Operational Effects of Nontraversable Medians and Two-Way Left-Turn Lanes: A Comparison

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Two popular arterial highway cross-section designs—two-way left-turn lanes (TWLTLs) and nontraversable medians (NTMs, raised or depressed) on four-lane roads—are compared for operational efficiency under identical traffic and development situations. Two broad measures of operational effectiveness, delay and fuel consumption, are obtained through simulation performed using the TRAF-NETSIM model. A three-way factorial design is used to compare and contrast the variables of interest. The results suggest that driveway density, traffic volume on the arterial, and type of design (TWLTL or NTM) have a significant effect on the performance measures such as total delay, fuel consumption, and delay to left-turning traffic and through traffic on the arterial. At low driveway density and low traffic volume, the difference in total delay between the two designs is not found to be significant. At higher driveway densities, no significant difference in delay to left-turning traffic on the arterial can be expected between TWLTL and NTM. However, TWLTL design is found to cause less delay to through traffic and be more fuel efficient at all levels of driveway density and traffic volume.

Operational problems on urban and suburban arterial highways, especially those with commercial strip development, often are caused by the conflicts between through traffic and left-turning traffic into and from adjacent driveways. The magnitude of the problem is related to the type of access provided to adjacent land uses and streets. In this respect, two-way left-turn lanes (TWLTLs) offer unrestricted access to left-turning vehicles. On the other hand, a cross section with a raised or depressed nontraversable median (NTM) limits left-turn maneuvers to places at which a median opening is provided. The choice between these designs is often not clear and presents a challenge to highway and traffic engineers.

The important issues to be addressed when choosing between the two designs include the following:

- Which design is safer at a given traffic-volume level and land use intensity?
- Which design offers less congestion and more capacity for a given set of operating conditions and physical characteristics?
- Considering safety and operational efficiencies, which design is more cost-effective?

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The analysis presented in this paper is part of a recent study (*1*) in which accident experiences and operational effects of the two designs are examined in detail to develop a set of guidelines for choosing and recommending between one of the two designs in a given situation. Another part of the study examined safety-related issues of the two designs. This paper primarily deals with the operational evaluations of the two median designs, TWLTL and NTM, on delay and fuel consumption. The approach to the analysis is theoretical and limited to studying the differences by modeling a ½-mi section of an arterial roadway using the TRAF-NETSIM package for a number of scenarios with varying driveway density and traffic volume on the arterial. It should be noted that the main objective of the study is to compare the two designs under identical operating conditions. Because incorporating all the real-world variations is very difficult, suitable assumptions were made to simplify simulation analysis.

STUDY SECTION CHARACTERISTICS

Figures 1 and 2 show typical TWLTL and NTM designs on urban arterials. The most common type of application of TWLTL and NTM is on two-way four-lane roads, so only four-lane arterials are studied for both alternative designs. Driveways are assumed to be two-way two-lane facilities.

Length of Study Section

One of the important considerations for the study is the length of the study section. If the length is not sufficient, the results may not be realistic. For simulation studies such as this one, a ½-mi study section is considered to be reasonable (*2*). To simplify comparisons, no cross streets or traffic signals are modeled within this section. This assumption is justified from the fact that the main objective of the study is to examine the operational differences of the two designs under identical operational conditions.

