Calibrating and Validating Traffic Simulation Models for Unconventional Arterial Intersection Designs

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Computer simulation has become an important tool for evaluating transportation strategies quickly and efficiently. Simulation is especially critical in assessing the potential of innovative traffic control alternatives. The calibration and validation of simulation models characterized by unconventional design and operation strategies is presented. This effort was part of a project to investigate unconventional traffic control alternatives for the North Carolina Department of Transportation. Three alternatives were selected for in-depth investigation: the Florida continuous green T-intersection, an application of the modern roundabout, and the Michigan median U-turn intersection. These strategies were examined using Traf-Netsim 4.0 and the macroscopic analysis package SIDRA 4.07. Models for each of the three alternatives were developed and efforts were made to calibrate and, in two cases, validate them with field data collected in Florida, Maryland, and Michigan. The highlights of the calibration included (*a*) updated critical gap distributions for the six-lane median U-turn and the roundabout, (*b*) a larger saturation flow rate for the median U-turn, (*c*) an average roundabout speed, and (*d*) a distribution of traffic into the free flow lane(s) for the continuous green T-intersection. The validation effort showed that the Traf-Netsim and SIDRA results compared reasonably well to field measurements.

Computer simulation has become one of the most viable evaluation tools that transportation engineers have. With dwindling transportation budgets and high public expectations, the engineer must be able to evaluate transportation strategies quickly and efficiently. As traffic congestion reaches unprecedented levels, innovative techniques will be needed to increase the capacity of existing transportation facilities and maximize the benefits of future proposed facilities. Evaluating the potential of new and innovative traffic control alternatives is one area where simulation techniques can make a significant contribution.

Computer simulation provides a host of benefits to the transportation engineer. First, simulation is a much less expensive means of experimentation than most other alternatives. Evaluation through computer simulation requires no expensive construction, can be completed relatively quickly, and does not impair the safety or convenience of motorists. Simulation allows an analyst to control many variables that would be difficult or impossible in a field test. Finally, adjustments are easier to make with simulation modeling than with field tests.

Although traffic simulation can provide many benefits, analysts must use caution when using this approach. The results provided by such models are only as good as the data that go into them; hence engineers must make an effort to ensure that the models are developed properly and function reliably. The calibration and validation of simulation models characterized by unconventional design and operation strategies is presented. This effort was part of a large project investigating unconventional traffic control alternatives for the North Carolina Department of Transportation (*1*).

Four alternatives were selected for an in-depth investigation. Three of them—the Florida continuous green T-intersection, an application of the modern roundabout, and the Michigan median U-turn intersection—were examined using Traf-Netsim (*2*). Traf-Netsim is a microscopic, stochastic simulation package developed by the FHWA. To supplement Traf-Netsim during the analysis of the modern roundabout application, the team used SIDRA (*3*). SIDRA is a macroscopic intersection analysis package developed by the Australian Road Research Board designed to evaluate roundabouts explicitly. During the research, models were developed for each of the three alternatives and efforts were made to calibrate and in most instances validate each of them.

The research team made data collection trips to Florida, Michigan, and Maryland (home of one of the East Coast's first modern roundabout installations) to collect calibration and validation data on working installations of the three alternatives. The data collection trips targeted both geometric and traffic flow data. Some of the data collected in the field was used to calibrate the models. The rest was used to validate the models by examining the models' ability to forecast the behavior observed in the field for a given set of conditions. Each of the alternatives is discussed separately, and the team's data collection efforts and attempts to calibrate and validate the models are described.

MEDIAN U-TURN

To calibrate and validate the median U-turn model, a data collection trip was made to the Detroit, Michigan area during the summer of 1993. The team visited numerous intersections where left turns were facilitated using median U-turn crossovers (see Figure 1). Two locations were selected for data collection based on three criteria. First, the team wanted to examine four-lane and six-lane arterial applications. Second, the analysts wanted to evaluate signalized and stop-controlled median U-turn crossovers. Third, the team preferred sites where driveways did not significantly influence the behavior observed at the intersection. Based on these criteria, the analysts selected the intersection of Big Beaver and Livernois (two 4-lane arterials with one set of signal-controlled U-turn crossovers) and the intersection of Mound and Hall/M59 (a six-lane and a four-lane arterial with one set of Stop sign-controlled U-turn crossovers).

