Simulated Capacity of Roundabouts and Impact of Roundabout Within a Progressed Signalized Road

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Abstract
Many intersections in the urban areas are signalized. As roundabouts are beginning to multiply, they are being considered adjacent to signalized intersections and for replacing some signalized intersections. Traffic simulation has been used to study the performance of both signalized and un-signalized intersections. This research uses simulation to study the traffic impacts of roundabouts. In this paper, two problems are studied. Firstly, urban single lane and dual lane roundabouts are modeled in VISSIM traffic simulation software. Simulation results are compared with the results of RODEL (empirical model) and aaSIDRA (analytical model). Comparison with real data collected from various sites in United States shows that VISSIM results are closer to the real data than the RODEL and aaSIDRA results. Secondly, the impact of signalized intersection proximity to roundabouts is studied using the developed model. More specifically, the impact of coordinated signalized arterial when a roundabout is inserted within an arterial corridor is studied. Results of average delay measures are comparable to the signalization alternative when the roundabout is operating below capacity. However, at heavy volumes, when the roundabout is operating at capacity, then the performance of signalization is slightly better.

INTRODUCTION

Roundabouts are beginning to multiply in the United States; they are being considered adjacent to signalized intersections and are replacing some of the signalized intersections. Roundabouts have proved to be a safer alternative to at-grade signalized intersection for both motor vehicles and pedestrians (*1*). As roundabouts are becoming increasingly popular in the United States, it is of utmost importance to conduct research on the traffic performance at roundabouts. Traditionally, empirical (e.g. RODEL (*2*)) and analytical (e.g. aaSIDRA (*3*)) models have been developed to study the traffic performance. Empirical models are developed based on regression using data collected at currently operating roundabouts. The analytical models consider geometry, time gaps, and follow-up time among other variables while modeling the roundabouts.

Traffic simulation has been used to study the performance of both signalized and un-signalized intersections. However, simulation has not been used much in the past to study the roundabout performance. One major reason for this is the difficulty to model roundabouts using simulation software. Not many simulation software are flexible enough to allow the user to model roundabouts. VISSIM (*4*) is one of the few simulation software that can be used to model roundabouts. In this paper, two problems are studied. Firstly, urban single lane and dual lane roundabouts are modeled in VISSIM traffic simulation software. Simulation results are compared with the results of RODEL (empirical model) (*2*), aaSIDRA (analytical model) (*3*), and field data. Secondly, the impact of signalized intersection proximity to roundabouts is studied using the developed model. More specifically, the impact of coordinated signalized arterial when roundabouts are inserted within an arterial corridor is studied.

ORGANIZATION OF THE PAPER

The paper is organized in the following way – first section explains the simulation modeling of typical single lane and dual lane roundabouts, second section presents the results of capacity analysis, third section starts the second topic of the paper - roundabout within a signalized arterial, simulation results and conclusions are presented in the final section.

TYPICAL ROUNDABOUTS AND SIMULATION MODELING

The geometry of single lane and dual lane roundabouts modeled in this paper are shown in Table 1. VISSIM simulation software is used to model the traffic operations at roundabouts. VISSIM is a microscopic, time-step and behavior based simulation model developed to model urban traffic operations.

Simulation in VISSIM involves three modules – input module, simulator module, and output module. The input module has a Windows-based graphic user interface. The simulator is used for generation, movement, system status update, and collection of statistical data. The output module is usually either a text file or an animation file (*4*). Figure 1 shows the VISSIM screen shot of single lane and dual lane roundabouts.

A CAD layout of the roundabout is imported into the VISSIM software and set as background on which the VISSIM links are drawn. Appropriate scale and units are entered so that all the measurements are in the same units. While drawing the links, number of lanes, lane widths, and gradients are specified. Desired speeds on the approaches are set between 30mph to 36mph for cars and 25mph to 28mph for trucks; and on entries, circulating, and exiting curves between 15mph to 18mph for cars and 12mph to 15mph for trucks. The most important aspect of modeling a roundabout in VISSIM lies in setting the priority rules for entering, and exiting traffic movements. VISSIM priority rules check for two basic parameters – minimum gap time and minimum headway. Vehicles enter the roundabout only when the time gap and headway as measured from the conflict marker are greater than the respective minimum values. The values for these parameters are set partly based on field experience and partly based on viewing the simulation animation to have no visible collisions between vehicles. But, appropriate caution needs to be taken while setting priority rules, as higher values of these parameters could decrease the capacity of a roundabout considerably.

In VISSIM, a priority rule consists of one stop line and one or more conflict markers that are associated with the stop line (see Figure 2). The stop line decides whether to allow or not to allow the vehicles to cross depending on the current gap time and headway available at the conflict marker (by checking with minimum headway and the minimum gap time set by the user).

First, during the simulation, the current gap time is determined every time step by the time an approaching vehicle will require to reach the conflict marker, assuming it continues to travel at its current speed. If the current gap time is less than the minimum gap time defined for the conflict marker, the corresponding stop line stops any approaching vehicle (see Figure 2) (*4*). Second, the minimum headway can be typically defined as the length of the conflict area. During the simulation, the distance between the conflict marker and the first vehicle approaching it determines current headway. Whenever the current headway is less than the minimum headway, the corresponding stop line stops any approaching vehicle (see Figure 2).

