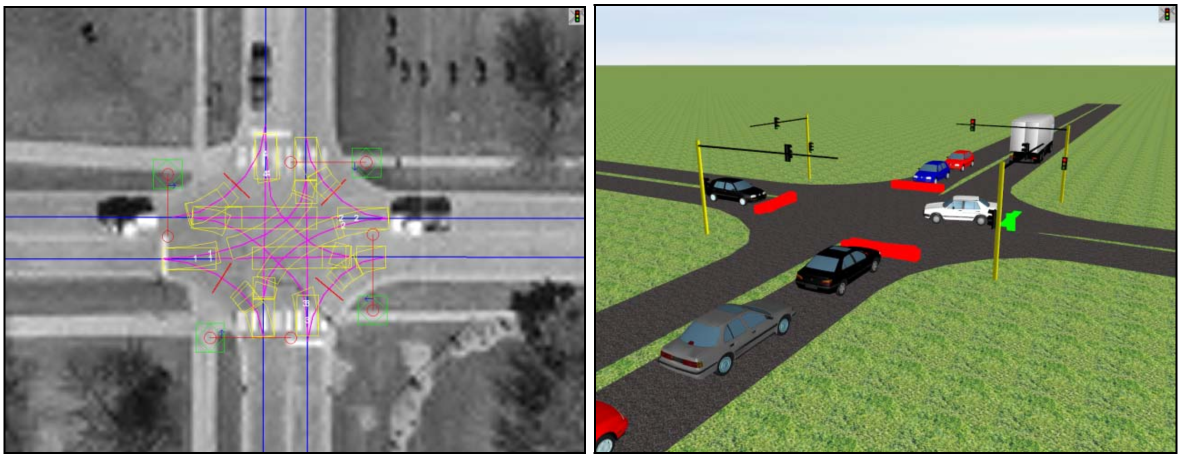
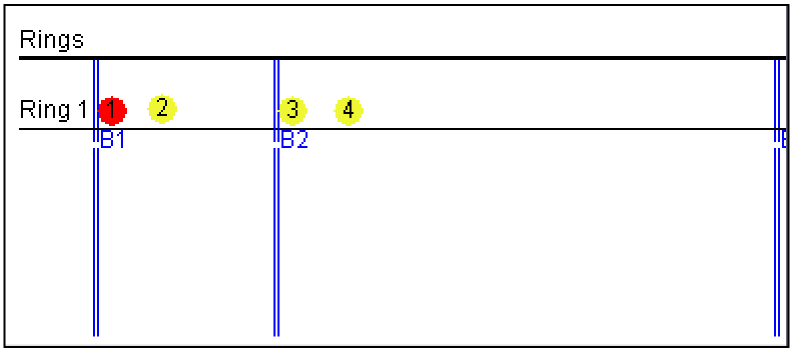


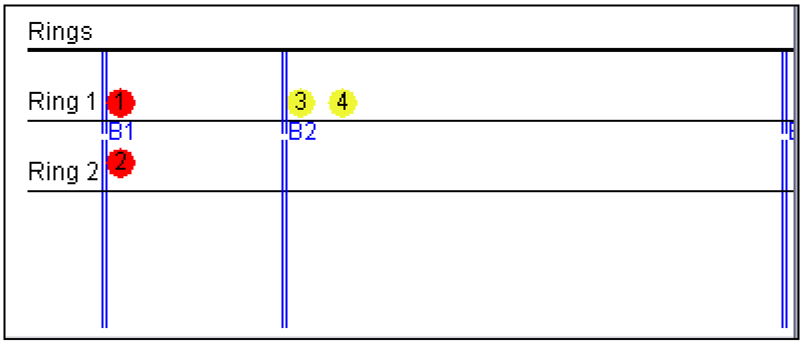
Figure 9-53. Split-phase VISSIM setup and 3-D model in operation

Two split phasing plans were created using the recommended cycle length and total splits, as output by Synchro 6. Both split-signal plans were based on the same timing, but with different ring and barrier configurations, as shown in Figure 9-54. The full split phasing, illustrated in the top image in Figure 9-54, shows that the green phase starts on NEMA phase 1, which is eastbound, and rotates in sequential order through the different directions, as shown in Table 9-9.

