PERFORMANCE EVALUATION OF MODERN ROUNDABOUTS ON SOUTH GOLDEN ROAD

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In 1998, the City of Golden, Colorado implemented a plan that would transform a one-kilometer section of South Golden Road. South Golden Road is both a major arterial street serving southeast to northwest movement and a commercially active area with many deeded access points.

The goals for redevelopment were to improve the aesthetics, increase vehicle and pedestrian safety, reduce delays for entering traffic at Utah Street, reduce travel speeds and maintain through capacity. Two concepts were considered by the City of Golden. The first concept consisted of medians and a new signal at Utah and the second concept was also with medians but roundabouts at Utah and Ulysses instead of signals. A series of four roundabouts was ultimately implemented with roundabouts at Utah, Ulysees, Lunnanhaus and Johnson.

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. 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.

Modern Roundabouts

Despite having a well-established international presence, it has only been during the past several years that roundabouts have been considered as a traffic control option with much frequency in North America. Not until the 2000 version of the Highway Capacity Manual (FHWA, 2000) was released was there a unified attempt to describe the design and operation of North American modern roundabouts.

Roundabouts have characteristics that differentiate them from traffic circles, rotaries and traffic calming circles. The primary distinctions are listed in Table 1. Figure 1 illustrates the features of a typical modern roundabout design.

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). The superior

Table 1
Distinctive Characteristics of Roundabouts

	Roundabouts	Traffic Calming Circles	Traffic Circles/ Rotaries
Traffic Control	YIELD control on all entries	May use STOP, YIELD or no control	May use STOP, YIELD or no control
Priority	Circulating vehicles always have the right of way	Circulating vehicles typically have the right of way	Some traffic circles require circulating traffic to yield to entering traffic
Design Speed	Arterial - <50 km/h Local - <25 km/h	Low speed	May be 70 km/h or higher
Pedestrian Access	Only allowed across the approach legs behind the yield line	Typically on the approach legs ahead of the yield line	Some circles allow access to the center island
Direction of Circulation	Always counter-clockwise and pass to right of the center island	Left turning vehicles may be permitted to pass to the left of the island	Typically counter-clockwise and pass to right of the center island
(AUSTROADS, 1993 and FHWA, 2000)			

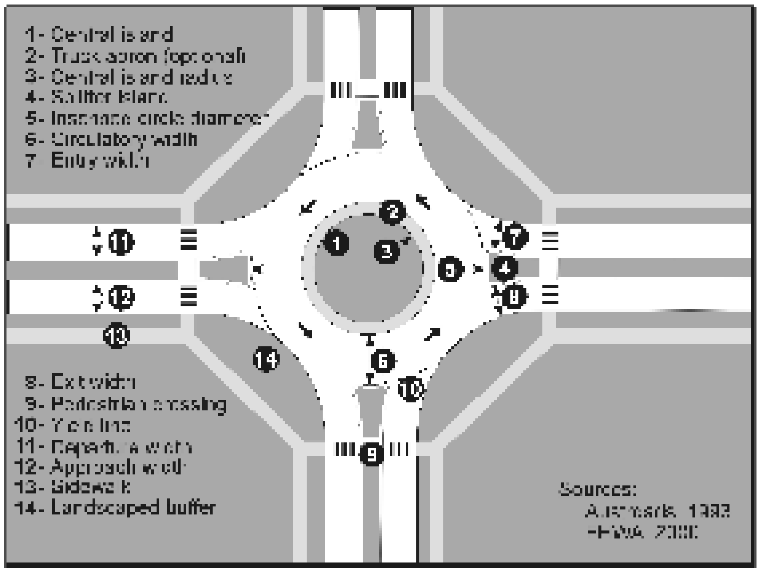

Figure 1 - Typical Roundabout Design Components

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
- roundabouts require a conscious action by all drivers regardless of whether pedestrians or other vehicles are present

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).

Corridor Configuration and Volumes

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. Figure 2 illustrates the lane configurations and traffic control for each intersection both in 1998 and 2000. 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