Setting priority rules for a single lane roundabout is straightforward. A minimum time gap of 3s for cars and 3.5s for trucks, a minimum headway of 16ft are used (*4, 5, 6*) (these values are arrived at only after numerous iterations or suggested by the manual/literature). We can see that the time gap used for trucks is higher than the gap used for cars, this is due to the fact that trucks entering the roundabout have lower acceleration capabilities as compared to the acceleration capabilities of cars, and hence would require greater amount of time gap to safely enter the roundabout.

In a single lane roundabout (Figure 3), one stop line is used at each roundabout approach. Two conflict markers are defined for this stop line as shown in the figure (1&2 in the figure). Conflict marker 1 sets the conditions for normal traffic conditions (time gap and headway), while conflict marker 2 secures the conflict area during slow moving traffic and congestion inside the roundabout (headway is the only criteria). Conditions at both the markers must be satisfied for a vehicle to enter the roundabout. As mentioned before, different set of stop lines and the corresponding conflict markers are used for trucks (in the figure the markers for cars and trucks overlap each other). The time gap and headway parameter values are shown in Table 2.

Priority rules are set in a similar way for a dual lane roundabout also, however, the procedure is quite complicated as it involves interactions between two entering lanes and two circulating lanes. Several priority rules are necessary to model the entry of dual lane roundabout. Each priority rule serves a different purpose. Due to the difference in acceleration capabilities and the vehicle lengths, cars and trucks are modeled separately. In Figure 4, the two lanes of roundabout approach are numbered. Outer lane is numbered 1, and the inside lane is numbered 2. There are 12 priority rules that are used in VISSIM to completely define the roundabout entry traffic behavior, 5 rules for lane 1, and 7 rules for lane 2. Due to the space constraint of the paper, it is not possible to show all priority rules. In the following paragraph, three major priority rules are explained.

Entering traffic using lane 1 should satisfy the following conditions to enter the roundabout - 1) look for minimum distance headway (16ft) during traffic conditions where circulating traffic is moving slowly (during congestion within roundabout), 2) look for minimum time headway of approaching circulating vehicles during traffic conditions where circulating traffic is moving at higher speeds (3s for passenger cars and 3.5s for trucks), 3) vehicles entering should also look out for circulating vehicles in the inner lane of the roundabout, by checking for a minimum time gap for the approaching vehicles (2s for both cars and trucks).

Other than the priority rules at the roundabout entrances, priority rules are set at exits also. In Figure 4, inner lane is numbered 3, and outer lane is numbered 4. Vehicles exiting the roundabout from lane 3 should yield for circulating vehicles in lane 4, and vice versa. The priority rules set for these lanes look only for the minimum headway violation (minimum gap time is set to 0s). Minimum headway of 40ft for cars and 60ft for trucks is used on both lanes. Again, these values are obtained only after numerous iterations checking for any potential vehicle incidents.

RESULTS AND CAPACITY COMPARISON

The modeled roundabouts are used to determine capacities by flooding an entry at a time and facilitating a wide variation of circulating volumes. For each approach, the maximum entry capacity and the corresponding conflicting flow are determined from simulation. In VISSIM, we assumed that an approach has reached capacity when the throughput is less than the input volume for that approach by more than 100vph and average delay for that approach exceeds 70s. The same procedure is repeated for several traffic scenarios and the 'maximum entry capacity vs conflicting flow' plot is obtained. Capacity estimates using RODEL, and aaSIDRA are also computed for corresponding circulating volumes.

Figures 5 and 6 show the capacity plots for single lane and dual lane roundabouts respectively. In Figure 6, VISSIM results for two different minimum time gaps are plotted (2.5s and 3s for cars at roundabout entry). For the single lane, we can infer that the VISSIM capacity values are less than both RODEL and aaSIDRA predictions (for most of the cases). However, the behavior of VISSIM plot is similar to the aaSIDRA plot (displaced by about 200 veh/hr).

For the dual lane roundabout, again, VISSIM capacity values are lower than the aaSIDRA and RODEL predictions. Also, the VISSIM plot and aaSIDRA plot are parallel to each other displaced by about 500veh/hr. VISSIM capacity estimates do not change considerably when the minimum time gap at the roundabout entry is changed from 3s to 2.5s for cars and 3.5s to 3s for trucks.

Figures 7 and 8 are the plots of real data collected at different roundabout sites in United States (*6*). Data collected at the sites included ADT volumes, Crash data, Geometry data, Video data, and Speed data. Fifteen different sites of single lane roundabouts in U.S were selected for data collection, which resulted in generating 434 1-min data values that can be used for capacity analysis. For dual lane roundabouts, data was collected at seven different U.S sites, resulting in 252 1-min data values. In the plots shown in Figures 7 and 8, 'qe' denotes the Entry traffic flow rate, and 'x' denotes the Degree of saturation. Different types of regression models (linear and exponential) are used to fit this collected data. Details regarding the data fitting can be obtained from the ongoing NCHRP Project No. 3-65 (*6*).

