EVALUATION OF A SERIES OF ROUNDABOUTS IMPLEMENTED ON SOUTH GOLDEN ROAD

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Introduction

The implementation of roundabouts on a heavily traveled urban commercial corridor has potential for maintaining overall level-of-service through the corridor while achieving a high degree of traffic calming and safety, both in terms of speeding along the corridor and in terms of the number of traffic conflicts occurring at major intersections. In 1998, the City of Golden, Colorado implemented a plan that would transform a one-kilometer section of South Golden Road, a major arterial street serving southeast to northwest movement and a commercially active area with many deeded accesses.

The goals for redevelopment were to improve the aesthetics, increase vehicle and pedestrian safety, minimize delays at major intersections, reduce travel speeds between intersections and maintain through capacity. Figure 1 shows South Golden Road in 1998 as an urban arterial corridor consisting of two signalized intersections at Johnson and Ulysses and two stop-controlled intersections at Lunnanhaus and Utah. Major problems were being experienced with speeding between intersections, traffic conflicts at intersections and significant delays, particularly at the Utah intersection. Figure 1 shows the transformation to a series of four roundabouts at Utah, Ulysees, Lunnanhaus and Johnson, which were to address the various traffic concerns.

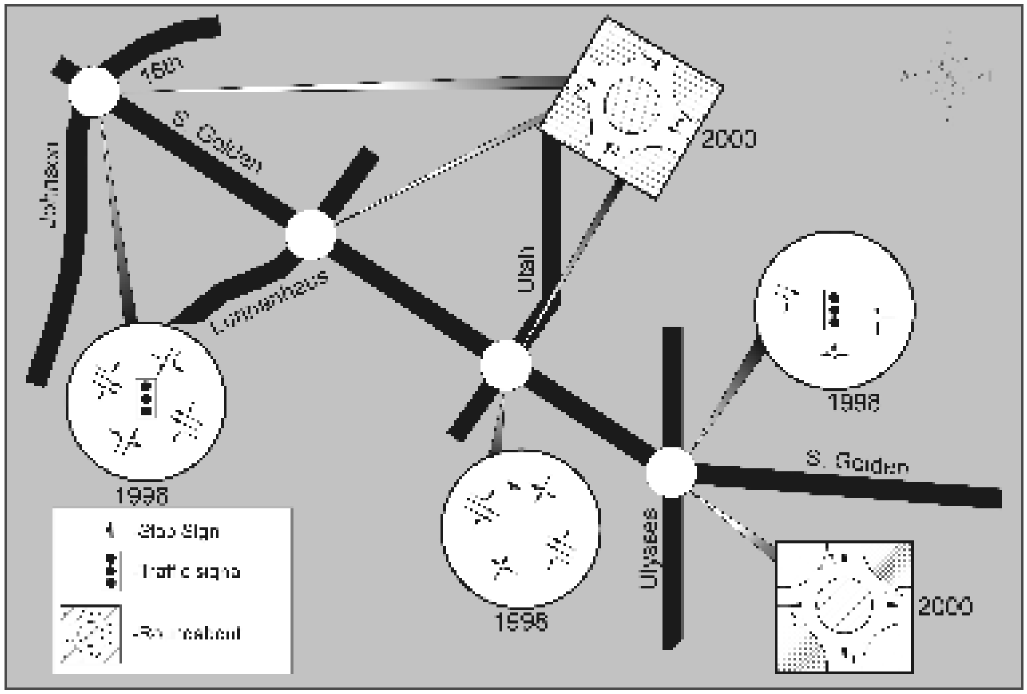


Figure 1 - Lane Configurations and Traffic Control

This study was undertaken to determine the net effect on travel times and vehicle delay at individual intersections due to the transformation of the corridor. Also included is a comparison of pre-construction, post-construction and theoretical travel times through the corridor, delay at individual intersections and a comparison of estimated delay to a Synchro/SimTraffic simulation if the corridor had been rebuilt with a new signal at Utah Street/South Golden Road. These performance measures were used to gauge the operational result of the transformation.