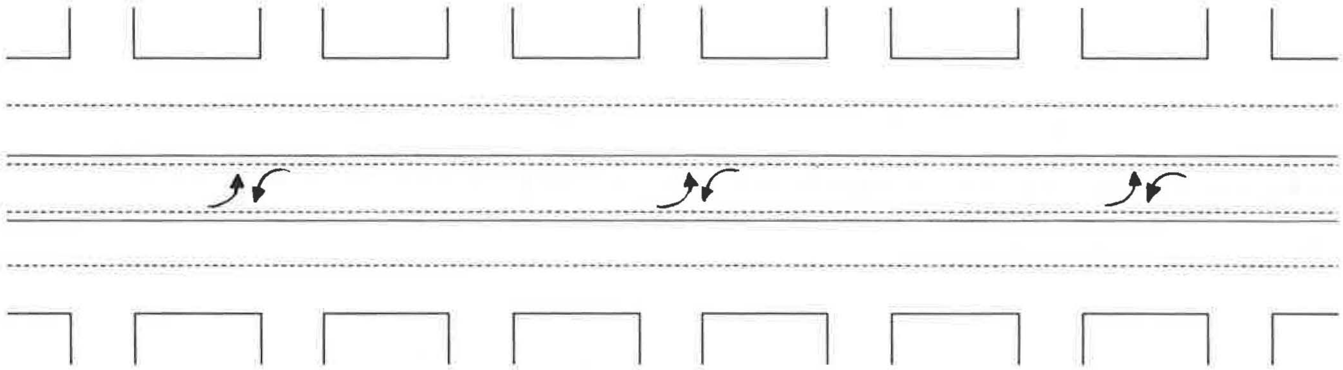

FIGURE 1 Typical TWLTL design section.

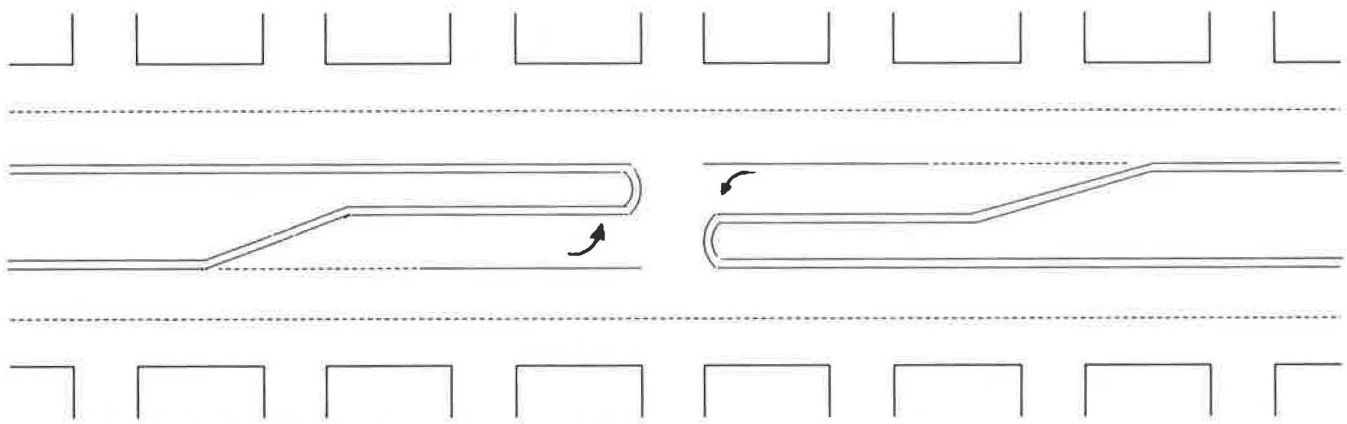

FIGURE 2 Typical NTM design section.

Driveway Density

Generally, driveways along an urban or suburban arterial have an irregular pattern with varied spacing and other characteristics. Some developments have a pair of one-way driveways for entry and exit traffic, whereas some developments have driveways with bidirectional flow. Adopting every possible driveway configuration into the study is impractical, so two average driveway densities are adopted to represent low and medium-high densities of development as follows:

- Low-density development: 32 driveways per mile, that is, driveways on both sides of the arterial at every 330 ft.
- Medium-high density development: 64 driveways per mile, that is, driveway on both sides of the arterial and every 165 ft.

For simplicity, no offset is considered for local driveway locations. In other words, driveways are assumed to be located on both sides of the arterial directly across from each other and at equal intervals to simplify the study process.

