HIGH-CAPACITY ROUNDABOUT INTERSECTION ANALYSIS: GOING AROUND IN CIRCLES

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Abstract. Roundabouts have become increasingly popular in recent years as an innovative operational and safety solution at both low volume and high volume intersections. And while tools are available for evaluating roundabout intersection operations, the answers provided by these tools can vary widely. This is particularly true for high-capacity roundabouts (that is, those with flared entry or double lanes). In the U. S., the benefits to installing single-lane roundabouts compared to signalized intersections have been demonstrated, but relatively few high-capacity roundabouts have been built. It is unclear how well the high-capacity roundabout will operate and under which circumstances it will perform better than a signalized intersection.

This paper compares the capacity analysis suggested in the FHWA roundabout guidelines with the results of the analysis software packages RODEL, aaSIDRA, VISSIM, and Paramics. The macroscopic models RODEL and aaSIDRA apply formulas based on observed data from U. K. and Australia, respectively. These models use roadway geometry and/or driver behavior to estimate intersection capacity. The microscopic models VISSIM and Paramics simulate individual driver decisions in navigating the roadway network using a stochastic process. As a result, the microscopic model can be more closely calibrated to observed traffic conditions.

The authors have found that the macroscopic models may not accurately measure multi-lane roundabout operations in all cases because these models lack sensitivity related to the effects of roadway geometry and gap acceptance. Microsimulation models were found to provide more accurate and reasonable results in this study, but required detailed calibration to accurately represent roundabouts with unique characteristics such as skewed approaches or closely-spaced intersections.

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4/29/2004

Introduction

Roundabouts are an increasingly popular alternative to traffic signals for intersection control in the United States. Roundabouts have a number of advantages over traffic signals depending on the conditions. They reduce the severity of crashes since head-on and right-angle conflicts are nearly eliminated. They reduce through traffic speeds to provide a "calmer" roadway environment. They may consume less land area since turn pocket lanes are not needed. They have lower energy and maintenance costs.

Primarily, roundabouts have been built in recent years as part of traffic calming efforts to improve the livability of residential areas. This type of yield-entry modern roundabout generally is installed at the intersection of two two-lane streets. However, roundabouts also may be a viable alternative for major arterial intersections depending on traffic volumes, roadway geometry, and available right-of-way. To provide sufficient capacity in these situations, the roundabout typically needs two or more lanes in the circulatory roadway. These high-capacity roundabouts are not as common as the single-lane variety. Consequently, less is known about their traffic operations characteristics or how to analyze them.

This paper first discusses the methodologies and software programs that are available to analyze traffic operations at high-capacity roundabouts. Then, the methodologies are applied to two case studies of proposed roundabout intersections at freeway interchanges in northern California. Finally, the results of the traffic operations analysis are discussed and conclusions are drawn from these results.

Roundabout Operations Analysis Methodology

As noted in the *Highway Capacity Manual* (Transportation Research Board, 2000), intersection analysis models can be classified into two types: empirical and analytical models. Empirical models use observations at many different intersections under all types of conditions to develop regression equations that match intersection characteristics with intersection capacity. Analytical models estimate capacity based on gap-acceptance relationships that do not require observations under congested conditions.

The *Highway Capacity Manual* (HCM 2000) provides an analysis method for roundabouts using gap acceptance theory to determine the approach capacity. However, no calculation for control delay is provided, and the method is limited to one-lane roundabouts. No analysis method is recommended for roundabouts with two or more lanes due to the lack of experience with these intersections in the United States.

The Federal Highway Administration (FHWA) provides guidelines for roundabouts based on European experience and academic research in *Roundabouts: an Informational Guide* (2000). The chapter on traffic operations analysis provides an empirical equation for calculating control delay at high-capacity roundabouts, but this equation is based on observations from roundabouts in the United Kingdom, not in North America.

Roundabout Analysis Software

The FHWA guidelines list available computer software programs that analyze traffic operations at roundabouts. The software can be divided into two types: macroscopic and microscopic models. Macroscopic models use traffic volume flows to model intersections as isolated locations. Microscopic models simulate the movement of individual vehicles thereby allowing a network-wide analysis. For this study, we have applied two macroscopic (RODEL and aaSIDRA) and two microscopic (VISSIM and Paramics) software programs that analyze traffic operations at roundabouts. (CORSIM, a widely-used simulation program developed by FHWA, does not directly model roundabouts).