In Tables 3 and 4, we compare the VISSIM capacity estimates with the real data (actually one of the regression equation of real data – Tanner-Wu fitted equation). The 6 data points for single and dual lane roundabouts are surprisingly comparable except at low circulating traffic volume indicated as observation 1.

ROUNDABOUT WITHIN A SIGNALIZED ROAD

Description of the Design and Simulation

The second part of this paper deals with the study of the impact of signalized intersection proximity to roundabouts. It is our hypothesis that when a roundabout replaces a signalized intersection within an arterial, the overall traffic performance would not be worse than the fully signalized design (Figures 9, and 10). To check this hypothesis, the middle signalized intersection is replaced with a dual lane roundabout. Both alternatives are simulated in VISSIM and the results were comparable.

A section of an arterial consisting of three signalized intersections is analyzed. The intersections are separated by a 1/4 mile each. The arterial consists of two through lanes and one exclusive left turn and right turn lanes at each intersection (Figure 9). The signals are coordinated and have short cycle lengths (60 sec). Signal coordination is achieved by using signal optimization software, TRANSYT-7F. The arterial is simulated in VISSIM for three hypothetical traffic cases (Table 5a, b, c), and average delays per vehicle were recorded from the simulation.

The second intersection is now replaced with a dual lane roundabout (Figure 10). The network is simulated for the same traffic flow cases (Table 5). Simulation results are shown in Table 6. For Case 2 and Case 3 flows, the hypothesis proves to be true, i.e., roundabout performance is better than signalization. However, when the roundabout approaches are operating near capacity (Case 1), the fully signalized design has slightly lower overall delay.

CONCLUSIONS

In this paper, two problems were studied - Firstly, urban single lane and dual lane roundabouts are modeled in VISSIM traffic simulation software. Simulation results are compared with the results of RODEL (empirical model) and aaSIDRA (analytical model). Secondly, the impact of signalized intersection proximity to roundabouts is studied using the developed models. Specifically, the impact of coordinated signalized arterial when a roundabout is inserted within an arterial corridor is studied. The following conclusions can be made from the analysis and results:

- Simulated capacities of Single-lane roundabouts are noticeably lower than RODEL and aaSIDRA, however, they are comparable to fitted U.S field capacity data.
- Similarly, capacities of dual-lane roundabouts as simulated by VISSIM are significantly lower than RODEL and aaSIDRA, and are comparable to U.S field capacity data for a certain fitted regression.
- A roundabout placed within a signalized, coordinated arterial placed quarter mile from adjacent signals showed comparable delays to a fully signalized arterial. This finding is true when the roundabout is operating at or below capacity.

RECOMMENDATION FOR FUTURE RESEARCH

In this paper, traffic performance of the roundabouts was studied using simulation. In the future, safety impacts of roundabouts would be studied using simulation. Surrogate safety assessment model is currently under development at FHWA, and after its completion, we expect to use it to compare the safety aspects of roundabouts and signalized intersections (isolated and within an arterial). The proposed safety model aims at extracting the safety features from traffic simulation models (VISSIM, AIMSUN, and TEXAS Model) by analyzing the trajectory of vehicles and estimating their proximity in terms of time, speed differentials and deceleration rates. Another recommendation would be to study the pedestrian performance at roundabouts.

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LIST OF TABLES AND FIGURES

TABLE 1 Geometry of the modeled roundabouts

	Single Lane	Dual Lane
Inscribed circle diameter	35m	55m
Entry radius	20m	40m
Exit radius	20m	40m
Entry width	4.5m	8.5m
Approach width	4m	7.3m
Departure width	4m	7.3m
Exit width	4.5m	8.5m
Circulatory road width	6m	9.5m

TABLE 2 Priority rules for a Single lane roundabout in VISSIM

	Marker 1 - Cars	Marker 2 - Cars	Marker 1 - Trucks	Marker 2 - Trucks
Time Gap	3s	0s	3.5s	0s
Headway	16ft	16ft	16ft	16ft

TABLE 3 Single lane roundabout - Comparison of VISSIM results with Real Data

Observation No.	Conflicting Flow (veh/hr)	Maximum Entry Flow (veh/hr)	
		Real Data (veh/hr)	VISSIM (veh/hr)
1	120	1020	1250
2	300	852	930
3	480	690	700
4	600	588	550
5	720	480	400
6	900	312	290

TABLE 4 Dual lane roundabout - Comparison of VISSIM results with Real Data

Observation No.	Conflicting Flow (veh/hr)	Maximum Entry Flow (veh/hr)	
		Real Data (veh/hr)	VISSIM (veh/hr)
1	300	1620	1800
2	600	1290	1350
3	900	990	1000
4	1200	750	700
5	1500	552	450
6	1800	372	300

TABLE 5a Traffic flows at each intersection

			Directional Flows (Veh/hr)	
CASE 1		*Int 1*	*Int 2*	*Int 3*
	EB Left	200	150	100
	EB Thru	850	850	850
	EB Right	100	100	150
	NB Left	100	150	100
	NB Thru	400	600	400
	NB Right	150	150	100
	SB Left	100	100	100
	SB Thru	500	500	500
	SB Right	150	150	100
	WB Left	100	150	200
	WB Thru	700	650	700
	WB Right	100	100	150