Study Methodology

In August1998 and September 2000, intersection and lane geometry measurements were collected in addition to the video-taped traffic data. The post-construction counts were approximately one month after the final asphalt overlay was installed and landscaping was almost completed. In both cases, video cameras were set up on a nearby bluff to record the intersections and collect volumes and vehicle classification for each approach during the peak hours. Queue lengths for some approaches could also be observed from the video tapes.

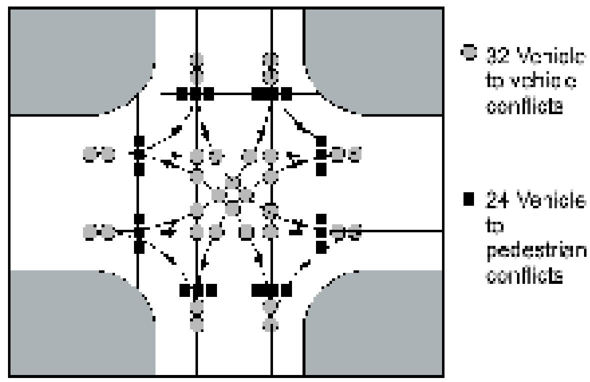
The theoretical timings for each intersection's traffic signal were optimized using the Synchro/SimTraffic 5.0 software program. Travel times within the theoretical model were determined by identifying vehicles as they entered the network and measuring their travel time to respective points in the model.

A comparison of travel times and levels of service between pre-construction, post-construction and simulation configurations was performed to determine the benefits of each.

Safety Benefits of Modern Roundabouts

Roundabouts have a proven safety record that is superior to other forms of traffic control (Oursten and Bared, 1995, Insurance Institute for Highway Safety, 2000, Schoon and van Minnen, 1994). Roundabouts have eight conflict points and the accidents that occur at roundabouts occur at lower speed than those at traffic circles and more traditional intersections. A four-way intersection controlled by a traffic signal or Stop signs has 32 vehicle-to-vehicle conflict points. Figure 2 illustrates the conflict points for both a roundabout and a four-way intersection. The superior safety record of roundabouts is attributed to the following factors:

- the reduction in vehicle speeds
- elimination of high angles of conflict
- reduced complexity of decision making
- splitter islands provide a safe refuge for pedestrians
- splitter islands permit pedestrians to cross one direction of traffic at a time
- a conscious action by all drivers is required regardless of the presence of pedestrians or other vehicles



Corridor Configuration and Volumes

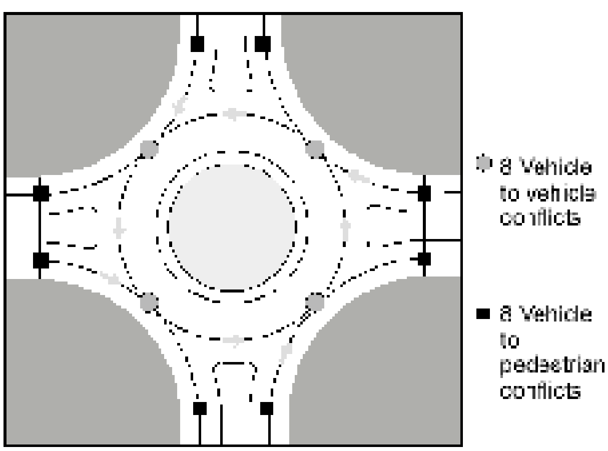


Figure 2 - Conflicts: Roundabout Versus 4-Way

Roundabouts are not appropriate for all intersections just as traffic signals are not appropriate for certain sets of conditions. Given the appropriate conditions, a one-lane roundabout can service between 20,000 and 26,000 vehicles per day (vpd) depending on turning volume distributions. A two-lane roundabout can service between 40,000 and 50,000 vpd (FHWA, 2000).

The South Golden Road corridor consists of four intersections along a 1,000-meter roadway. Prior to reconstruction, the majority of the corridor was 25.6 meters wide consisting of two travel lanes in each direction, a two-way left-turn lane, bike lanes and on-street parking. The lane configurations and traffic control for each intersection in 1998 and 2000 are shown back in Figure 1. South Golden Road is also a bus route and a truck route.