RODEL, distributed by Barry Crown, is an empirical macroscopic analysis model for roundabouts that is based on many observations in the United Kingdom. Using these observations, the geometric characteristics of a roundabout approach (such as diameter, entry width, and flare length) have been related to the approach capacity. As a result, the program is an interactive design tool that allows the user to adjust the design features of the roundabout to provide more or less capacity, as needed. The drawback of this method is that the approach capacity only depends on the intersection approach geometry. No provision is made for the effect of conflicting movements on capacity.

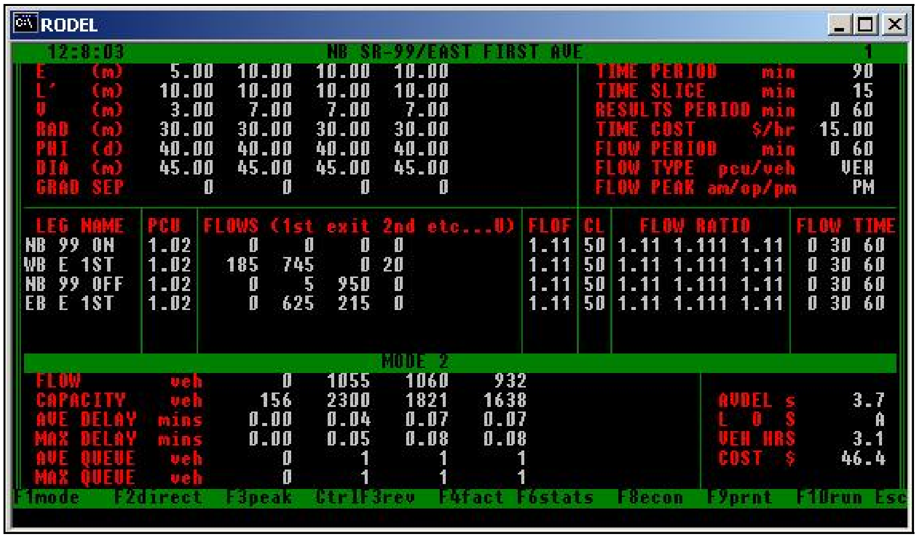


Figure 1. RODEL Data Entry Screen

Distributed by Akcelik and Associates, aaSIDRA is an intersection analysis tool that applies Australian methodologies similar to way that the Highway Capacity Software applies the HCM methodologies. The roundabout analysis feature uses gap acceptance to determine the capacity for each approach and for the entire intersection. The gap acceptance parameters can be adjusted to local conditions based on field observations of vehicle headways. The methodology allows for up to eight legs at the intersection, unbalanced lane utilization, and flared lanes for right turns.

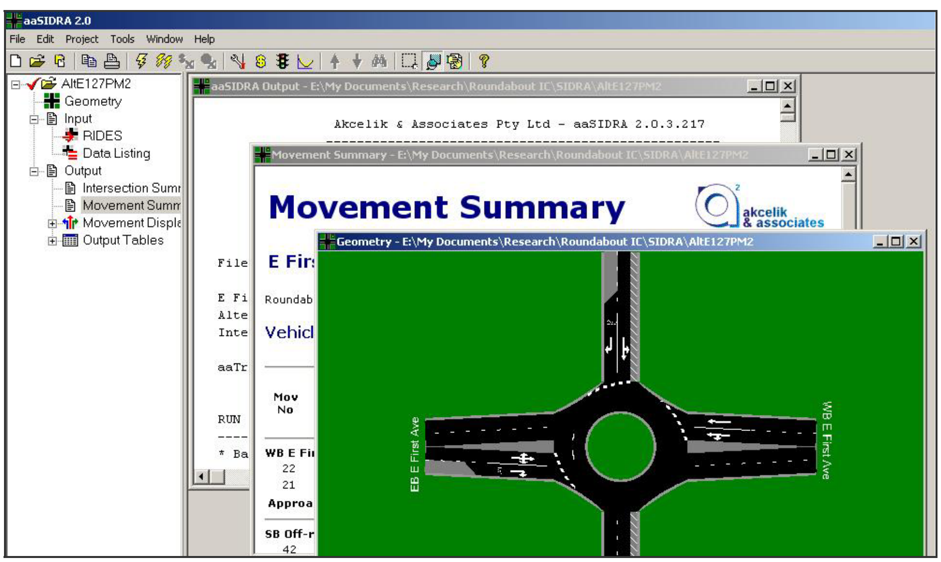


Figure 2. aaSIDRA Display

Paramics, distributed by Quadstone from the United Kingdom, is a stochastic microscopic model that analyzes traffic operations based on the individual driver behavior and vehicle characteristics. This software uses a link and node structure to define the roadway network and an origin-destination matrix to define vehicle paths through the study area. Paramics automatically creates a roundabout with default parameters to model the yield-on-entry operation. The output includes both technical data for measures of effectiveness (vehicle delay, speed, etc.) and vehicle animation for visual inspection.