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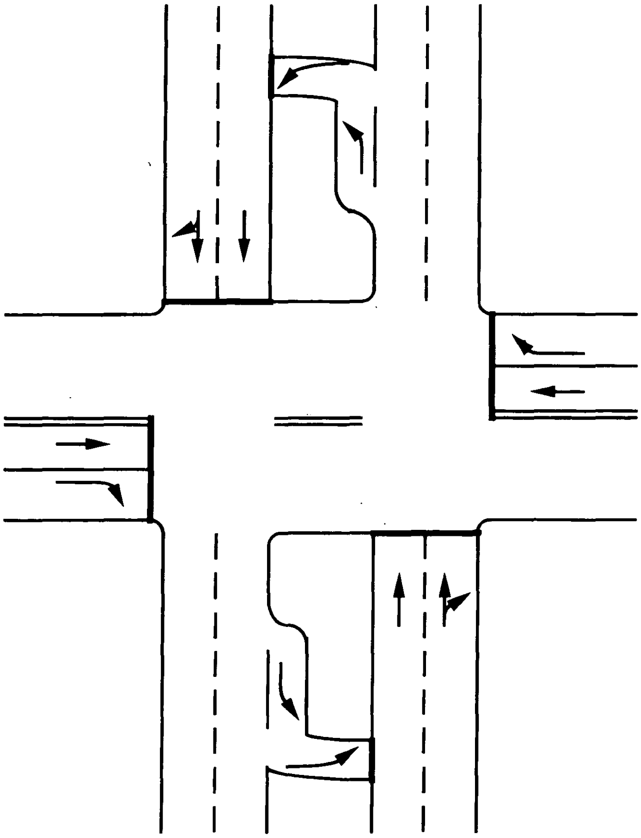

FIGURE 1 Median U-turn intersection.

Model Calibration

To calibrate the models before simulation, the researchers collected saturation flow data at the primary intersection and gap acceptance data at the crossovers. For each intersection, the data collection team recorded mean ideal saturation flows slightly higher than 2,000 passenger cars per hour per lane. Traf-Netsim provided a default value of 1,800 vehicles per hour per lane.

To investigate local motorists' gap acceptance behavior, approximately 1 hr 30 min of videotape was recorded at one of the Stop sign-controlled median crossovers at the intersection of Mound and Hall/M59. After downloading the data using Traffic Data Input Manager (TDIP *4*), Ramsey and Routledge's (*5*) method was applied to obtain a critical gap distribution. The analysis included 224 accepted gaps and 377 rejected gaps.

Although gap acceptance data were not collected at the intersection of Big Beaver and Livernois, the data associated with the two inside through lanes at the intersection of Mound and Hall/M59 were adapted for this purpose. A comparison of the values obtained during the analysis with the default values provided by Traf-Netsim indicates that the Traf-Netsim default values adequately describe the behavior exhibited at the crossovers along Big Beaver (a four-lane arterial), but not at Mound and Hall/M59. Figures 2 and 3 illustrate the comparison between the observed values and the Traf-Netsim default distribution. Based on the derived distribution, motorists turning left onto Mound (a six-lane arterial) from a U-turn crossover exhibit more aggressive behavior. This is not surprising given the high volumes along the six-lane arterial.

Model Validation

After collecting the data to calibrate the models, volume, travel time, and stopped delay data were gathered to validate the models. To collect the volume data, counts were taken over two consecutive 15-min intervals, alternating between the primary intersection and the median U-turn crossovers. For those alternating periods when the team did not count, they interpolated from the available data.

The team applied the average vehicle technique to conduct the travel time study. In all, 36 runs were completed over a 2-hr span for each intersection. At each intersection, data was collected on six movements, including left turns from each approach and through movements along the arterial with the U-turn crossovers.

On the day after collecting the travel time data, for the same 2-hr period, the stop delay behavior was recorded for two of the approaches at each intersection. For each approach, the team collected two 30-min periods of stopped delay data, counting the number of stopped vehicles at consecutive 15-sec intervals.

Based on the Michigan data, the research team developed a model for the intersection of Mound and Hall/M59 and three potential models for the intersection of Big Beaver and Livernois. Three potential models were considered because motorists in Michigan

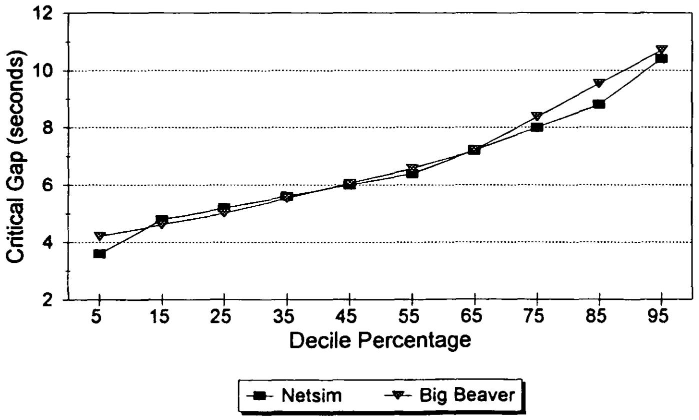

FIGURE 2 Observed Big Beaver and Livernois critical gap distribution versus Traf-Netsim default distribution.