The second split-phase signal plan involves splitting the higher left turning volume in the northbound approach with the southbound approach, giving the green phase to both the eastbound and westbound approaches. This setup is shown on the bottom image in Figure 9-54, where NEMA phases 1 and 2 are highlighted in red, telling VISSIM to start the simulation on the eastbound and westbound approaches before cycling to the 3 and 4 NEMA phase, as described in Table 9-9.



All approach split phasing



Northbound and southbound split phasing

Figure 9-54. Split phasing ring and barrier configurations for each case

Table 9-9. Northwest Ash Street and Prairie Ridge Drive proposed signal timing (fully actuated)

	Eastbound	Westbound	Northbound	Southbound
NEMA Phasing	1	2	3	3
Lane Config.	Shrd.	Shrd.	Shrd.	Shrd.
Volume (veh./hr.)	283	203	211	242
Cycle length	120	120	120	120
Offset	N/A	N/A	N/A	N/A
Passage	4	4	4	4
All-red clearance	1	1	1	1
Amber phase	3.5	3.5	3.5	3.5
Min green	15	15	15	15
Max 1 green	22.5	20.5	38.5	20.5
Total split	27	25	43	25

9.3.6. Evaluation of Alternatives

Like the corridor studies, evaluating a single intersection can be quite complicated. The corridor studies, as described in sections 9.1 and 9.2 in this report, rely heavily on corridor travel time to determine delay and stopped delay. When an isolated intersection such as Northwest Ash Street and Prairie Ridge Drive is being analyzed, the node established in the conflict areas can be used to set a boundary for intersection analysis. Figure 9-55 shows the node created around the study intersection that includes all immediate links and nodes. Using the Node Evaluation tool, also illustrated in Figure 9-55, allows detailed operations analyses to be performed on the intersection within the node. Along with intersection operations, analyses can be performed on pedestrian crossing, fuel consumption, and air emissions.

For this evaluation, three items were analyzed: stopped delay, average delay, and average queue. Because VISSIM takes into account every link within the node, turning movement operations can be performed. However, because the intersection geometry included a single lane for all approaches, turning movement data was binned for each approach.