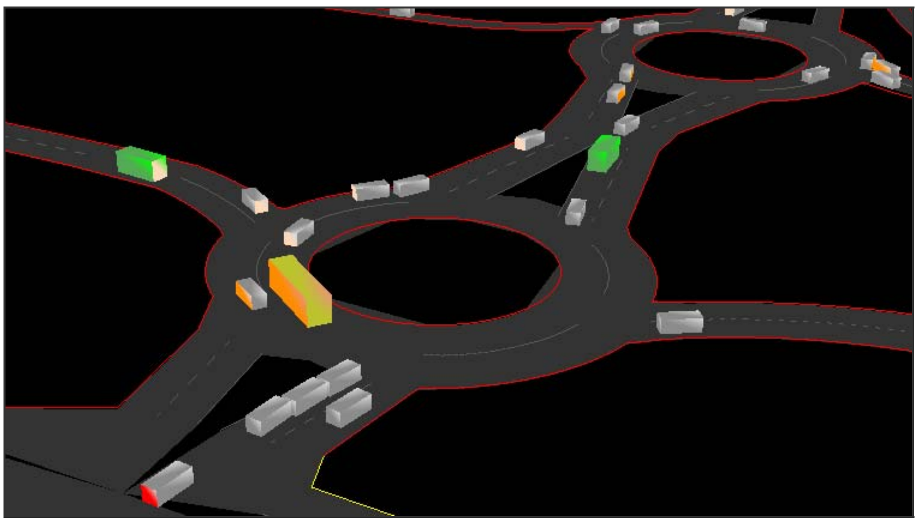


Figure 3. Paramics 3-D View

VISSIM, distributed by PTV America (formerly Innnovative Transportation Concepts), is a microscopic simulation model similar to Paramics. Individual driver behavior and vehicle characteristics are used to model traffic operations to provide the output measures of effectiveness (vehicle delay, speed, etc.) and vehicle animation for visual inspection. Unlike Paramics, VISSIM uses a link-connector network structure that is more time-consuming to construct, but provides more modeling flexibility. This flexibility allows for fine-tuning of the gap acceptance parameters for each approach to a roundabout.