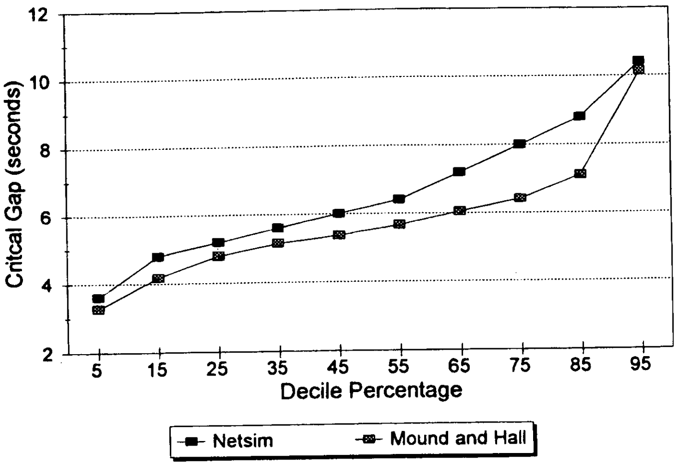

FIGURE 3 Observed Mound and Hall/M59 critical gap distribution versus Traf-Netsim default distribution.

observe the Western left turn rule. This rule allows a motorist to turn left from a crossover during the red signal phase. Traf-Netsim does not allow this type of movement. To emulate this behavior, the researchers first modeled the crossover as a conventional signalized T-intersection with no turns allowed during the red phase. The second model incorporated a signal on the arterial, 15 m upstream of the U-turn crossover, allowing the crossover to act as an unsignalized intersection subject to the gap acceptance parameters recorded during the trip. Figure 4 illustrates this alternative. Finally, a model converting the left turns at the crossover to right turns was developed as shown in Figure 5.

The analysts compared the three models using similar volumes, signal timing plans, and gap acceptance parameters to determine the most appropriate model. The researchers created a model for each 30-min observation period and compiled average results based on 10 runs per observation period. The runs within an observation period differed only in their random number seeds (the numbers used by Traf-Netsim to assign driver characteristics, decide whether a vehicle should turn at a given intersection, etc.).

Big Beaver and Livernois Validation Results

As mentioned previously, the analysts developed three models in an attempt to accurately simulate the behavior at this particular intersection. Table 1 summarizes the field measurements and the estimates provided by each of the models. As expected, the first model, without left turns on red, overestimated the travel times in the range of 3 to 60 percent. As a whole, however, the model overestimated the total travel time for all six movements by less than 20 percent. Given that the model did not allow left turns onto the arterial during the red phase of the signal cycle, its performance is impressive. In terms of stopped delay, the first model also performed reasonably well. For the southbound approach at the primary intersection, the model estimated an average stopped delay of 43.6 sec, a value 27 percent less than that observed in the field. The stopped delay estimate for the U-turn crossover was less than 55 percent of that observed in the field. This is particularly interesting considering that a left turn on red is not allowed by this particular model. The second model, with the signal just upstream of the U-turn model, provided the best travel-time estimates. As with the other two competing models, it overestimated the travel time for the eastbound through movement, but otherwise performed reasonably well. Overall, in terms of estimating the total travel time for the six movements, the model provided an estimate 10 percent higher than that observed in the field. Although the second model adequately esti-

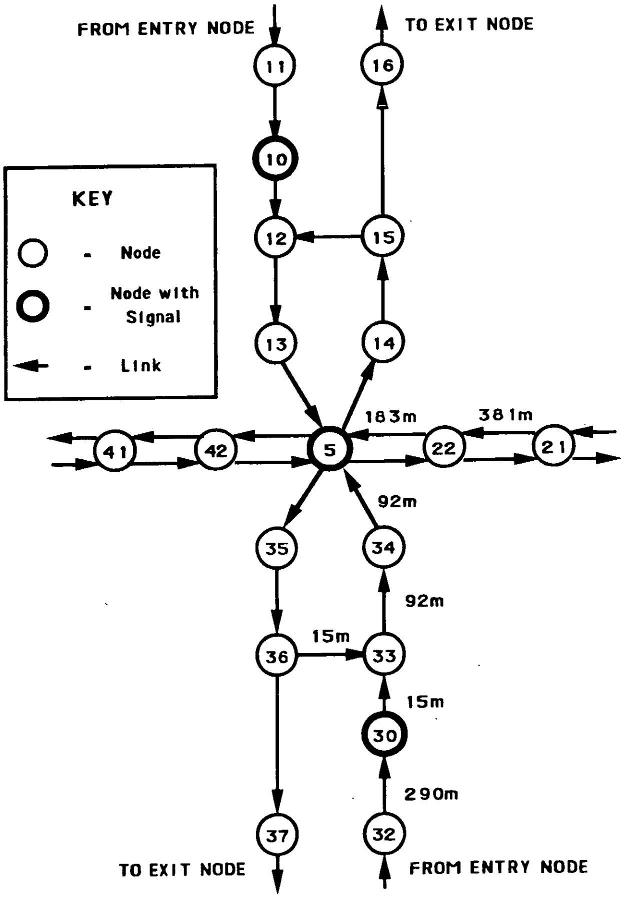

FIGURE 4 Traf-Netsim network for median U-turn option with signals before crossovers.