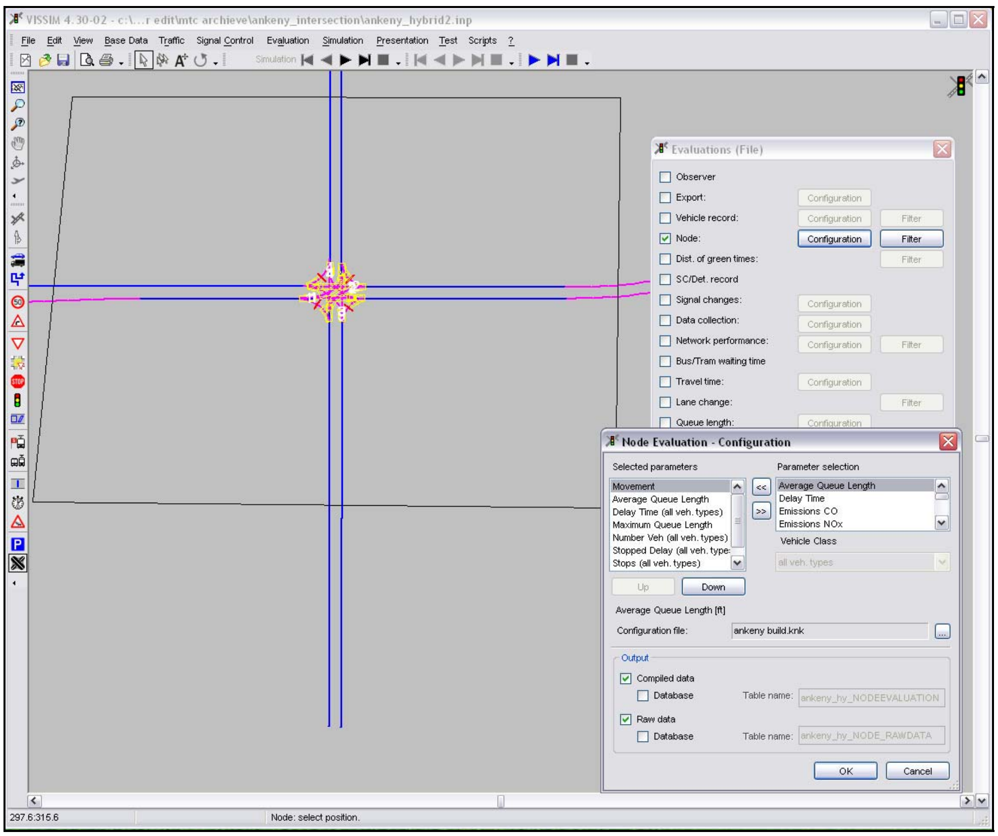


Figure 9-55. VISSIM node evaluation tool

Key Operational Findings

Using VISSIM's analysis tools described above, one hour of data was collected from each proposed improvement between 7:00 a.m. and 8:00 a.m., with 15 minutes of loading time. Figures 9-56 through 9-59 show the results of the analysis for each intersection approach. As the figures show, both split-phase signalized intersection improvements had the highest delay and stopped delay times, as well as the longest average queue lengths. The proposed single-lane urban roundabout was shown to be the most effective design for all approaches, although it led to greater delays for the northbound and southbound approaches than for the existing four-way and proposed two-way stopped-controlled improvements. The two-way stopped controlled improvement appeared effective on the eastbound and westbound approaches because these approaches were given priority, while the northbound and southbound approaches showed little reduction in delay times and queue lengths.