TABLE 5b Traffic flows at each intersection

			Directional Flows (Veh/hr)	
CASE 2		*Int 1*	*Int 2*	*Int 3*
	EB Left	150	110	88
	EB Thru	638	628	618
	EB Right	75	88	110
	NB Left	75	113	75
	NB Thru	300	450	300
	NB Right	113	113	75
	SB Left	75	75	75
	SB Thru	375	375	375
	SB Right	113	113	75
	WB Left	100	126	150
	WB Thru	513	474	525
	WB Right	87	75	113

TABLE 5c Traffic flows at each intersection

			Directional Flows	
CASE 3		*Int 1*	*Int 2*	*Int 3*
	EB Left	100	75	50
	EB Thru	425	425	425
	EB Right	50	50	75
	NB Left	50	75	50
	NB Thru	200	s300	200
	NB Right	75	75	50
	SB Left	50	50	50
	SB Thru	250	250	250
	SB Right	75	75	50
	WB Left	75	50	100
	WB Thru	350	325	350
	WB Right	50	75	75

TABLE 6 Comparison of traffic performance

	Average Delay (sec/veh)		Average Queue (ft)	
	VISSIM-Signalized Intersection	VISSIM-Roundabout	VISSIM-Signalized Intersection	VISSIM-Roundabout
CASE 1	35	42	53	72
CASE 2	28	24	18	15
CASE 3	27	25	28	23

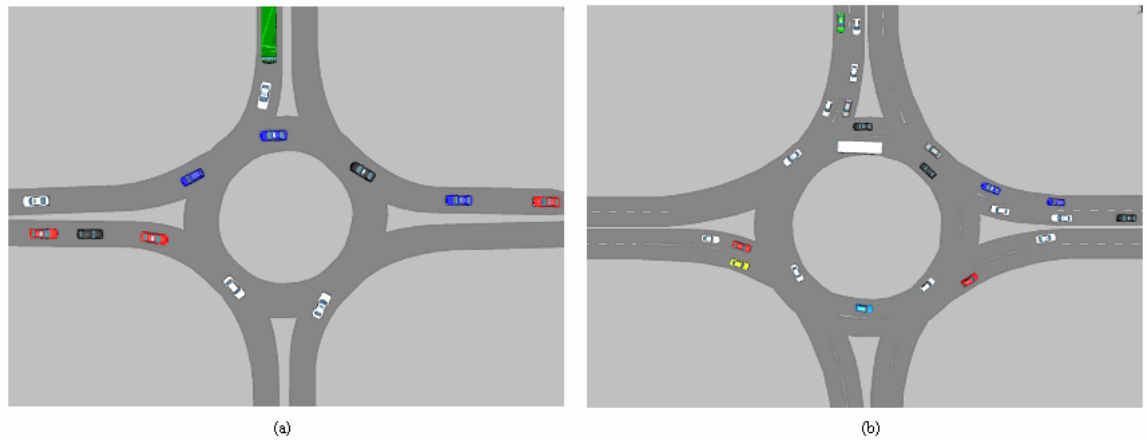

FIGURE 1 (a) Layout of a Single Lane Roundabout in VISSIM, (b) Layout of a Dual Lane Roundabout in VISSIM.

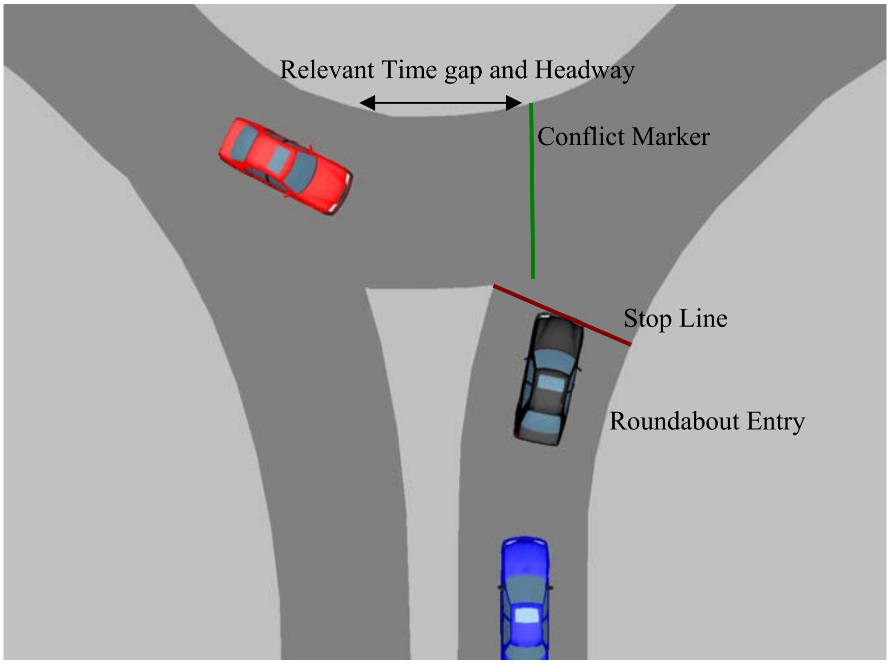

FIGURE 2 Definition of Priority Rules.