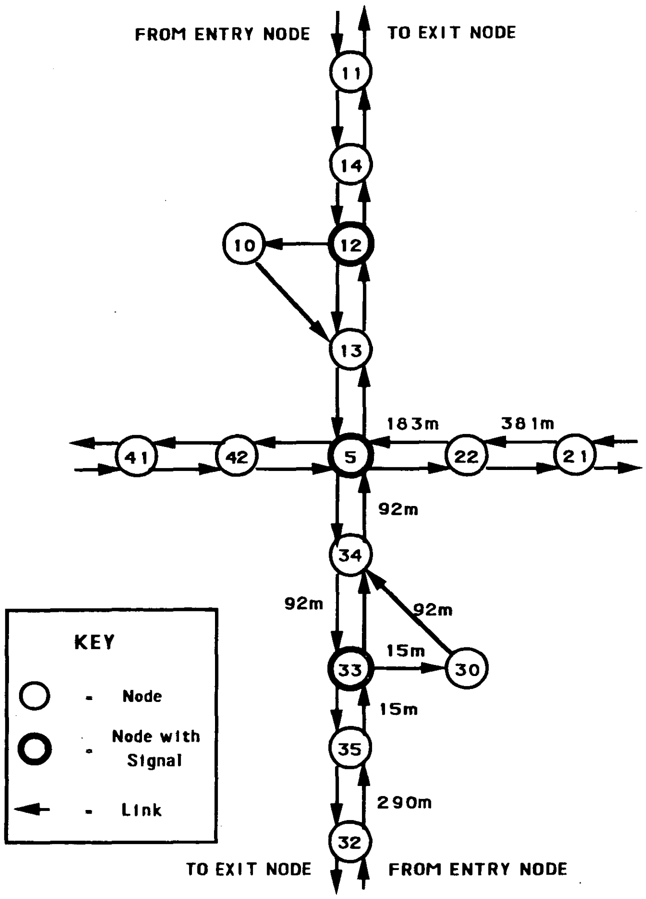

FIGURE 5 Traf-Netsim network for median U-turn option converting left turns from crossover to right turns.

mated the stopped delay for the southbound approach to the main intersection, it significantly underestimated the delay observed at the U-turn crossover. This indicates that relying on an upstream signal to model the left turns on red at the crossover may not properly imitate the behavior observed in the field. The third model provided the most consistent results of the three models evaluated. Besides the eastbound through movement, each of the travel time estimates ranged between 3 and 20 percent of the observed values. The stopped delay estimates provided by this model were also more reasonable, with 8 to 56 percent differences from the observed values. For the most part, each of the three models failed to accurately predict the stopped delay behavior associated with the U-turn crossover, although the third model provided better estimates.

Mound and Hall/M59 Validation Results

The analysts developed one model to simulate the intersection of Mound and Hall/M59. The results, shown in Table 2, indicate that Traf-Netsim was a reasonable predictor of the behavior observed in the field. A two-sample t-test revealed that four of the six pairs of travel time results were not significantly different at the 95 percent confidence level. The remaining two travel estimates provided by the model are within 10 and 20 percent of the times recorded in the field. The stopped delay estimates were also fairly consistent with the delay observed in the field. Although the differences range from 40 to 88 percent of the observed delay, because the delays observed in the field were relatively low, the difference between the observed and estimated values was not particularly alarming.

While developing the model, some difficulties were encountered due to the high volumes and the very high eastbound right turn volume. The version of Traf-Netsim used during the experiment (4.0) lacks the capability to assign vehicles to a given lane based on future actions by the vehicle. In particular, Traf-Netsim lacked the ability to direct vehicles wishing to turn right on the downstream link to the outside lane of the preceding upstream link. For several of the scenarios evaluated (due to the heavy volumes involved), vehicles in the inside through lane wishing to turn right from the next downstream link would stop and wait for an adequate gap to merge into the adjacent through lane to access the right turn lane. This caused midblock queues greater than 300 m long during a 30-min simulation period. To remedy this, an additional through lane was added to links experiencing the queueing problems. The through lane helped minimize the effects associated with this behavior, but it did not completely resolve the problem. Future versions of Traf-Netsim are expected to address this problem with an improved lane-changing algorithm (*6*).