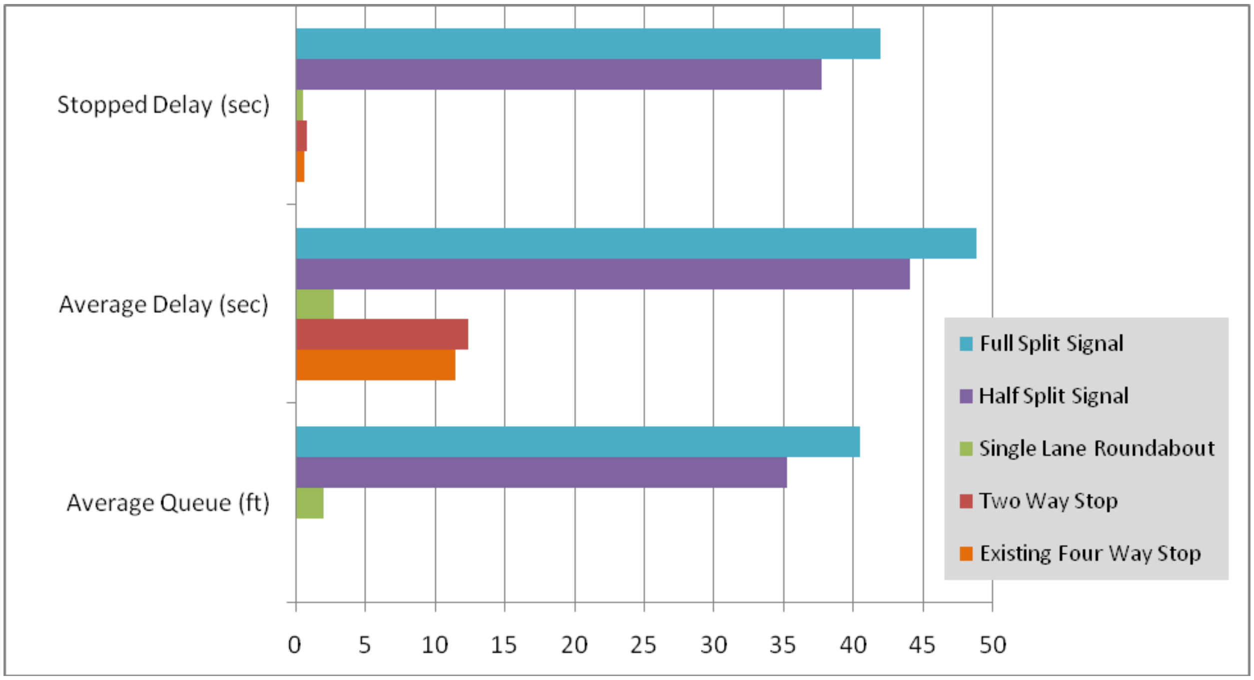


Figure 9-56. Northbound approach summary

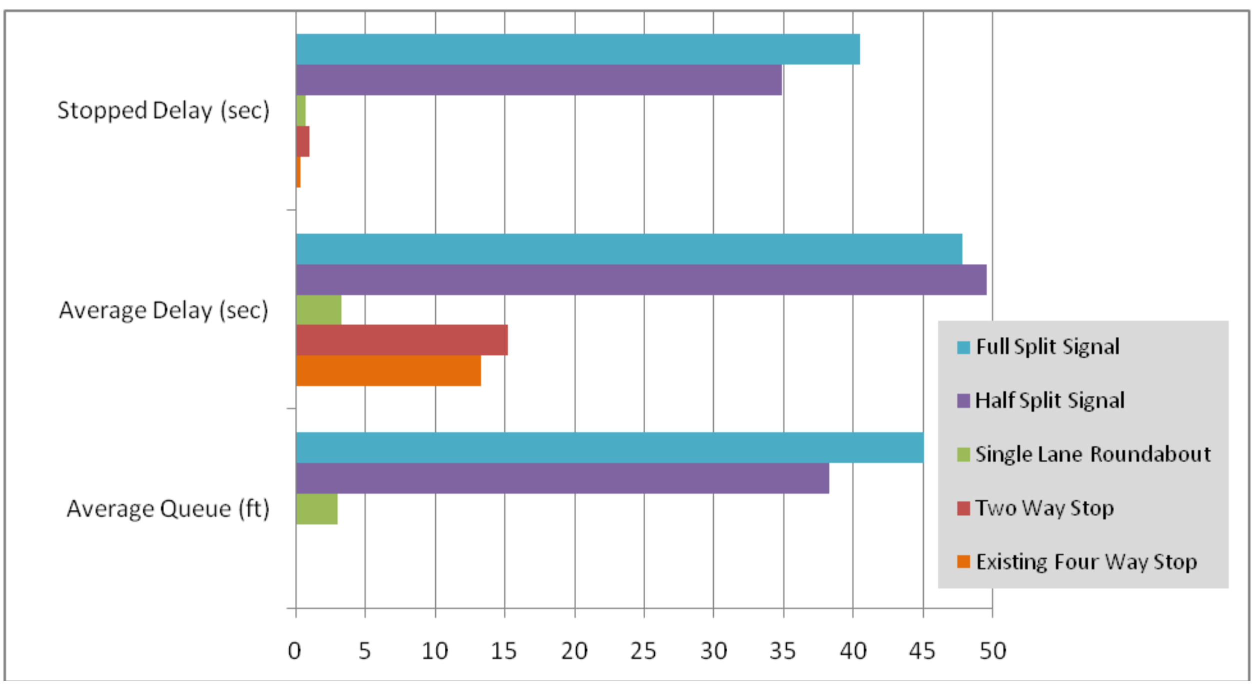


Figure 9-57. Southbound approach summary

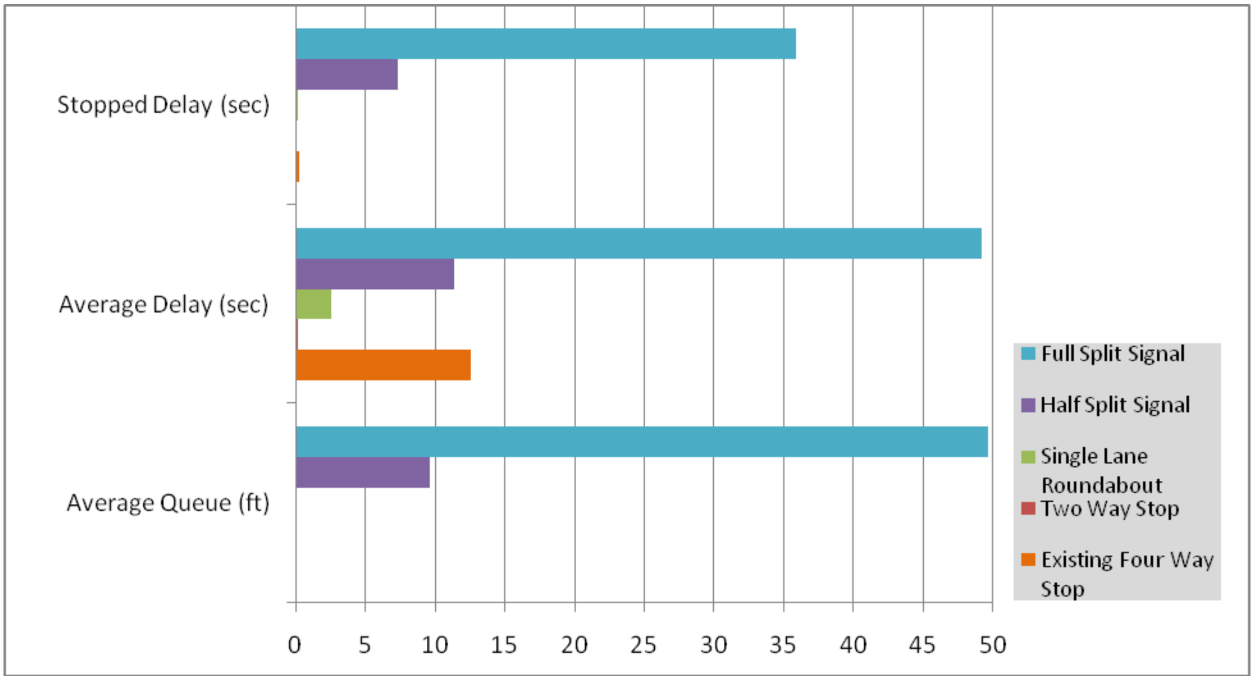