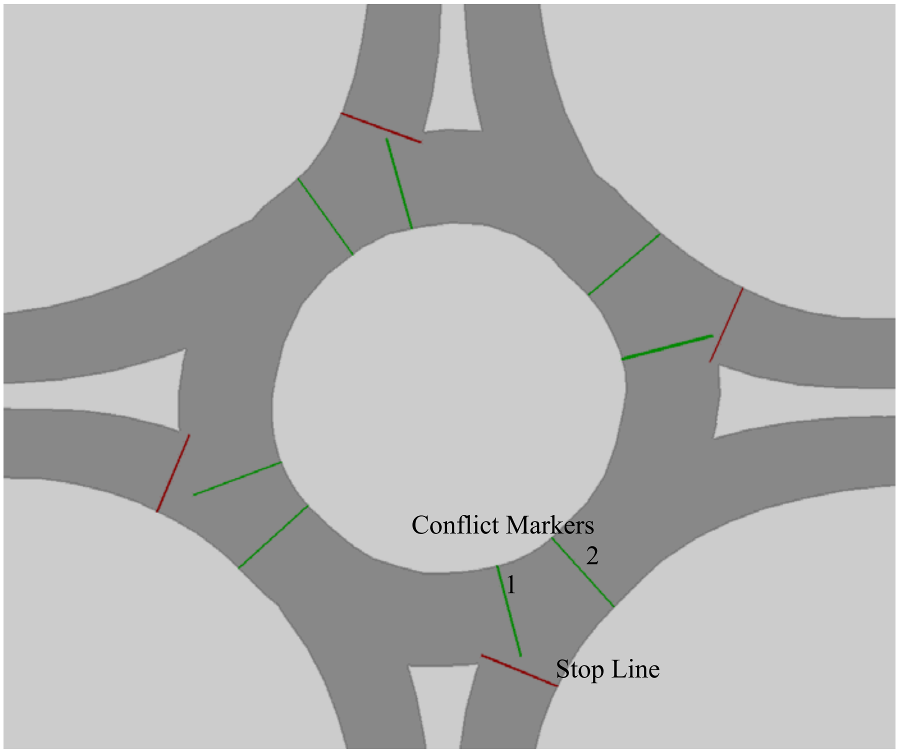

FIGURE 3 Single Lane Roundabout – Priority rules in VISSIM.

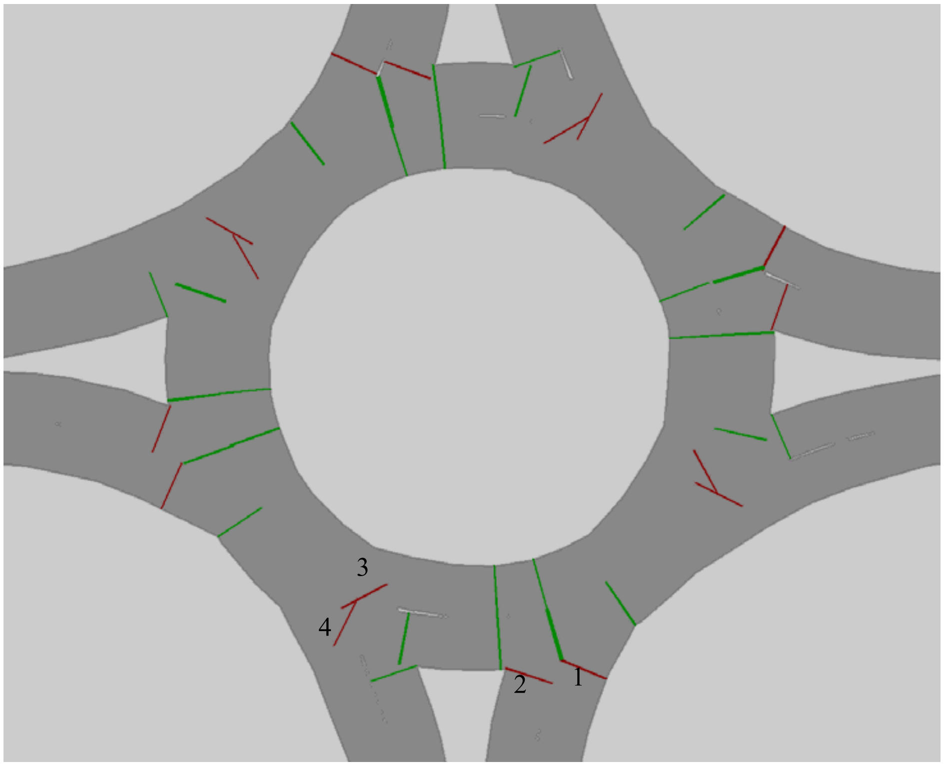

FIGURE 4 Dual Lane Roundabout – Priority rules in VISSIM.

