EVALUATING THE TRAFFIC FLOW IMPACTS OF ROUNDABOUTS IN SIGNALIZED CORRIDORS

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ABSTRACT

The typical installation of a roundabout in the United States is at an isolated intersection where it is implemented to address location specific safety and/or operational needs. Their use in a signalized corridor however, has not been well evaluated although they have been used in several communities. It is commonly believed that roundabouts can improve traffic flow and travel speeds along an urban corridor since unnecessary delay due to idling at intersections is removed.

However, there is some concern that the implementation of a roundabout in a coordinated signalized corridor will disrupt continuous traffic flow since downstream signals can more efficiently process vehicles in a platoon and roundabouts disperse rather than form platoons. Additionally, roundabouts can discharge vehicles more efficiently when traffic arrives randomly. As a result, unnecessary queuing may result when roundabouts are downstream of signalized intersections.

Since little research was available to compare the traffic flow impacts of implementing roundabouts within a signalized corridor, two case studies were evaluated using the microscopic traffic simulation package, VISSIM. A roundabout and two signalized alternatives as well as a roundabout and a four-way stop controlled alternative were compared at intersections along signalized corridors in Ames, Iowa and Woodbury, Minnesota, respectively. The traffic data and corridor geometry were coded into VISSIM and traditional intersection traffic control within the corridors was compared to a scenario with a two-lane roundabouts. Using the microsimulation software, average travel time, stopped delay and average delay for the entire corridor were compared.

INTRODUCTION

The typical installation of a roundabout in the United States is at an isolated intersection where it is implemented to address location specific safety and/or operational needs and as a result, much of the information about the safety and operational impacts are based on information obtained from isolated intersections. The impact of a roundabout in a corridor is expected to be much different than for an isolated intersection. While the roundabout may solve safety and operational problems at one intersection, it may adversely affect another intersection upstream or downstream, or corridor performance as a whole. As a result, consideration should be given to how roundabouts affect traffic operations in a corridor.

One of the common benefits cited for roundabouts is improvement in traffic flow, since unnecessary delay due to vehicle idling at intersections is reduced. When a roundabout is used in conjunction with traffic signals along a corridor, proponents have suggested that travel time through the corridor will be reduced due to consistent speeds. Flow is also expected to be smoother since a roundabout reduces acceleration and decelerations that occur with signalization.

However, there is some concern that use of a roundabout in a signalized corridor will disrupt traffic flow rather than providing more efficient flow. In a signalized corridor, vehicle platoons form upstream and downstream at signalized intersections. If the signalized corridor has proper progression, vehicles arriving downstream in a platoon can be served in a much shorter amount of green time than vehicles arriving randomly. This leads to better utilization of capacity. It is also difficult to coordinate a series of traffic signals without formation of platoons upstream. In addition, platooning creates a recurring pattern of gaps which traffic on minor streets downstream can utilize to enter the corridor or cross the corridor at unsignalized locations

(1).

Roundabouts disperse traffic randomly and can discharge vehicles more efficiently when traffic arrives randomly. As a result, roundabouts which are upstream of a signalized intersection will disperse rather than create platoons which can cause inefficiency downstream and may make it difficult to coordinate a set of signals. When a roundabout is within a signalized corridor, queuing also may occur if platoons of vehicles arrive from an upstream signalized intersection.

Roundabouts do have the potential to alleviate congestion at critical intersections (i.e. bottlenecks) within a coordinated signaled corridor but this should be assessed carefully. Impacts are specific to corridor traffic volumes, percent turning vehicles, intersection spacing and vehicle types.

Although roundabouts are often believed to cause less queuing and delay, their impact on a signalized corridor has not been well demonstrated. Several studies have evaluated the traffic flow impacts of a roundabout within a corridor but results are not well documented. Bared and Edara (2) used a microscopic simulation program, VISSIM, to evaluate the performance of a roundabout within a coordinated set of signals. The study evaluated a corridor with three intersections spaced at quarter mile intervals. Initially the authors evaluated the corridor with all three intersections being signalized. They also optimized coordination using TRANSYT-7F. This was compared to a scenario where the center intersection was replaced with a roundabout. Results of the VISSIM analysis 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 signal scenario resulted in slightly lower overall delay.

The City of Golden, Colorado, replaced signalized intersections with roundabouts which had a heavy retail land use including strip malls, grocery stores, and fast food restaurants. Traffic operations were compared before and after installation of the roundabouts. 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 (3).

A series of roundabouts was implemented in Edina, Minnesota. The existing four-lane roadway was reduced to a two-lane roadway and three roundabouts were implemented in the corridor. Prior to installation of the roundabouts in Edina, traffic during peak travel times had a difficult time entering the corridor. Although the roundabouts have only been open for a short time when the city evaluated them, they indicated 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 (4).

There is also a concern that if drivers perceive that roundabouts along a corridor interfere with traffic flow they may divert to other roadways causing safety and operational problems on those roadways.