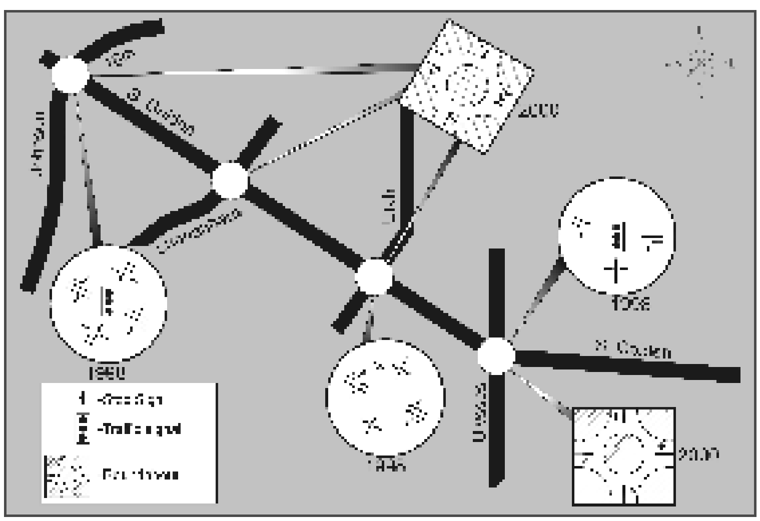

Figure 2 - Lane Configurations and Traffic Control

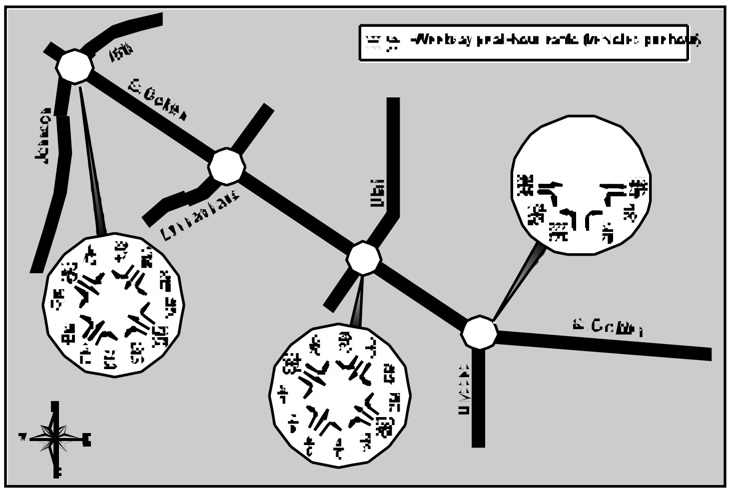

Figure 3 - 1998 Traffic Volumes

were counted simultaneously to eliminate the need to balance volumes. Other corridor data collected included vehicle classifications and bicycle/pedestrian counts. The vehicle classification data were used 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.

Simulation Model Calibration

Synchro/SimTraffic 5.0 was chosen to simulate the corridor signalization scenario. This included evaluating possible signal timings, measuring theoretical travel times within the corridor and measuring delay at the intersections. 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

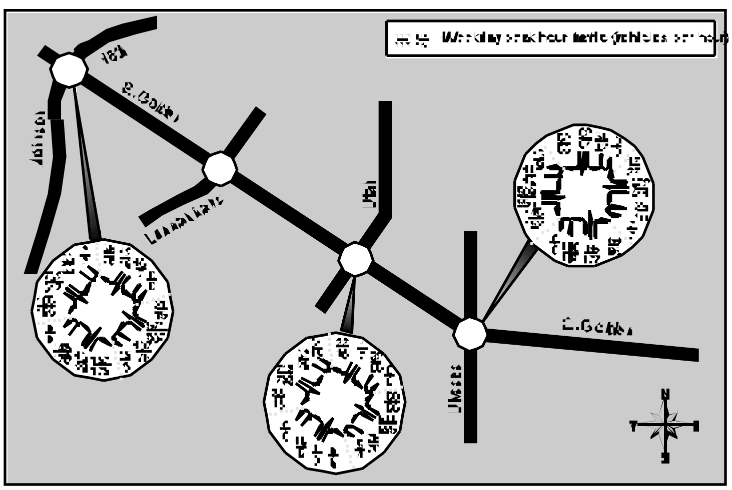

Figure 4 - 2000 Traffic Volumes

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

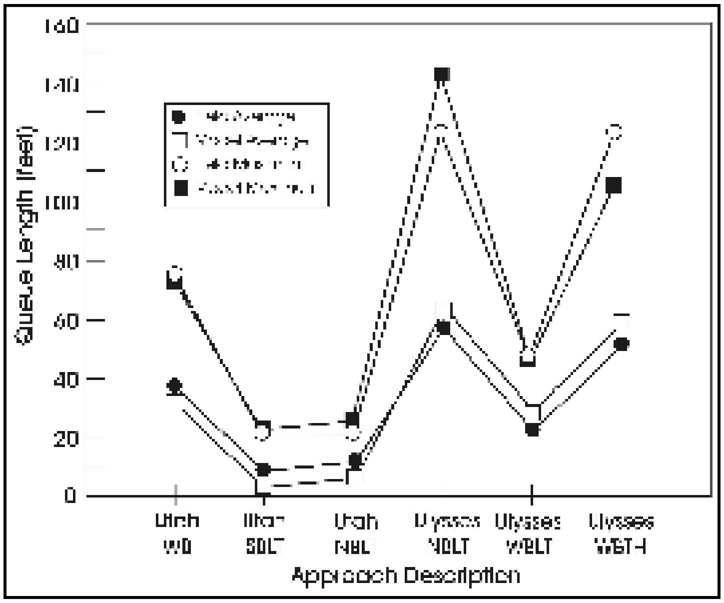

Figure 5 - Peak Hour Queue Lengths

comparison. Figure 5 shows these values illustratively. Data was collected from the SimTraffic simulation runs and the video tapes and then compared using linear regression and R-squared tests.