Figures 3 and 4 show 1998 and 2000 peak-hour turning movements at the intersections of Johnson, Utah and Ulysses. All of the intersections were counted simultaneously to eliminate the need to balance volumes; other data collected included vehicle classifications and bicycle/pedestrian counts. The vehicle classification data were needed to calibrate the Synchro/SimTraffic model. Travel times within and through the corridor were collected using the Average Vehicle Method (Robertson, 1994). Sidra 5.20 was chosen as the analysis package for the operation of individual roundabouts because it incorporates a gap-analysis methodology which was selected for the evaluation of roundabouts.

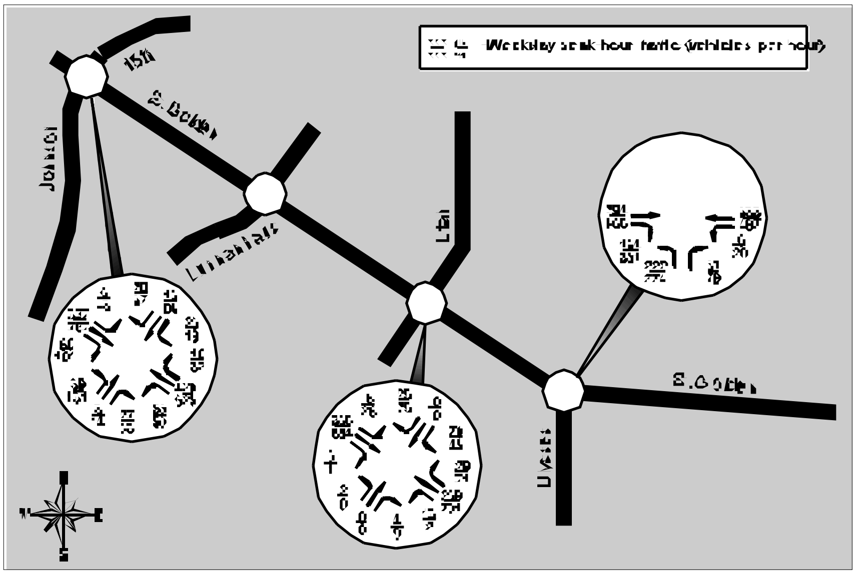


Figure 3 - 1998 Traffic Volumes

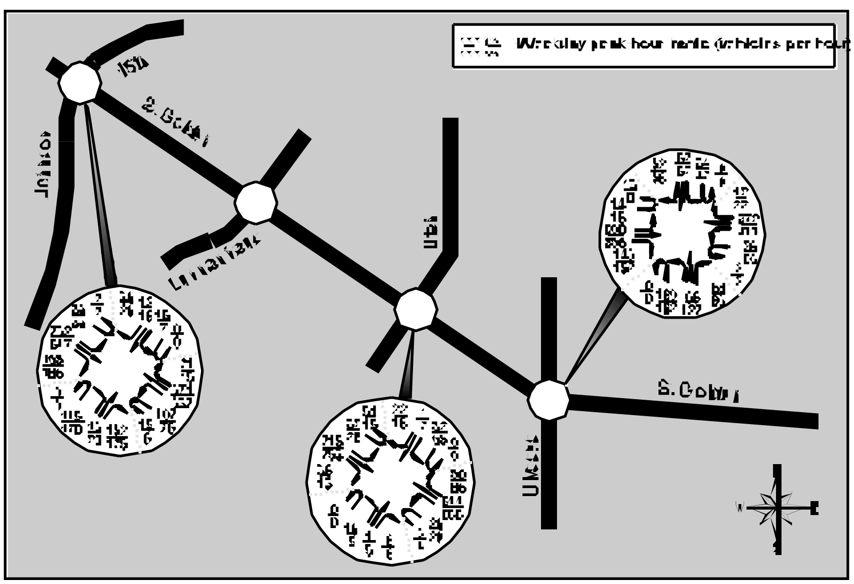


Figure 4 - 2000 Traffic Volumes

Simulation Model Calibration

Synchro/SimTraffic 5.0 was chosen to simulate the corridor signalization scenario and to evaluate possible signal timings, measure theoretical travel times within the corridor and measure intersection delay. Synchro was also used to select appropriate traffic signal timings based on the desired corridor travel speed and traffic volumes. Highway Capacity Software version 4.1 was selected as the analysis software for signalized and unsignalized intersections since it is the industry standard in Colorado and can be compared to Sidra.