PROBLEM STATEMENT

Since little research was available to evaluate the impact of roundabouts within a signalized corridor, two case studies were developed and analyzed using microscopic traffic simulation. One case study was in a suburb of Minneapolis/St Paul, MN and the other was in Ames, Iowa. The case studies compared existing corridor geometry with the implementation of a roundabout at one intersection along the corridor. The case studies compared average corridor travel time, delay, and stop time in each direction of travel for one case study. It is acknowledged that the information obtained from simulation modeling of alternatives only offers speculative evidence about the performance of a roundabout within a corridor. However, it is extremely difficult to conduct a field study to obtain before and after data to document the impact. As a result, simulation modeling can be used to provide some preliminary evidence of the impact so that agencies who wish to implement roundabouts in a corridor have some information about what the expected impacts might be. This information is also useful for agencies who wish to model roundabouts within a corridor in a simulation model since there are several challenges as addressed in the following sections.

MODELING ROUNDABOUTS IN A CORRIDOR

A detailed description of each case study is provided in the corresponding section. The following paragraphs describe general information about how the corridors were developed and analyzed in VISSIM.

Building a network in VISSIM

The microscopic simulation program VISSIM version 4.30 (5) was used to model both case studies. VISSIM is a link-link based stochastic traffic microscopic simulation program which is ideal for simulating and evaluating complex networks and multi-lane roundabouts. The link-link structure allows complex geometry such as that found in roundabouts to be modeled explicitly and VISSIM allows users to define driver reactions to changes in the roadway geometry. VISSIM also has a complex driver behavior model that can be adjusted to calibrate specific conditions and extensive vehicle operations evaluation output.

Scaled aerial photographs were used as a background to code the existing street network for each corridor into VISSIM. Existing signal timing and volumes were used to develop the initial model. The roundabout was then developed and coded into an alternative scenario. Vehicles were loaded and unloaded from the network based on the signalized intersection turning movement volumes. Both case studies modeled the evening peak hour traffic volume through the corridor. VISSIM includes several calibration tools which were used to adjust the models to reflect actual conditions as much as possible. They include:

- Priority rules: adjusts acceptable gaps which includes minimum headway, minimum gap per second time, and which driver has the right-of-way at intersections or roundabout entry point
- Reduced speed areas: allows for temporary driver speed reduction through specific areas such as through a turning maneuver and, in this case, through the circulating roadways of the roundabout
- Driver behavior: is a set of parameters within the program designed to specify how drivers react once they are at the roundabout or intersection. For example how far downstream they can see, how many approaches they observe, and how aggressive they are on the roadway
- Vehicle characteristics: this allows the VISSIM network to include vehicles such vehicles as heavy trucks or transit buses as well as passenger cars.
- Routing decisions: controls turning movements throughout the network and stochastically distributes the potential volume throughout the network

- Speed input: roadways in the model were assigned a specific speed distribution based on the posted speed limit. Geometric changes in the case study model resulted in a change in vehicle speed
- Signal timing: signal timing plans were developed in Synchro and replicated in VISSIM using the NEMA phase editor. Loop detectors were placed in the model as well for minor street vehicle detection at signalized intersections.

Each of the base scenarios (i.e. existing conditions) were calibrated using methods described in the FHWA's *Traffic Analysis Tools Volume III* (7) as well as through observing the corridor operations in the field during the evening peak hour.

One of the most important aspects of modeling a safe roundabout in VISSIM is giving priority to vehicles circulating within the roundabout while the approach vehicles yield. Priority rules are specified in the program to determine at what point it is safe for a vehicle to enter the roundabout and it depends on which lane it is in at the yield point. Figures 1 and 2 show the recommended rules given for each approach lane (5).

A significant amount of time was spent attempting to ensure that the base condition reflected actual conditions at the intersections. For instance, the model tended to result in a lower level of service than was actually present. Additionally, once the roundabout scenario was implemented, the model was checked for problems that appeared to be inconsistent with what would be expected. For instance, it was determined initially that vehicles entering the roundabout were adversely affecting the circulating traffic flow without making an appropriate or adequate yield. As a result, the minimum gap time of the vehicles in the outside circulating lane was increased to 2.25 seconds to give drivers more time to react in the approaching outside lane to the inside lane of the circulating traffic. For additional information about calibration of the model see Hallmark et al, 2008 (8).

Pedestrian traffic was very minimal for both case studies. As a result, pedestrians were not considered for either case study.

Analysis and Results

After each scenario was coded and calibrated, a sample of vehicles in the network were used to determine corridor travel time, average delay, and stopped delay. Measures of effectiveness for a representative sample of vehicles that enter at the furthest north or south points of the corridor and traverse the entire length of the corridor were output. Twenty five percent of the total vehicles which traversed the entire corridor were randomly selected as "probe vehicles". Delay metrics were output for these vehicles and used to compare the different scenarios.

Each alternative was evaluated in VISSIM. Microscopic simulation modeling uses random seeds to introduce randomness into the model. As a result, different results will occur for each different random seed that is used. A selected number of runs are typically made to account for variation. In this case, 20 runs were evaluated for each scenario for each alternative. The same random seeds and incremental steps were used between alternatives so that results were comparable. VISSIM allows a number of runs to be made and then the model aggregates the results.