MODERN ROUNDABOUT

Although traffic circles are not uncommon in the United States, few modern roundabouts have been constructed in recent years. As a

TABLE 1 Big Beaver and Livernois Model Validation

Measure of Effectiveness	Movement	Mean value of MOE			
		Field Measurement	Model 1 (no LTOR)	Model 2 (Fig. 4)	Model 3 (Fig. 5)
Travel Time (sec./veh.)	WB Through	95	110	113	110
	EB Through	71	113	117	116
	WB Left	183	188	171	176
	NB Left	157	165	141	152
	EB Left	132	171	151	161
	SB Left	186	227	201	220
Stopped Delay (sec./veh.)	SB Through	60	44	69	65
	Crossover	57	26	11	25

TABLE 2 Mound and Hall model validation

Measure of Effectiveness	Movement	Mean value of MOE	
		Field Measurement	Model
Travel Time (sec./veh.)	WB Through	136	139
	EB Through	99	107
	WB Left	229	228
	NB Left	179	215
	EB Left	178	163
	SB Left	140	180
Stopped Delay (sec./veh.)	SB Through, Time 1	5	10
	SB Through, Time 2	11	17
	WB Through, Time 1	7	11
	WB Through, Time 2	23	13

result, selecting an appropriate site to collect the data necessary to validate the roundabout models was difficult. Based on the project literature review (*1*), the most recent modern roundabout installation on the East Coast at the time of the study was at the junction of Routes 94 and 144 in Lisbon, Maryland, 50 km west of Baltimore. After constructing a temporary version of the roundabout in April 1993, the Maryland State Highway Association (SHA) finalized the design and constructed the current version of the roundabout in the fall of 1993.

Software Selection and Model Calibration

Two software packages were used to analyze the modern roundabout. Although not specifically intended for the analysis of roundabouts, Traf-Netsim 4.0 was chosen as one means to model the roundabout. Of particular importance was its ability to track individual vehicles as they approached and negotiated the roundabout and the surrounding road network. This ability to model an entire network is critical when attempting to evaluate situations such as the "raindrop" (*7*), in which individual roundabouts make up only a portion of the configuration. SIDRA 4.07, a macroscopic intersection analysis package developed by the Australian Road Research Board, was also selected to analyze the roundabout (*3*).

During a visit to Lisbon, the data collection team collected estimates of travel time, stopped delay, time in queue, and percentage stops at entry. Because of the differences between the two analysis packages, the research could only compare the stopped delay estimate for the two models. SIDRA does not estimate travel times and, although Traf-Netsim provides an estimate for the total number of stops, it cannot differentiate between stops associated with queueing and stops at the entry to the roundabout.

To calibrate the Traf-Netsim roundabout model depicted in Figure 6, the team collected gap acceptance data and recorded roundabout circulation speeds. Eight hours of gap acceptance behavior were collected on two approaches to the roundabout. After reducing the data with the aid of TDIP (*6*), the analysts applied Ramsey and Routledge's (*5*) method to obtain an estimate of the critical gap distribution. The comparison between the observed critical gap distribution and the Traf-Netsim default critical gap distribution shown in Figure 7 indicated that motorists entering the roundabout exhibited more aggressive behavior than the behavior described by the Traf-Netsim default distribution. An analysis of the circulation speed within the roundabout revealed an average circulation speed of 24 km/hr. To obtain the speed estimate, average speeds for three of the primary movements at the intersection were obtained and then weighted by the corresponding movement volume.

Because of relatively low volumes at the site and the importance of driver variation for the analysis, travel-time data were collected through a license plate study. The data collection crew examined two approaches to the intersection; one person was stationed along

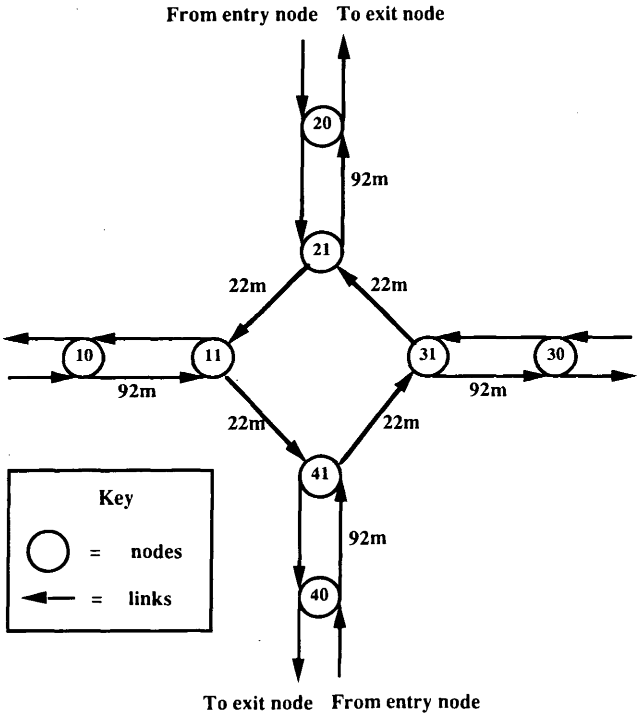

FIGURE 6 Traf-Netsim diagram for roundabout.