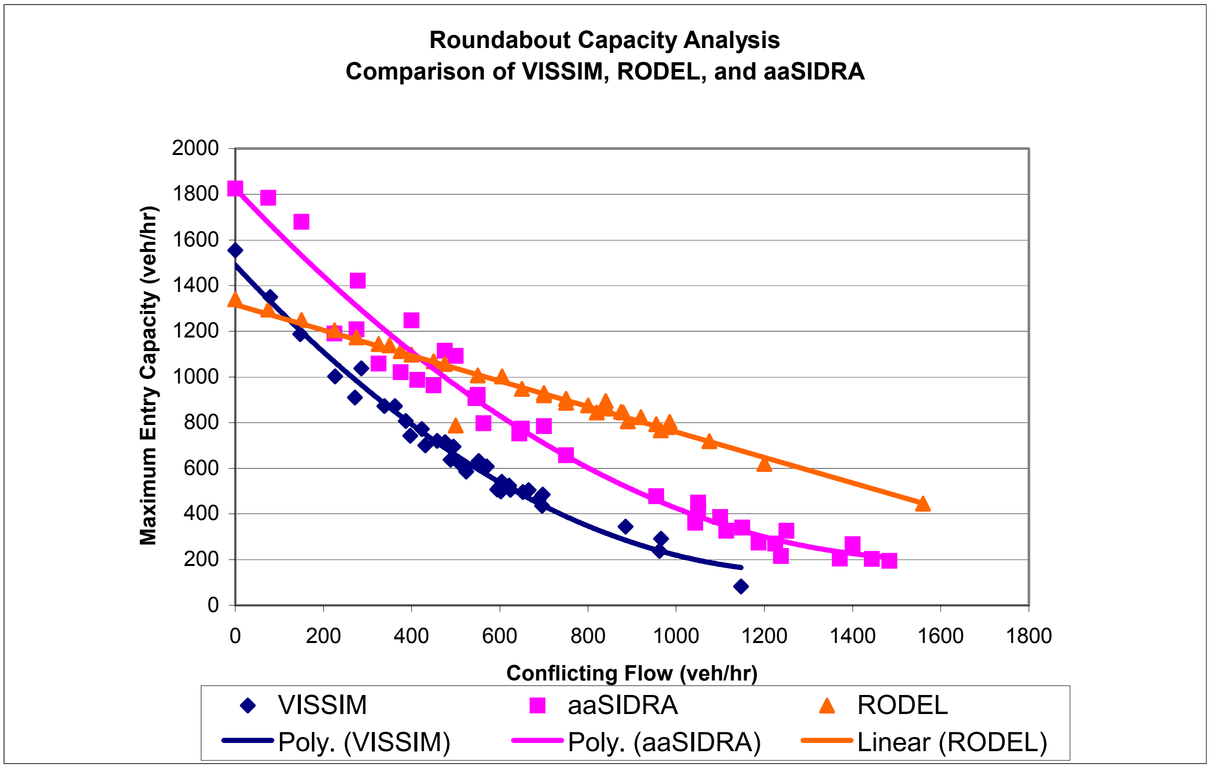

FIGURE 5 Single Lane Roundabout Capacity Analysis.

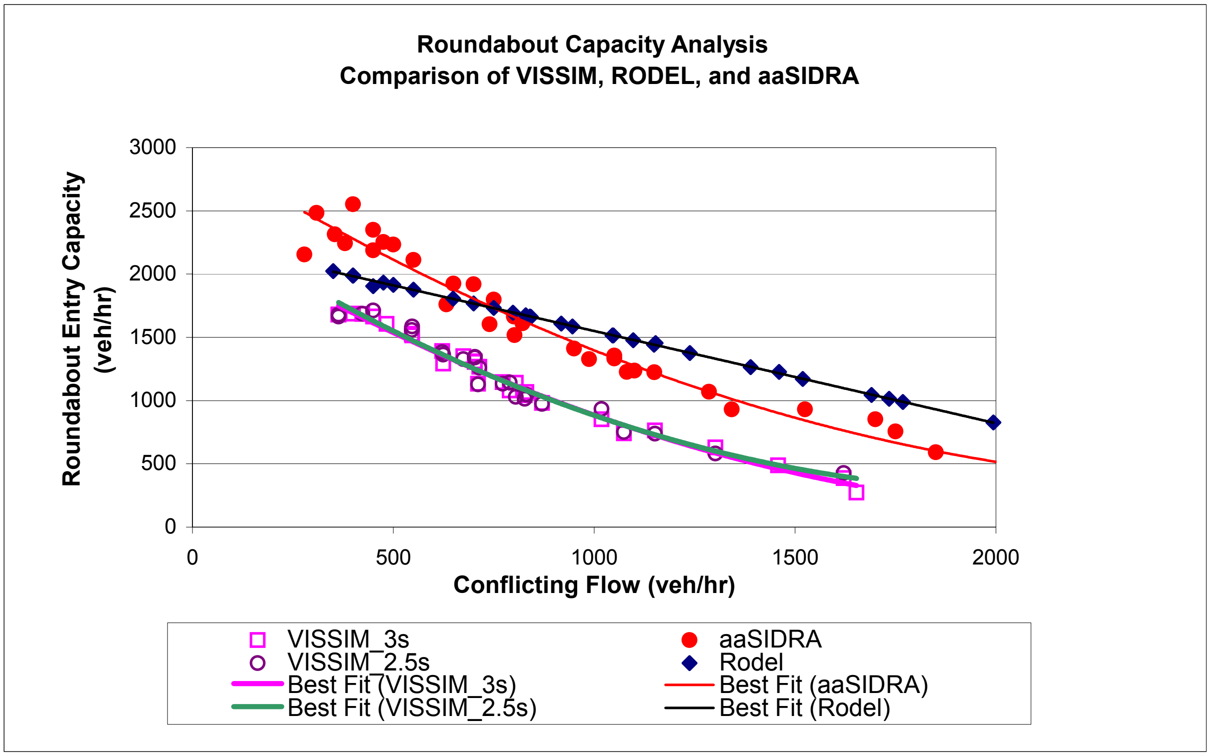

FIGURE 6 Dual Lane Roundabout Capacity Analysis.