CASE STUDIES

The following sections describe the two case studies.

US 69/Grand Avenue corridor in Ames, Iowa

US 69 (Grand Avenue) is a signalized corridor in Ames, Iowa. The corridor is a four-lane undivided major collector with an annual average daily traffic (AADT) of 17,000 with 1 percent heavy trucks and transit buses. The corridor serves residential (driveways), local (local collector streets) and through traffic (major collector). The majority of land use along the corridor is residential, with the exception of the area south of 6th Street and north of 24th Street. South of 6th Street is a downtown business district which has significant strip commercial development. The development just north of 24th Street includes a mall, big box retail, a grocery store, and various small retail and other businesses.

Five signalized intersections, as shown in Figure 3, are present along the 1.4 mile section of the corridor. Table 1 provides details for each of the five intersections along the corridor. The intersection at 13th Street and Grand Avenue has 2,900 vph during the afternoon peak hour and is the most congested intersection along the corridor. The intersection serves the city as a cross point for two major roadways. 13th Street is the primary route to Iowa State University from the north and east of Ames, including the route from Interstate 35, as well as a direct route to the hospital and medical campus. No left-turn lanes are currently present for any of the approaches, which cause significant delay. The traffic signal has a split phase signal operation to accommodate the high number of left turning vehicles. 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 and safety through the corridor. The city reported that the existing intersection configuration performed at a LOS of F, with an average peak-hour delay of 207 seconds (3.5 minutes).

Signal plans were obtained from the City of Ames. The city uses the intersection at 13th and Grand as the zero point of offset coordination for the signals. Offsets for the other four intersections vary between 20 and 80 seconds.

Three intersection alternatives were considered. The first alternative included using the existing geometry with updated optimized signal timing and coordinated offset. The existing intersections were optimized first using Synchro and then coded into VISSIM using the NEMA phase editor. The second alternative included the addition of left lanes at the intersection of 13th Street and Grand Avenue for each approach and the optimization of the signal timing and offsets including the left turn lanes. The third alternative replaced the signal at 13th and Grand with a two-lane roundabout leaving the original offset optimized signal timing plan, for the remained of the intersections. The two-lane roundabout was laid out at the planning level but design guidelines from FHWA's *Roundabouts: An Informational Guide* (6) were referenced. Planning level design features included a 174 foot (53.7 m) inscribed circle diameter with a 34 foot (10.4 m) circulating roadway width and 15 foot (4.6 m) truck apron. The existing layout of the intersection and a schematic of the three alternatives are shown in Figures 4, 5, and 6.

All alternatives were modeled in VISSIM according to the procedure described previously. The afternoon peak period from 5:00–6:00 PM was the model scenario with a 15 minute loading time. The posted speed limit along the corridor is 35 mph (56 kph). The speed distribution specified for the each of the alternative models was between 29.8 to 36 miles per hour (48 to 58 kph). However, depending on the operation of each alternative, vehicles may not have reached speeds within this distribution.

The model was calibrated using an "average car" travel time study. These values were compared to the results found in the existing condition model for travel time.
Several measures of effectiveness were used to compare the three alternatives. Total travel time, total stopped delay, and total average delay through the corridor was output from VISSIM for each alternative. Average delay is the total delay per vehicle which is computed by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time it would take to traverse the entire corridor if there were no other vehicles, signal controls, or other stops in the link (5). Stopped delay is the time a vehicle is stopped in queue waiting to access the intersection. In most cases, VISSIM outputs measures of effectiveness for individual intersections rather than for a corridor. As mentioned previously, in order to obtain corridor information, "probe vehicles," described above, were coded into the model. Data is captured for these vehicles for their entire journey.

Results from the analysis for each alternative are shown in Figure 7. Results are shown by direction of travel. Northbound is the predominant direction of travel for the afternoon peak period. The results show delay and travel time for probe vehicles travelling through the corridor. Vehicles turning onto and off of the system mid-corridor were not included in the analysis.

As illustrated in Table 2, the existing alternative which had an optimized signal timing plan, resulted in higher travel time, stopped delay, and average delay than the other two alternatives in both directions. Results for the northbound direction of travel indicate that the roundabout alternative produced lower average delay and stopped delay than the alternative with signals and left-turn lanes. However, similar travel times resulted for the two alternatives. For the southbound direction of travel, the signal with left-turn lanes alternative produced lower average delay, stopped delay, and travel time than the roundabout alternative.

Overall, considering both the northbound and southbound results, the signals with left-turn lanes and roundabout alternatives have similar results, suggesting that in this scenario a two-lane roundabout does not provide a significant advantage in terms of traffic operations, at these traffic volumes when compared to the alternative where left turn lanes are added. However, corridor operation is only one of the many factors considered when evaluating a corridor and/or intersection. This case study did not evaluate the potential safety impacts of the roundabout compared to the signalized intersection with left turn lanes.