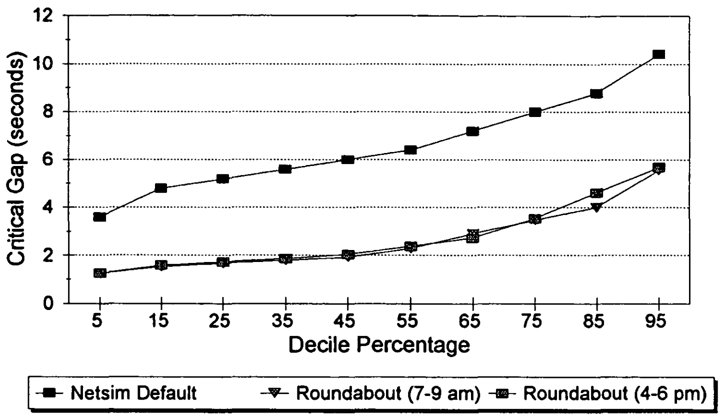

FIGURE 7 Observed roundabout critical gap distribution versus Traf-Netsim default distribution.

the approach leg and the other person moved from one downstream leg to another every 20 min.

Relatively light volumes at the intersection allowed the data collection team to collect the approach volume, stopped delay, and percentage stop data simultaneously. Because tracking vehicles through the roundabout to obtain turning percentages was difficult, the team recorded only the gross approach volumes. To estimate turning movement percentages, a set of November 1990 turning movement counts for the intersection were obtained from the SHA. A comparison of the approach volumes recorded during the trip and those provided by the SHA showed that the overall volumes had changed very little since November 1990.

The average stopped delay was estimated using the same technique as the median U-turn study. Based on the field data, vehicles entering the intersection during the morning or afternoon peak experienced an average stopped delay ranging from 0.5 sec to less than 3 sec. The results also indicate that many of those vehicles approaching the roundabout enter without having to stop.

Validation Results

Table 3 compares the parameters observed in the field with those predicted by Traf-Netsim and SIDRA. The travel time estimates reveal that, on the whole, Traf-Netsim provided a reasonable prediction of the travel times observed in the field with a tendency toward underestimation. Traf-Netsim also provided a low estimate of the number of stops. This is particularly striking considering that the stop percentage estimate provided by Traf-Netsim includes stops resulting from queueing and entry to the roundabout. In terms of stopped delay and time in queue, the values provided by Traf-Netsim also appear somewhat conservative. However, considering the relatively small amount of delay experienced at the intersection, the difference is insignificant. SIDRA also tended to underestimate the average stopped delay. In terms of stops upon entry, SIDRA provided a consistently accurate estimate, particularly as the number of stops increased.

CONTINUOUS GREEN T-INTERSECTION

To gather the data necessary to analyze the continuous green T-intersection (CGT), the team completed a 4-day data collection trip to Jacksonville, Florida. The CGT alternative may be applied to three-legged intersections with little pedestrian activity and high through volumes. Figure 8 illustrates this alternative.

To model this configuration, the team identified two primary areas where additional information was needed. First, the team investigated the typical geometry of the CGT, and then examined the typical distribution of traffic between the free-flow lane(s) and the signalized through lane associated with this configuration. In the first area, the team collected geometric data at 11 sites to develop a model that would represent the typical CGT application. The most significant piece of information to come from this portion of the investigation was the average distance upstream of the intersection where the vehicles were segregated into the outside free-flow lane(s) and the inside through lane subject to stopped conditions at the intersection. On average, the vehicles were segregated approximately 60 m upstream of the intersection and remained segregated for 60 m downstream of the intersection. With this information, the next step was to develop a model with one or two lanes subject to continuous movement, and another subject to signal control. Figure 9 shows the network developed for the CGT based on the geometric data collected.

The second area of calibration for the CGT was to identify the distribution of vehicles between the free-flow lane(s) and the lane subject to stopping for any given through volume. The team collected 86 15-min data points at six sites for lane distribution analysis. Observations for four-lane and six-lane arterials were represented within the data collected. With these data, least squares regression equations were developed relating the amount of traffic in the free-flow lane(s) to the total through volume. The R^2 values associated with these equations were more than 0.99 and suggest that the percentage of vehicles within the free-flow lane(s) is consistent at about 77 percent for four-lane arterials and 81 percent for six-lane arterials. Figure 10 shows the observations at the four-lane CGTs and the resulting least squares regression equation.