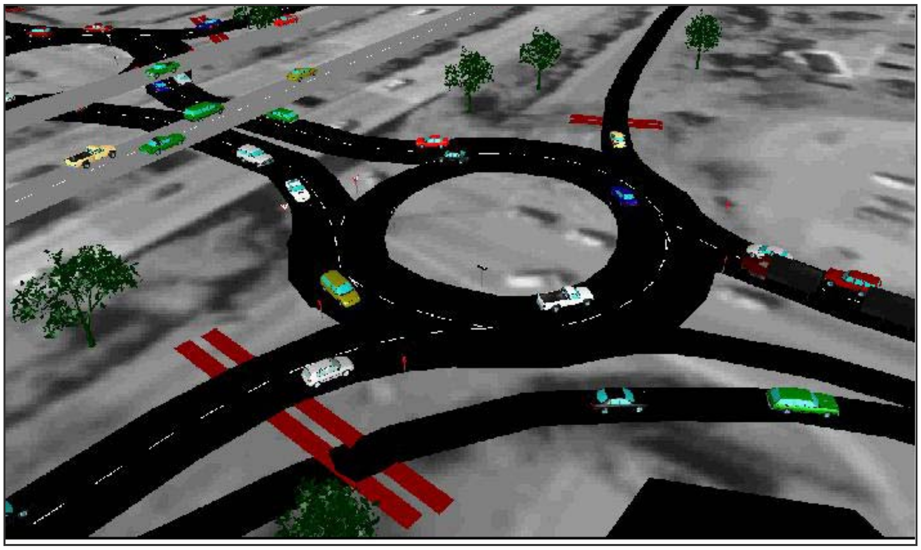


Figure 4. VISSIM 3-D View

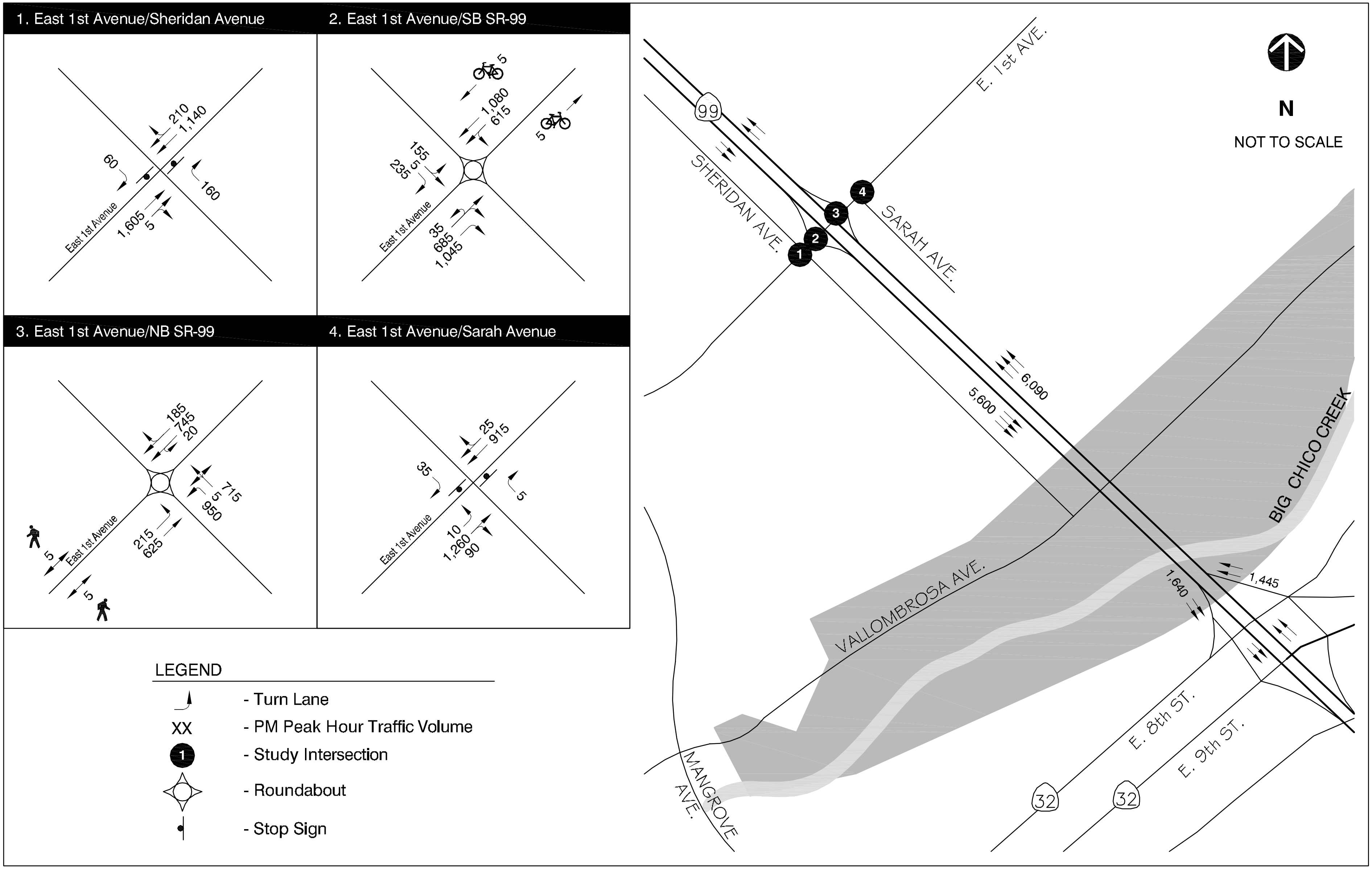
Methodology Comparison

The five methodologies presented above have some similarities and differences. Both the FHWA equations and the RODEL software are based on United Kingdom empirical regression equations. And, these methods do not use gap acceptance factors or lane configuration to estimate intersection delays. The other macroscopic model, aaSIDRA, uses gap acceptance to estimate capacity and has more flexibility to adjust the analysis to meet the project conditions.