Radio Drive / County Road 13 corridor in Woodbury, Minnesota

The second case study was a corridor along Radio Drive/County Road 13 in Woodbury, Minnesota outside of the Minneapolis/St. Paul, Minnesota metro area. 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 intersection at Radio Drive and Bailey Road has 1,200 entering vehicles during peak hour. The land use along the corridor is predominantly residential with a school east on Bailey Road. The one-mile corridor included in this case study had three major intersections, one four-way stop and two signalized intersections, as shown in Table 3 (The four-way stop was being constructed as a two-lane roundabout, in 2007, while this study was being conducted). A map of the corridor is shown in Figure 8.

Two alternatives were considered in the VISSIM analysis. The first included the existing signalized corridor with a four-way stop at the Bailey Rd and Radio Drive intersection. The second alternative modeled the signalized corridor was with a two-lane roundabout at the Bailey Rd and Radio Drive intersection. The roundabout geometry utilized was from the planning level layouts of the intersection. The peak period modeled was 5:00 – 6:00 PM for both scenarios with 15 minutes of traffic loading time. Both models included two speed distributions based on the posted speed limits of 50 mph for north- and southbound, and 35 mph (56.4 kph) for east- and westbound. A speed distribution was selected for these two posted speed limits which included 46.6 to 60.2 mph (75.0 to 96.9 kph) for north- and southbound, and 29.8 to 36 mph (48 to 58 kph) for east- and westbound.

The results compared delay, stopped delay, and travel time for "probe vehicles" travelling through the system. Vehicles turning onto and off of the roadway at the signalized intersections and residential streets were not included in the analysis. Data for average travel time, stopped delay, and average delay through the corridor were output from VISSIM. Results from the analysis for each alternative are shown in Table 4 and are shown by direction of travel.

As illustrated, a small difference in total travel time resulted between the two alternatives for both the northbound and southbound directions of travel. Stopped delay was slightly longer for the four-way stop controlled alternative than for the two-lane roundabout alternative for both directions of travel. Average delay was 10 and 17 seconds longer for the four-way stop alternative for both the northbound and southbound directions of travel, respectively, than for the two-lane roundabout alternative.

Overall, considering both the northbound and southbound results, the two-lane roundabout has an advantage over the four-way stop controlled alternative in terms of operations for these traffic volumes (1,200 vph – peak hour), specifically average delay. Similar to the first case study, safety of the alternatives was not evaluated as a part of this analysis.

SUMMARY AND CONCLUSIONS

Minimal research is available to compare the traffic flow impacts of implementing roundabouts within a signalized corridor. As a result, two case studies were developed using VISSIM microscopic traffic simulation modeling software to evaluate the impacts. In each case, one intersection along the signalized corridor was evaluated as a two-lane roundabout. Average travel time, stopped delay and average delay for the corridor were compared in VISSIM to evaluate each corridor and the subsequent alternatives.

The US 69/Grand Avenue corridor in Ames, Iowa was modeled to compare three alternatives at an existing signalized intersection located in the middle of a coordinated signal system (13th Street and Grand Avenue intersection). The existing intersection has no left turn lanes and is operating with a split-phase traffic signal to accommodate the left turning vehicles. The city reported that this intersection performs at a LOS of F, with an average peak-hour delay of 207 seconds. The existing conditions were calibrated in VISSIM. The first alternative consisted of the existing traffic geometry with optimized signal timing and offsets. The second alternative provided left turn lanes at the intersection with optimized signal timing and offsets. The third alternative included a two-roundabout at the intersection where upstream and downstream signals were also optimized. Overall, the signals with left-turn lanes and roundabout alternatives had similar results, considering both northbound and southbound results together. This suggests that a roundabout in this scenario does not provide a significant advantage in terms of traffic operations through the corridor as compared to the alternative where left turn lanes were added. Conversely there was no evidence that the roundabout adversely affected traffic flow.

The Radio Drive corridor case study in Woodbury, MN included two signalized intersections and a comparison of a four-way stop controlled intersection to a two-lane roundabout. Results from VISSIM indicate that a small difference in total travel time resulted between the two alternatives for both the northbound and southbound directions of travel. Stopped delay was slightly longer for the four-way stop alternative than for the roundabout alternative for both directions of travel. Average delay was 10 and 17 seconds longer for the four-way stop alternative for both the northbound and southbound directions of travel, respectively.

In summary, the roundabout alternatives in both case studies did not result in significant operational benefits for the two signalized corridors for the traffic volumes evaluated. However, implementation of roundabouts in a signalized corridor did not appear to adversely impact traffic flow or operations either. It is now even more evident that additional research is needed in this area to evaluate more corridors and various traffic volumes.

Traffic operations measures of effectiveness were the only considered in these analyses. The safety and air quality impacts of a roundabout versus other types of traffic control should also be fully considered when determining whether to implement a roundabout in a signalized corridor.