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

For the maximum queue lengths, the generalized R-squared value for the average queue lengths of the South Golden Corridor, is 0.904 and for the maximum queue lengths the R-squared value is 0.949. 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 predictor of real world actions.

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 showed 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

The 1998 travel times are less comprehensive than the 2000 travel times and simulation travel times due to a lack of available information in 1998. During both the 1998 and 2000 counts there were no incidents or accidents that occurred in the corridor. The 1998 noon-hour travel time data and 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.

Both 1998 and 2000 levels of service were calculated with Sidra and HCS software and are summarized in Table 3. Operationally, there were not any 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 quite constant. Each intersection operated at LOS "B". As expected, the delay on Utah Street was significantly reduced during the afternoon peak hour (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

Table 3
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

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 previously uncontrolled thoroughfare. 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.

Travel Times and Levels of Service for the Simulation

All of the travel times for the corridor are shown in Figure 6. 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.

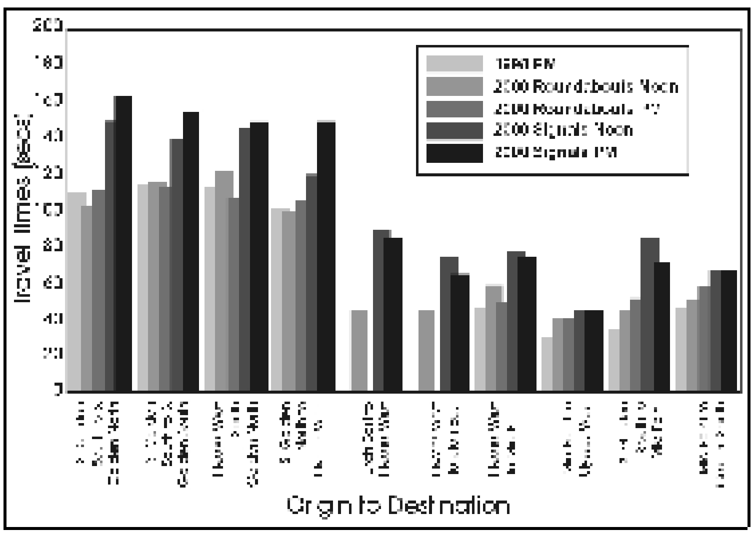

Figure 6 - Corridor Travel Times

The levels of service and delays for the intersections shown in Table 3 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.

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.

Comparison of Intersection Delays and Levels of Service

Figure 7 illustrates the evening peak hour delays for various intersections and approaches. In a comparison of 2000 afternoon peak hour delays, the roundabouts have the lowest delay per vehicle at the Ulysses and Johnson intersections. It is evident that the construction of the Utah roundabout has reduced the delay per vehicle on Utah Street. The delay per vehicle at Utah increases for the overall intersection but is dramatically reduced for the Utah approach with either a signal or a roundabout. A similar but less extreme improvement would occur if a signal was installed instead of a roundabout. Either configuration would have achieved the City's goal of reducing delay for Utah Street traffic entering the corridor.

Comparison of Corridor Travel Times

Figure 6 illustrates the travel times in the corridor for the various scenarios. Operational delay associated with mid-block turning

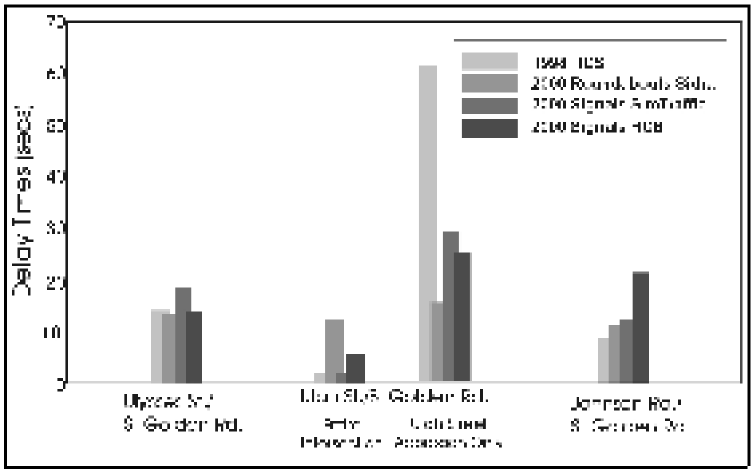

Figure 7 - Peak Hour Delays By Approach

movements is assumed to be equal in all three 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 85th 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 85th 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 Figure 6, 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 corridor. Instead it focused on the resulting operational changes due to the transformation of the entire corridor. From the analysis of the field data and simulations for South Golden Road, 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 of this study clearly indicate that travel times in the corridor are less for the roundabout option than the traffic signal option for both intersection delay and corridor travel times.

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. This study represents an argument for examining a series of roundabouts as a feasible alternative under certain corridor conditions.

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