The microscopic models Paramics and VISSIM require more input data and are more time-consuming to use. However, they can better match unusual project features and can be better calibrated to local conditions. VISSIM provides the most flexibility in modeling roundabouts by allowing different headways for gap acceptance by vehicle type and by approach lane.

Case Study #1 – Diamond Interchange with Roundabouts

The first case study is for the East First Avenue interchange on State Route 99 (SR-99) in Chico, CA. Figure 5 shows the traffic volumes and lane configurations for this scenario. Under existing conditions, signals at the diamond interchange are congested due to limited capacity on the ramps and East First Avenue. Typical alternatives such as widening East First Avenue and the ramps were proposed by the City of Chico and Caltrans and analyzed using CORSIM. During this process, an alternative to replace the signalized intersections with roundabouts was proposed by local residents.



CASE STUDY #1
SR-99/EAST FIRST AVENUE INTERCHANGE - TRAFFIC VOLUMES AND LANE CONFIGURATIONS
FIGURE 5

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The five methodologies described above were applied to a traffic operations analysis of year 2027 conditions during the PM peak hour. Table 1 shows the delay and level of service (LOS) results for the roundabout diamond interchange at the SR-99/East First Avenue interchange.

Table 1. Case Study #1 Results: Level of Service and Average Delay (sec/veh)

Methodology	Southbound Ramps	Northbound Ramps
FHWA	F / 59	A / 5
RODEL	D / 28	A / 4
aaSIDRA	F / 158	C / 28
Paramics	F / 86	C / 24
VISSIM	E / 48	B / 11

Note: Uses the HCM 2000 level of service criteria for unsignalized intersections.

The results from the FHWA equations show LOS F conditions at the southbound ramp terminal intersection caused by the high demand volume for the southbound on-ramp. However, the northbound ramp terminal intersection has very low delay. RODEL shows similar operations at the northbound ramps, but the southbound ramps has lower delay (LOS D). The lower delay estimate is based on the specific geometrics of the roundabout approaches without regard to conflicting volumes on the circulatory roadway. The results from aaSIDRA, which uses the gap acceptance method instead of the empirical method, shows higher delays at both roundabouts.

The two microscopic models have results that are similar to the aaSIDRA macroscopic models. Paramics and VISSIM both include the effect on delay at the northbound ramp intersection caused by queuing from the southbound ramp intersection. The headway factors for both models were adjusted by visual inspection such that vehicles traveled smoothly through the roundabout. However, VISSIM allowed for a finer adjustment (gap acceptance can vary by lane and approach) which yielded lower delays than Paramics.

All models identified the capacity problem at the southbound ramp terminal intersection except for RODEL. RODEL shows that the approaches have sufficient capacity, but, in this case, the circulatory roadway exceeds capacity. The severity of the capacity problem at the southbound ramp terminal intersection varied widely for each model. Both simulation models provided a clear understanding of the problem by viewing the simulation although VISSIM allowed for further adjustment of gap acceptance to provide more reasonable results.

Figure 6 shows the Southbound SR-99 ramps intersection as modeled in VISSIM. The high demand volume from eastbound and westbound East First Avenue to the southbound on-ramp exceeds the capacity of the circulatory roadway causing long queues on eastbound East First Avenue. At the intersection, the high left-turn volume leaves few gaps available for the even higher right-turn volume.