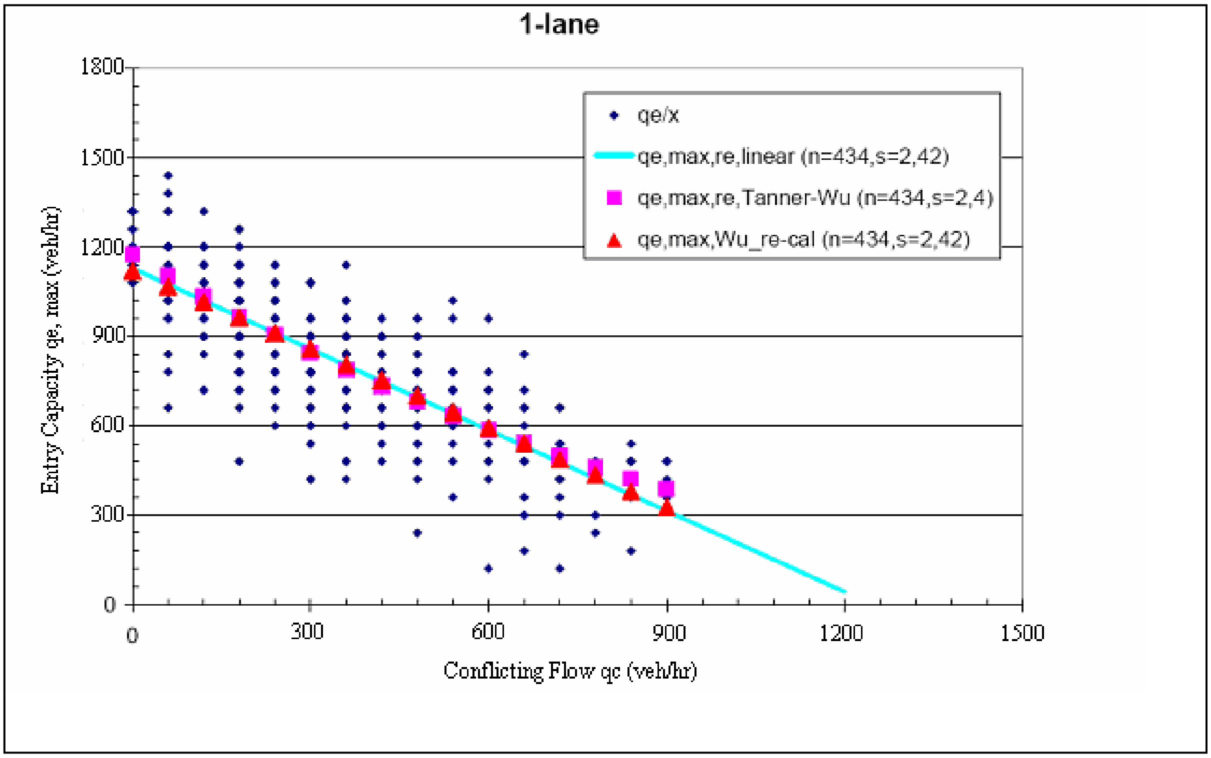

FIGURE 7 Single Lane Roundabout – Real data (*6*).