ACKNOWLDEGEMENTS

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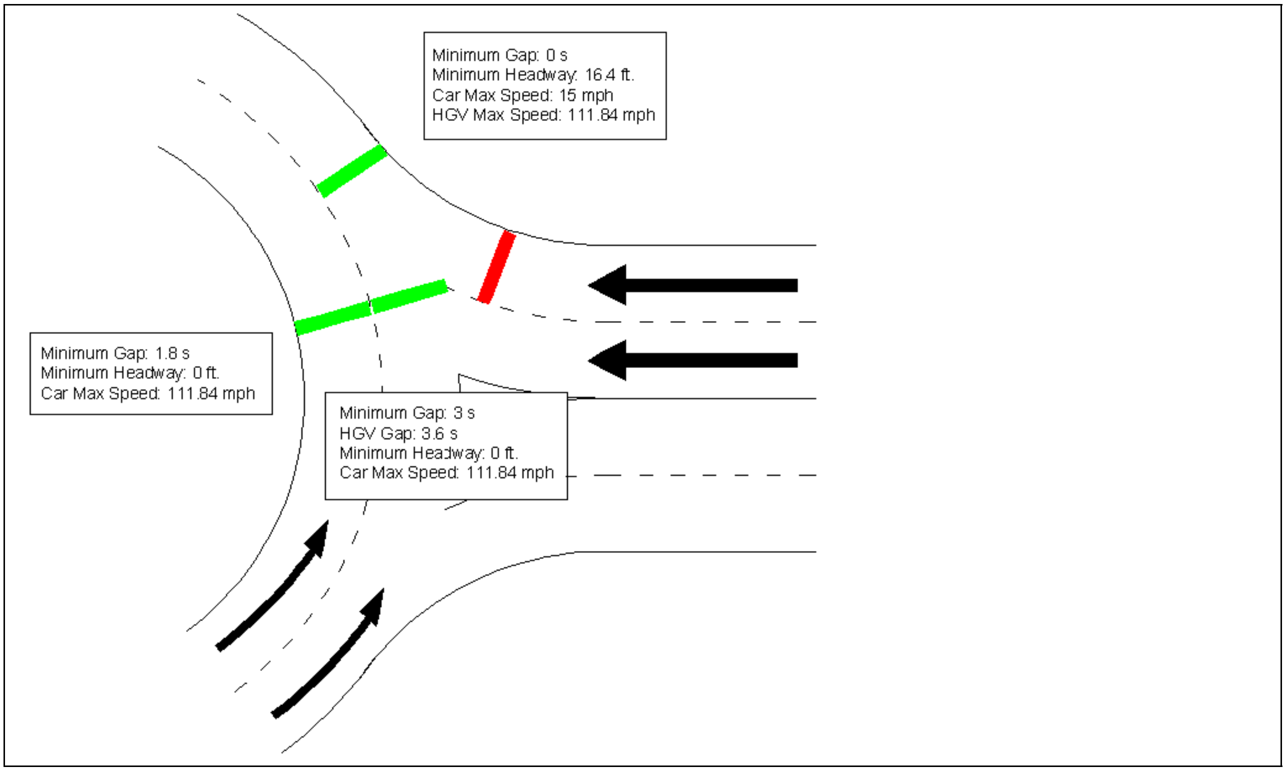

FIGURE 1 Priority rules for outside lane (image source: VISSIM User Manual, 2007)