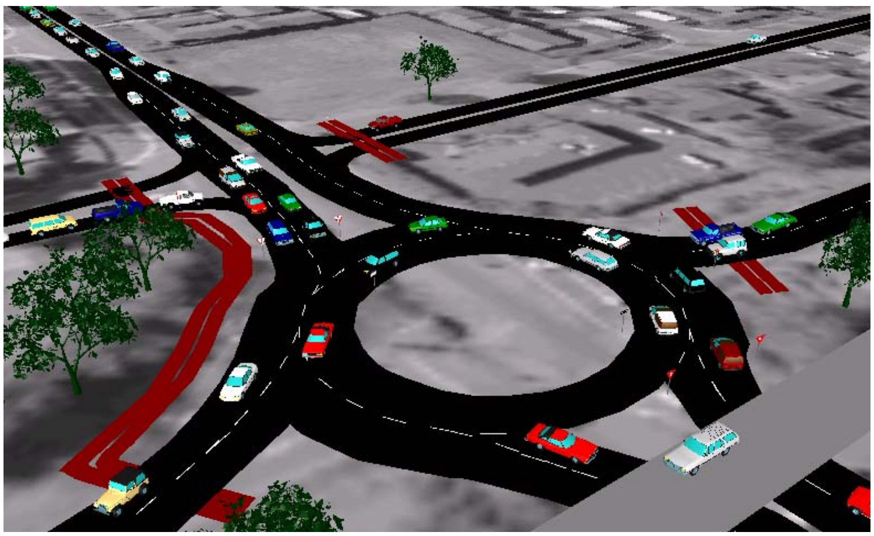
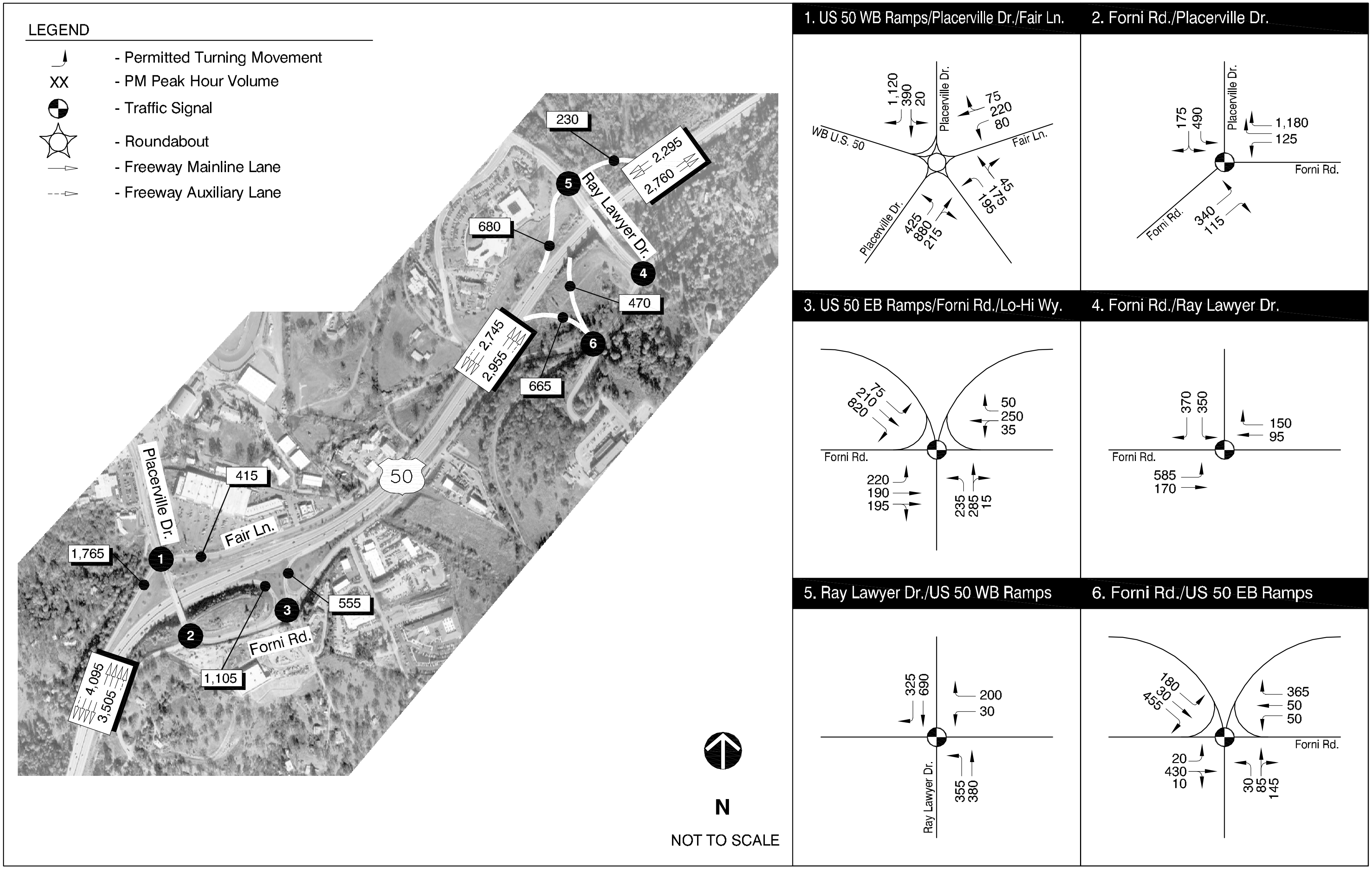


Figure 6. Southbound SR-99 Ramps Intersection (VISSIM)

Case Study #2 – Five-legged Roundabout at Interchange

The second case study is for the Placerville Drive/Forni Road interchange on U.S. Highway 50 (US-50) in Placerville, CA. Figure 7 shows the traffic volumes and lane configurations for this scenario. Under existing conditions, a single controller operates the signals at the closely-spaced intersections on Placerville Drive at the westbound off-ramp and the frontage road. One of the proposed alternatives would replace the two signalized intersections with a 5-leg roundabout.