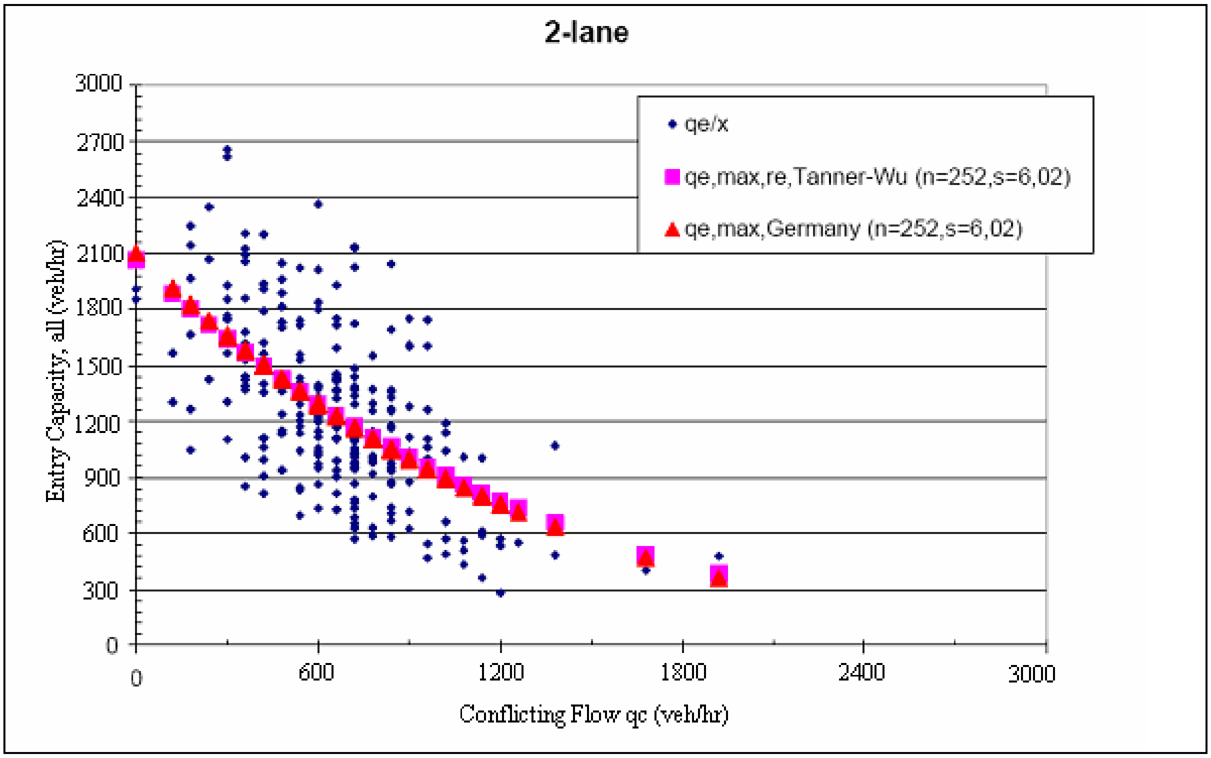

FIGURE 8 Dual Lane Roundabout – Real data (*6*)

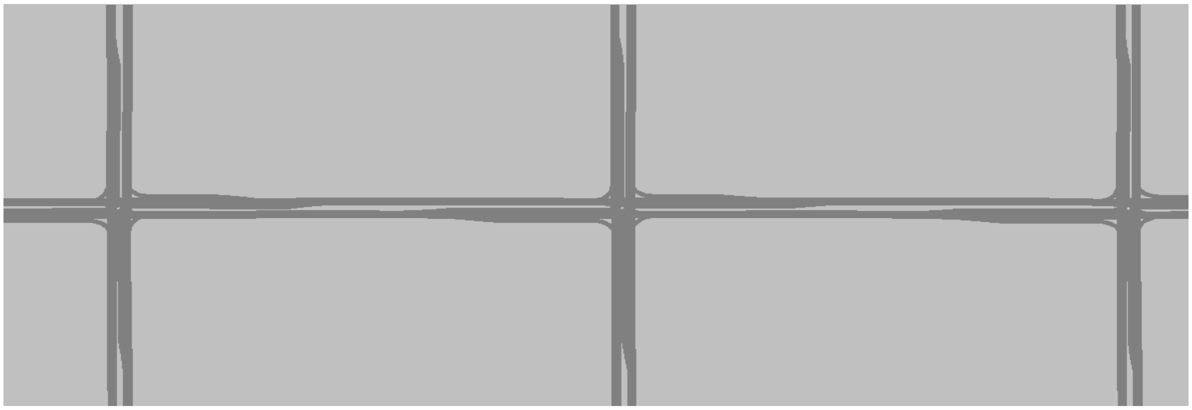

FIGURE 9 VISSIM screenshot of three coordinated signalized intersections.

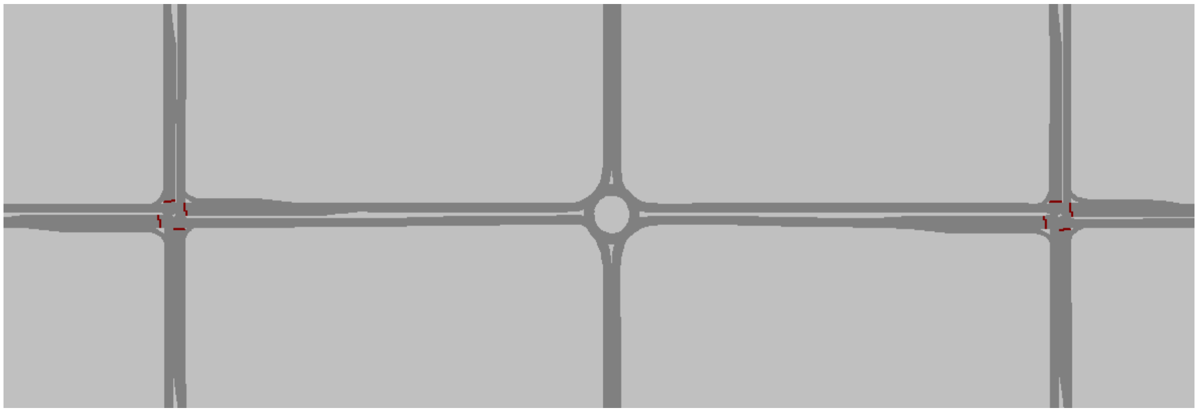

FIGURE 10 Second signal replaced by a roundabout.