Figure 9-58. Eastbound approach summary

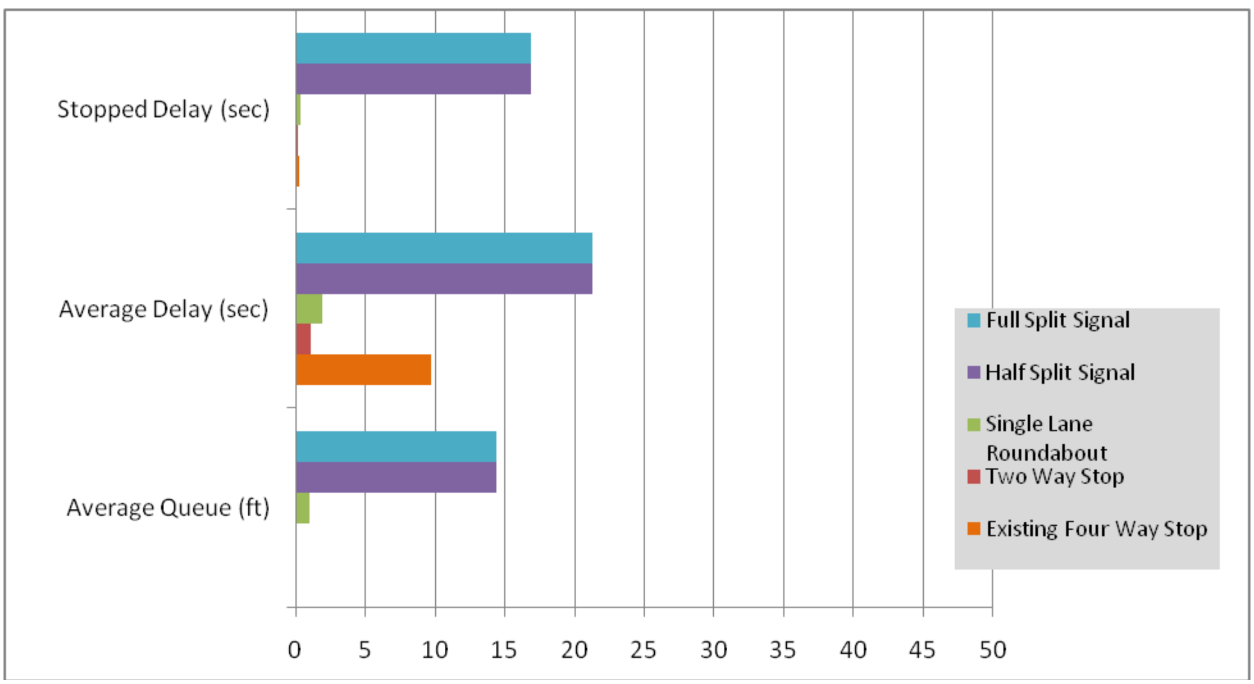


Figure 9-59. Westbound approach summary

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