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CASE STUDY #2
US-50/PLACERVILLE DRIVE INTERCHANGE
TRAFFIC VOLUMES AND LANE CONFIGURATIONS

FIGURE 7

For this case study, three of the methodologies described above were applied to test traffic operations for year 2030 conditions during the PM peak hour. The FHWA equation was not used because it applies only to roundabouts with four or fewer legs. Paramics was not used due to the additional effort of coding a microscopic model. Table 2 shows the delay and LOS results for the roundabout alternative for the US-50 interchange at Placerville Drive/Forni Road.

Table 2. Case Study #2 Results: Level of Service and Average Delay (sec/veh)

Methodology	Westbound Ramps
RODEL	B / 11
aaSIDRA	B / 15
VISSIM	F / 99

Note: Uses the HCM 2000 level of service criteria for unsignalized intersections.

Both RODEL and aaSIDRA report low intersection delay, but VISSIM shows very high intersection delay. The complex five-legged intersection with skewed approaches is difficult to model in RODEL and aaSIDRA. RODEL does not model the effects of one-lane exits or lane restrictions. The other macroscopic model cannot analyze the effect of approaches that are skewed at angles other than multiples of 45 degrees. Inspection of the VISSIM model shows insufficient gaps for the frontage road (Fair Lane) approach due to high demand volumes on the upstream approaches from Placerville Drive and the westbound off-ramp (see Figure 8).

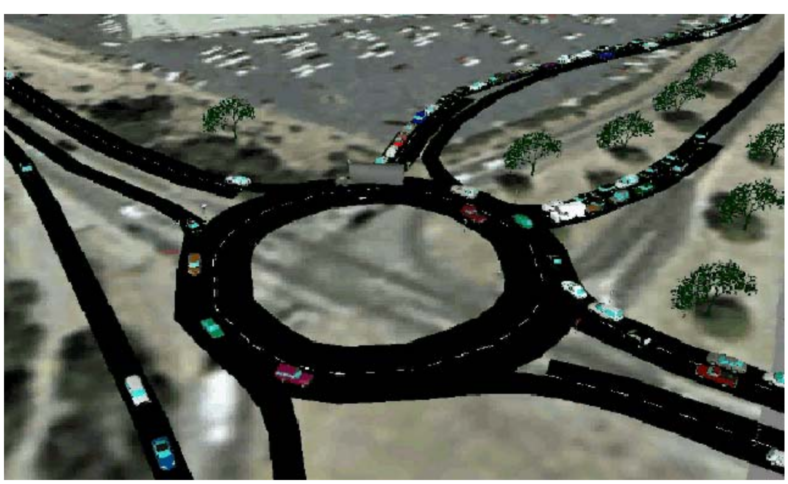

Figure 8. 5-leg Roundabout (VISSIM)

Conclusion

This study has reviewed the traffic operations analysis methods for high-capacity roundabouts. Five methodologies have been presented: the FHWA equations and the RODEL, aaSIDRA, Paramics, and VISSIM software programs. These methodologies were applied to two case studies of proposed roundabouts at interchanges. The differences in analysis results among the methodologies were then compared.

To determine which methodology provides the most accurate results, a study of an existing roundabout with two or more lanes should be done. However, because high-capacity roundabouts are rare in the United States, few high-capacity roundabouts exist to be analyzed. Even fewer of those are operating at or near capacity. Therefore, it is difficult to know which methodology should be preferred.

Based on the study results, we recommend that the macroscopic methods (FHWA, RODEL, and aaSIDRA) be used to analyze high-capacity roundabouts only for unsaturated conditions or for isolated locations with standard geometry. Microscopic methods (Paramics and VISSIM) should be used when over-saturated conditions are present in the study area or unique roadway geometry features are present. These models can also be used to analyze the effect of adjacent intersections, freeway ramps, and other geometric constraints that would otherwise be ignored by the other programs.

References

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