CONCLUSIONS

The calibration and validation of models of three unconventional arterial designs was described. Traf-Netsim was used for all three designs, and SIDRA was used for the roundabout alternative. The highlights of the calibration included updated critical gap distribu-

TABLE 3 Results of Roundabout Analysis Using Traf-Netsim and SIDRA

Time Interval	Movement	Travel Times		
		Observed	Traf-Netsim	SIDRA
7:00 - 8:00	EB Left	27 sec.	25.9 sec.	—
	EB Through	25 sec.	23.6 sec.	—
	EB Right	20 sec.	20.2 sec.	—
	SB Left	32 sec.	24.1 sec.	—
	SB Through	24 sec.	20.7 sec.	—
	SB Right	23 sec.	17.9 sec.	—
8:00 - 9:00	EB Left	27 sec.	25.1 sec.	—
	EB Through	25 sec.	22.7 sec.	—
	EB Right	20 sec.	19.2 sec.	—
	SB Left	32 sec.	23.9 sec.	—
	SB Through	24 sec.	20.3 sec.	—
	SB Right	23 sec.	18 sec.	—

Time Interval		Delay, Queue Time, and Stops		
		Observed	Traf-Netsim	SIDRA
7:00 - 8:00	**Eastbound**			
	Stopped Delay	0.088 hrs.	0.152 hrs.	0.06 hrs.
	Queue Time	0.175 hrs.	0.163 hrs.	—
	Number of Stops	45	30	51
	Southbound			
	Stopped Delay	0.05 hrs.	0.109 hrs.	0.01 hrs.
	Queue Time	0.192 hrs.	0.109 hrs.	
	Number of Stops	19	7	11
8:00 - 9:00	**Eastbound**			
	Stopped Delay	0.017 hrs.	0.061 hrs.	0.03 hrs.
	Queue Time	0.083 hrs.	0.064 hrs.	—
	Number of Stops	25	—	29
	Southbound			
	Stopped Delay	0.087 hrs.	0.068 hrs.	0.02 hrs.
	Queue Time	0.204 hrs.	0.068 hrs.	—
	Number of Stops	28	—	19
4:00 - 4:30	**Eastbound**			
	Stopped Delay	0.05 hrs.	0.014 hrs.	0.015 hrs.
	Queue Time	0.074 hrs.	0.015 hrs.	—
	Number of Stops	19	—	13
4:30 - 5:00	**Southbound**			
	Stopped Delay	0.05 hrs.	0.04 hrs.	0.025 hrs.
	Queue Time	0.117 hrs.	0.043 hrs.	—
	Number of Stops	28	—	21
5:00 - 6:00	**Eastbound**			
	Stopped Delay	0.033 hrs.	0.027 hrs.	0.02 hrs.
	Queue Time	0.038 hrs.	0.027 hrs.	—
	Number of Stops	17	—	19
	Southbound			
	Stopped Delay	0.094 hrs.	0.068 hrs.	0.03 hrs.
	Queue Time	0.183 hrs.	0.068 hrs.	—
	Number of Stops	35	—	35

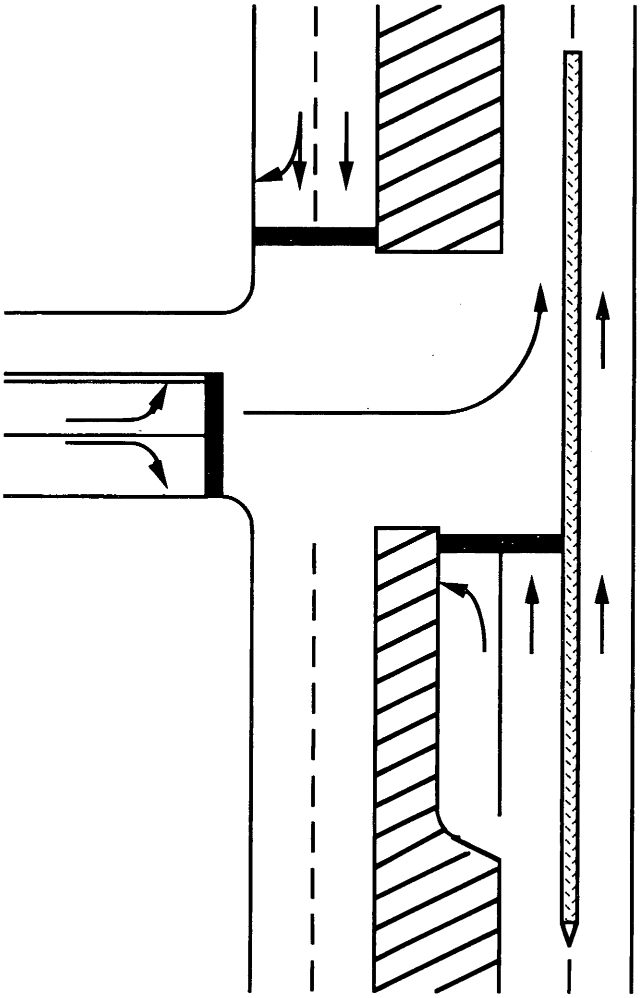

FIGURE 8 Continuous green T-intersection.

tions for the six-lane median U-turn and the roundabout, a larger saturation flow rate for the median U-turn, an average roundabout speed, and a distribution of traffic into the free-flow lane(s) for the CGT. Although this research investigated only the most important variables in the models that needed calibration, continued interest in these unconventional alternatives may warrant calibrating additional variables.