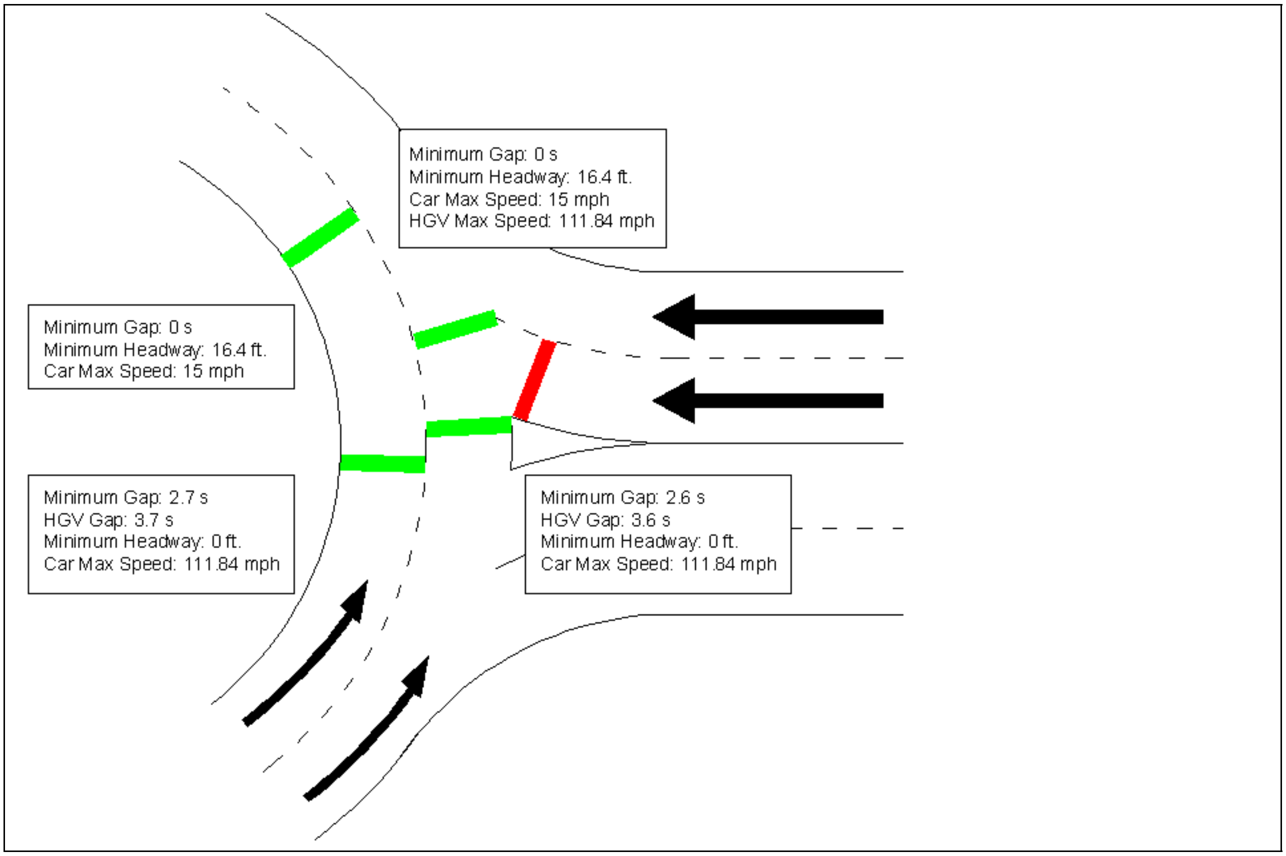

FIGURE 2 Priority rules for inside lane (image source: VISSIM User Manual, 2007)

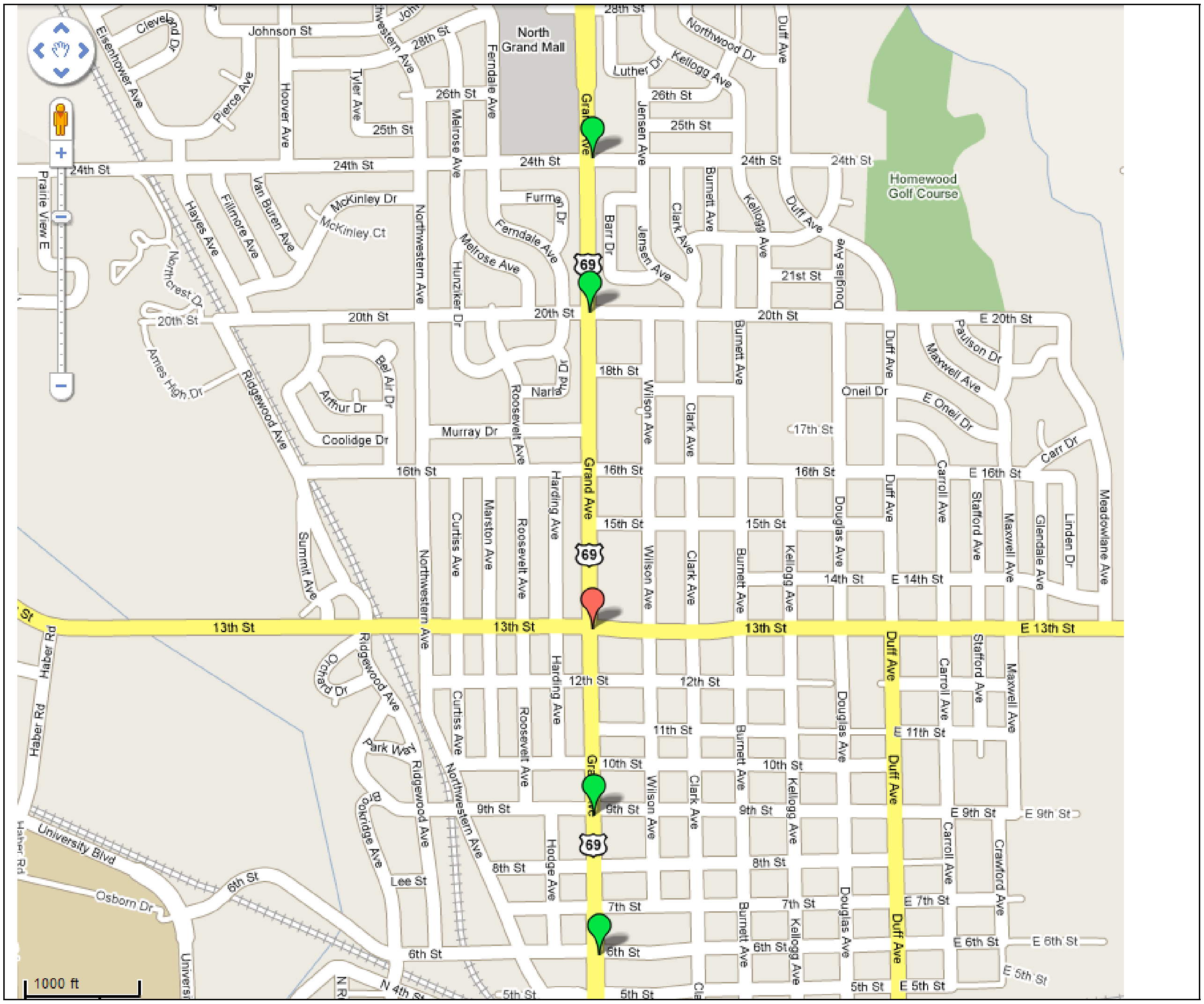

FIGURE 3: US 69 Corridor (Map source: Google Maps)