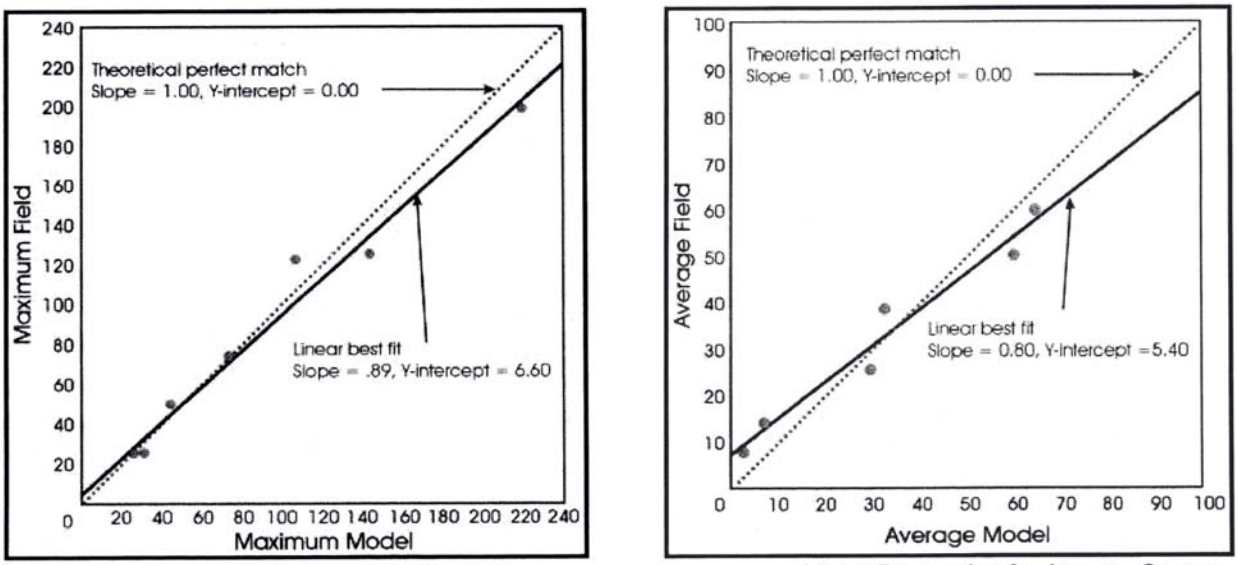
To calibrate the model, observed values of intersection queue lengths were compared with the simulation results. The network was calibrated to the 1998 counts to ensure that the simulated results resembled the actual traffic operations during that period. Adjustments were made to various program variables to reduce the differences between observed and modeled queues. The 2000 volumes were used with the vehicle/driver behavior from the calibrated model.

After calibration, the network was modified to reflect the redeveloped corridor assuming traffic signals were theoretically installed at the Ulysses Street, Utah Street and Johnson Road intersections. Vehicle queues were selected as the variable that would be used to calibrate the model. Queue lengths were simple to measure in SimTraffic and the 1998 video tapes contained enough information on base year queues for comparison. Data was collected from the SimTraffic simulation runs and the video tapes and then compared using linear regression and R-squared tests. Figure 5 shows the plot of peak hour field queue lengths versus the model queue lengths for both the maximum queues and the average queues.