For validation of the median U-turn model, Traf-Netsim's estimates of travel time and delay for each of the intersections matched the behavior observed in the field reasonably well. Traf-Netsim slightly overestimated the travel time and underestimated the stopped delay. The results also indicate that the third approach to modeling the signal-controlled crossover with left turns on red (treating the crossover as if it operated as a right turn approach) provided the most accurate overall estimates. For validation of the roundabout models, a comparison of the field data with predictions by Traf-Netsim and SIDRA indicates that both provided relatively consistent results. Both Traf-Netsim and SIDRA predicted an insignificant amount of stopped delay and showed that a significant portion of the approaching vehicles entered without having to stop at all. Traf-Netsim also provided an accurate estimate of the travel times observed at the junction. Researchers should consider comparing the two packages and field data at modern roundabouts with higher volumes.

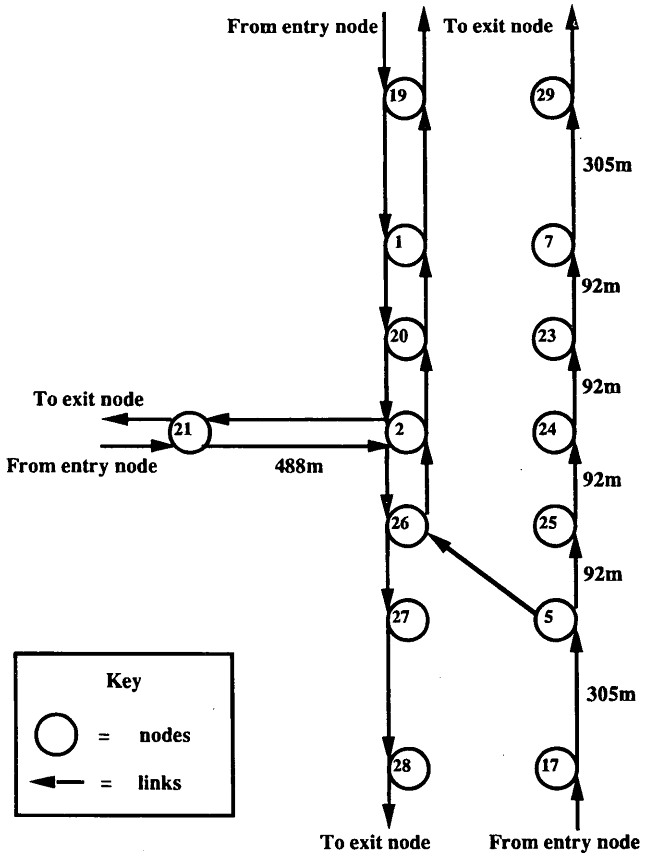

FIGURE 9 Traf-Netsim network for the continuous green T-intersection.

The models developed illustrate how simulation can provide reasonable predictions of field behavior at unconventional intersections. After determining that the models provided reasonable estimates for the measures of interest, the research team was able to gain some insight into what trends could be expected over a wide variety of geometry and traffic volumes.

The research reveals however, that additional work is needed. The CGT model, which appears to provide some potential benefits for application along suburban arterial corridors, still must be validated. As mentioned previously, validation of the roundabout model with higher volumes also would be helpful. Finally, there are several areas in which Traf-Netsim could be improved (e.g., the inability of Traf-Netsim to model left turns on red directly). Modifying Traf-Netsim to model two-lane crossovers and roundabouts would also be a worthwhile enhancement.

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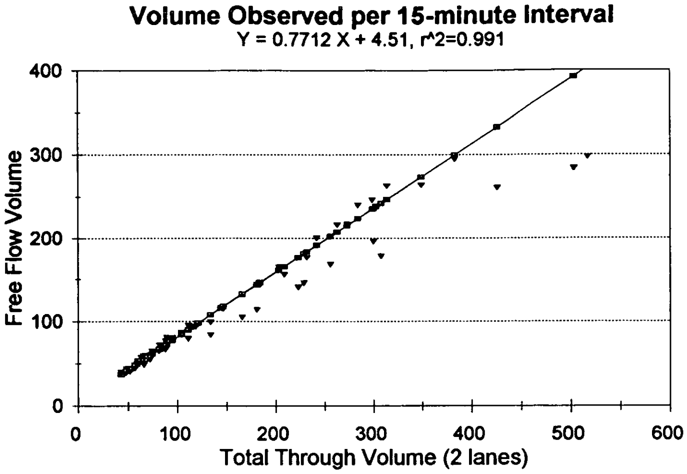

FIGURE 10 **Four-lane continuous green T-intersection lane distribution.**

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