FIGURE 4   Existing geometry at 13th Street and Grand Avenue (Aerial image source: Story County, Iowa)

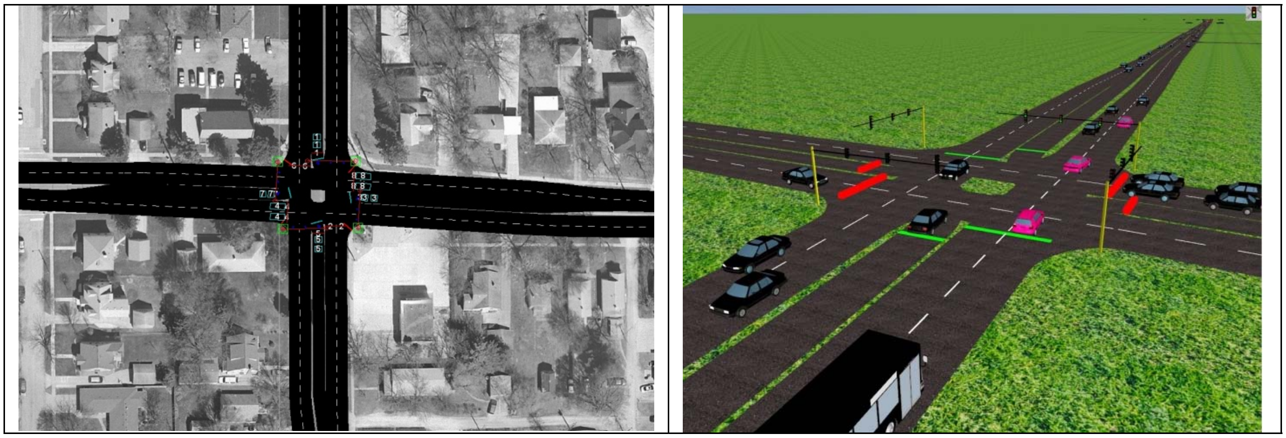

FIGURE 5 Alternative with addition of left-turn lanes at 13th Street and Grand Avenue (Aerial image source: Story County, Iowa)

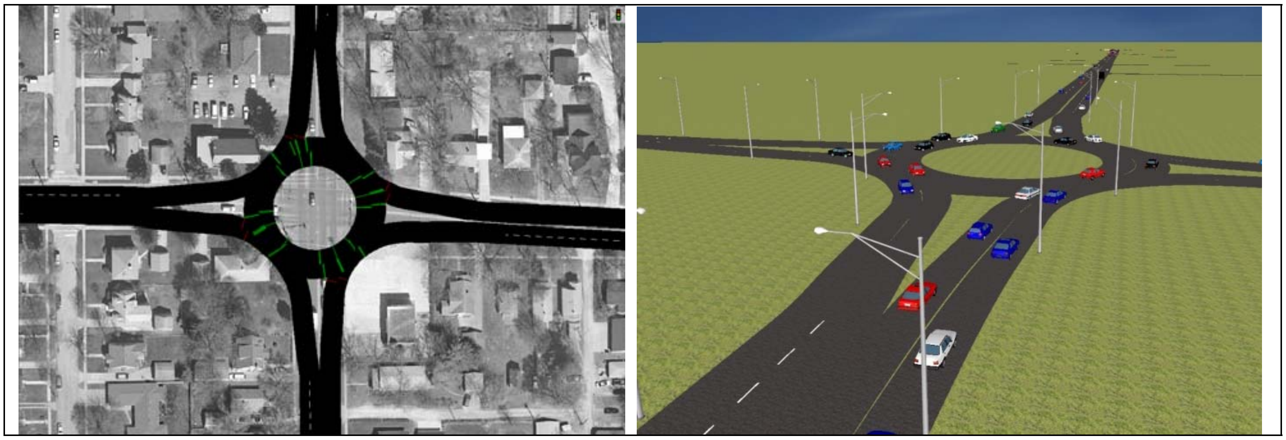

FIGURE 6 Roundabout alternative at 13th Street and Grand Avenue (Image Source: Story County, Iowa)

Figure 7: Existing geometry of the four-way stop controlled intersection and of the two-lane roundabout after construction (Aerial image source: Washington County, MN)