R-squared analyses were performed on the maximum and average queues (for observed and modeled data) to obtain estimates of the percentage variation explained by the simulation model. R-squared estimates the percentage variation explained by a model and is given by the following equation:

$$R^2 = 1 - \frac{\sum (Fieldqueue - Modelqueue)^2}{\sum (Fieldqueue - MeanofFieldqueue)^2}$$

For the maximum queue lengths at the intersections of the South Golden Corridor, the generalized R-squared value is 0.949, and for the average queue lengths the R-squared value is 0.904. As both of these values indicate that over 90 percent of the variation has been explained, it can be stated that the model is a good



Linear Regression for Maximum Queues   Linear Regression for Average Queues

Figure 5 - Field and Model Queue Lengths

predictor of real world queues. The slopes and intercepts of each linear regression analysis of observed versus estimated data were further tested for accuracy by performing t-tests. The t-tests proved that for both the average queue and maximum queue, the slopes were not significantly different than 1.0 and intercepts were not significantly different than 0. This is further confirmation that the SimTraffic model was calibrated to the 1998 field observations.

Travel Times and Levels of Service

For both the 1998 and 2000 counts there were no special events, incidents, or accidents that occurred in the corridor. Lack of available information in 1998 means that these travel times are less comprehensive than the 2000 travel times and simulation travel times. The 1998 noon-hour travel time data and corresponding peak hour counts were not collected as it was erroneously believed that the morning peak hour was higher than the noon peak hour. After the 48-hour counts were reviewed, it was apparent that the noon peak hour is significantly busier than the morning peak. This is primarily due to the high number of restaurants concentrated in the corridor. Since the noon peak hour contains high turning and through volumes on S. Golden Road, analysis of this peak was considered more important than the morning peak hour.

Comparisons of Configurations

There are significant differences between each of the three corridor configurations. Many of the differences have major impacts on delay and travel times. An attempt has been made to limit the comparisons between configurations that are essentially equivalent except for the roundabouts. For example, the comparison of Ulysses Street LOS in 1998 versus Ulysses Street LOS in 2000 or versus the SimTraffic model is irrelevant as the intersection was three-legged in 1998 but four-legged in 2000 and in the model. Similarly, the travel times required to traverse the entire corridor for 1998 versus 2000 and versus the SimTraffic model are not directly comparable for two primary reasons: 1) the posted speed limit on South Golden Road was lowered from 35 mph to 25 mph when the roundabouts were installed; and, 2) installation of any traffic control device will increase delay on the approaches that were not previously controlled.

Intersection Delays and Level of Service

Both 1998 and 2000 levels of service were calculated with Sidra and HCS software and are summarized in Table 1. The levels of service and delays for the intersections are the theoretical delays using the HCS software and the timings from Synchro. Also listed are the expected delays from an average of several separate simulation runs of SimTraffic.

Table 1
Intersection Level of Service and Delay per Vehicle (seconds)

		1998		2000 Round-abouts		2000 Signals		2000 Signals	
		AM	**PM**	**Noon**	**PM**	**Noon**	**Noon**	**PM**	**PM**
Software[1] / **Intersection**		H	H	S	S	H	ST	H	ST
Ulysses/S. Golden[2]		A 7.5	B 14.7	B 12.0	B 13.6	B 16.3	- - - 19.6	B 18.4	- - - 14.3
Utah/ South Golden	Entire Intersection	- - - 2.3	- - - 2.6	B 12.2	B 12.3	A 2.2	- - - 6.3	A 2.4	- - - 6.1
	Only Utah Approach	D 32.3	F 61.7	B 15.0	B 15.7	C 28.9	- - - 23.0	C 29.6	- - - 25.7
Johnson/S. Golden		A 7.5	A 8.4	B 11.9	B 11.8	B 12.8	- - - 13.7	B 12.6	- - - 21.3

Notes:
1 - Analysis Software used was H - Highway Capacity Software 2000, S - Sidra 5.20 or ST - SimTraffic 5.0
2 - This intersection was three-legged in 1998 and four-legged in 2000

Operationally, there were no significant congestion problems in 1998 or 2000. In 1998 during the afternoon peak hour, it was difficult for vehicles to execute a left turn from Utah Street onto S. Golden Road due to the large through volumes. This is confirmed by a calculation of more than one minute average delay per vehicle on Utah Street.