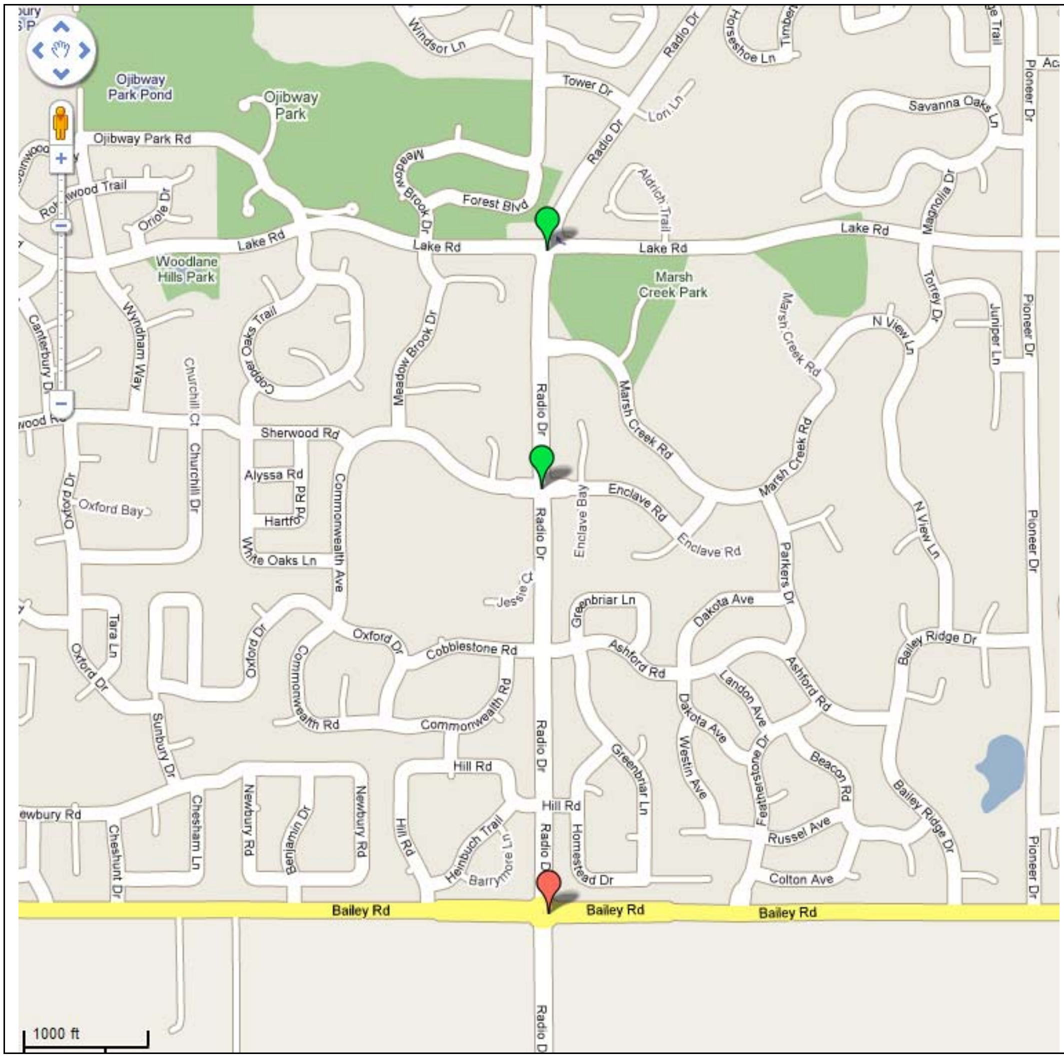

FIGURE 8 Radio Drive in Woodbury, Minnesota (Map Source: Google Maps)

TABLE 1 US 69/Grand Avenue Corridor

Intersection	**Signal Type**	**Distance to the next analysis intersection**
6th St/Grand Ave	Fully-actuated	1050 ft (320.3 m)
9th St/Grand Ave	Semi-actuated	1580 ft (481.9 m)
13th St/Grand Ave	Split phase	2640 ft (774.7 mi)
20th St/Grand Ave	Semi-actuated	1320 ft (402.6 mi)
24th St/Grand Ave	Fully-actuated	--

TABLE 2 Results for US 69/ Grand Avenue Corridor in Ames, Iowa

	Stopped Delay (sec.)	**Average Delay (sec.)**	**Travel Time (sec.)**
Northbound			
Existing Conditions	72.4	103.5	242.2
2-Lane Roundabout	14.1	40.9	200.5
Added Left Turning Lanes	27.2	48.6	200.9
Southbound			
Existing Conditions	72.3	103.5	279.9
2-Lane Roundabout	35.4	74.0	235.9
Added Left Turning Lanes	27.1	48.5	225.4

TABLE 3 Radio Drive/County Highway 13 Corridor

Intersection	**Intersection Type**	**Distance to the next intersection**
Bailey Rd/Radio Dr	Four-way Stop	3170 ft (966.9 m)
Commonwealth Ave/Radio Dr	Semi-actuated Signal	2110 ft (643.6 m)
Lake Rd/Radio Dr	Fully-actuated Signal	--

TABLE 4 Results for Radio Drive Corridor in Woodbury, Minnesota

	Stopped Delay (sec.)	Average Delay (sec.)	Travel Time (sec.)
Northbound			
4-Way Stop Controlled	16.0	32.8	185.3
2-Lane Roundabout	14.1	22.9	184.8
Southbound			
4-Way Stop Controlled	15.5	40.6	198.2
2-Lane Roundabout	11.5	23.9	194.3