The levels of service for noon and afternoon peak hours in 2000 are reasonably constant. Each intersection operated at LOS "B". As expected, the delay on Utah Street was significantly reduced, during the afternoon peak hour, to only 15.7 seconds from 61.7 seconds. At the same time, vehicles on South Golden experienced more delay at the Utah intersection due to the installation of the roundabout. An increase in delays for vehicles on South Golden was inevitable as the introduction of any control (signal, roundabout or Stop-sign) introduces delay to this former thoroughfare with priority traffic flow. Despite the addition of the fourth approach, during the evening peak hour the Ulysses intersection experienced a drop in delay per vehicle after the roundabout was installed.

Corridor Travel Times for the Simulation

All of the travel times for the corridor are shown in Table 2. Travel times from the signalized corridor simulation runs indicate that the signalized option would have greater travel times than the 1998 configuration. The increase would be due to a combination of factors including; 1) a reduced speed limit, 2) the introduction of traffic control for north/south movements at Utah, 3) sub-optimal intersection spacing for the desired progression speed, and, 4) the addition of a fourth approach to the Ulysses intersection.

Table 2- Corridor Travel Times (seconds)

	1998 PM	2000 Noon Roundabouts	2000 PM Roundabouts	2000 Noon Signals	2000 PM Signals
S. Golden South to S. Golden North	109	103	113	151	163
S. Golden North to S. Golden South	114	115	114	140	155
Ulysees West to S. Golden North	114	124	108	147	149
S. Golden North to Ulysees West	102	101	106	119	113
Utah East to Ulysees West	- - -	46	- - -	90	84
Ulysees West to Utah East	- - -	46	- - -	84	63
Ulysees West to Mid Point	48	59	50	77	73
Mid Point to Ulysees West	31	41	42	44	45

S. Golden South to Mid Point	36	46	52	85	72
Mid Point to S. Golden South	48	52	59	68	67

Table 2 shows the travel times in the corridor for the various scenarios. Operational delay associated with mid-block turning movements is assumed to be equal in all cases. Prior to the reconfiguration of the South Golden Road corridor, the posted speed limit in the study area was 35 mph. The current design has a posted speed limit of 25 mph. A 1998 speed study indicated that the 85^{th} percentile speed was approximately 48 mph. In combination with the installation of the roundabouts, the lower speed limit has contributed to a reduction in the 85^{th} percentile speed to approximately 33 mph. Over the length of the corridor, that would translate into approximately an additional 21 seconds of travel time without any delay due to congestion.

As shown in Table 2, the travel times to and from Utah Street are significantly less when comparing the roundabout configuration to the signalized configuration. Travel times through the entire network are similar with the roundabouts compared to the original configuration. If the desired speed reduction could have been achieved without changing the intersection controls, travel times in the corridor would have been increased by 21 seconds. Adding 21 seconds to the original travel times results in times that indicate the roundabout option would be more efficient than the original configuration at moving traffic.

Travel times are 40 to 50 seconds less with roundabouts compared to a signalized configuration. Despite an increase in delay for South Golden Road at Utah Street with a roundabout, the difference is primarily due to decreases in stopped time at the Johnson and Ulysses intersections.

Conclusions

This study did not attempt to identify every factor that may or may not have had an impact on delay in the South Golden corridor, but it focused on the resulting operational changes due to the transformation of the entire corridor. From the analysis the following conclusions can be made:

- The installation of a series of roundabouts on South Golden Road has resulted in lower travel times than would have been the case had a series of traffic signals been installed;
- The installation of a roundabout at the intersection of Utah Street/South Golden Road has resulted in a significant reduction in delay for Utah Street traffic;
- If a traffic signal had been installed at Utah Street/South Golden Road, the reduction in delay for Utah Street traffic would have been less than with a roundabout;
- This corridor was slated to undergo a transformation either with raised medians and roundabouts or raised medians and a new signal at Utah Street. The speed limit was to be reduced regardless of which option was selected. The results clearly indicate that travel times in the corridor and the intersection delays are less for the roundabout option than the traffic signal option.

It should be noted that this study is one of the first to compare overall corridor travel times and intersection delay where a series of signals plus stop control are replaced by a series of roundabouts. There are no indications that the findings of this study are limited to the corridor in question and could not be applied to other locations.

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