Turn Demand and Distribution of Traffic at Driveways

In practice, there is a considerable variation in turning demand at driveways, which is sensitive to many factors such as the size and type of land use, direction of flow, and through traffic volume. However, as for driveway spacing, studying all possible combinations of turn demand at driveways is a very difficult task. For simplicity, it is assumed for this study that 3 percent of the through arterial traffic will be turning at each pair of opposite driveways. That is, if traffic volume in one direction is 600 vehicles per hour (vph), nine vehicles (or 1.5 percent) will turn left and another nine vehicles (1.5 percent) will turn right at a driveway pair. If the traffic volume in the other direction is also 600 vph, traffic turning (left-turn and right-turn combined) into each driveway at a driveway pair will be (9 + 9 =) 18 vph. For the simulated hour, entry and exit volumes at driveways are assumed to be the same. Exit traffic from the driveways is also assumed to have a 50-50 split for turning in both directions of the arterial.

Because left turns from an arterial are prevented at most of the driveways in the case of a raised or depressed median design, the treatment of these turns is more complex. In this case, the prevented left turns waiting to enter into driveways are treated as is described.

Traffic intending to make a left turn at a particular driveway will traverse a segment beyond the destination until it reaches a median opening. At the median opening, three actions are possible, as illustrated in Figure 3. First, a U-turn may be executed and followed by travel in the opposite direction until the desired driveway is reached at which a right turn is executed to reach the destination (Action 1; Figure 3, *top*). Second, when a U-turn is not possible, a vehicle may turn right

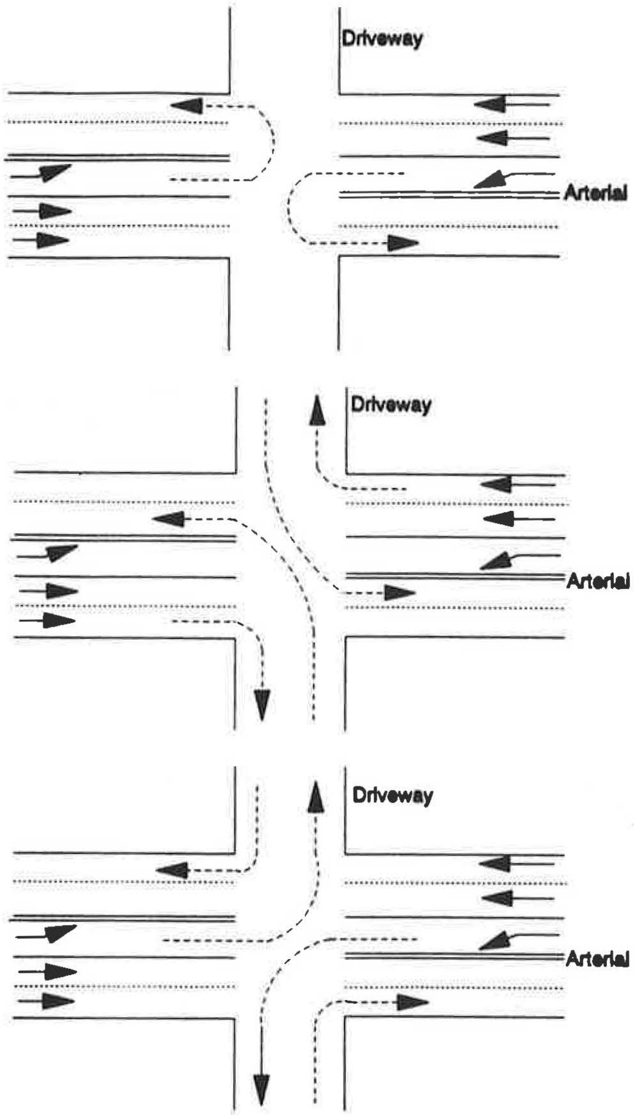

FIGURE 3 Reverse traversal at median openings: Action 1, simple U-turn (*top*); Action 2, right turn followed by left turn (*middle*); Action 3, left turn followed by right turn (*bottom*).

into the driveway at the median opening and from there turn left onto the arterial to head toward the desired direction (Action 2; Figure 3, *middle*). Third, a left turn may be executed into the driveway at the median cut, which would be followed by a right turn onto the arterial leading toward the desired driveway (Action 3; Figure 3, *bottom*).

In the same fashion, traffic prevented by the raised median from turning left from a driveway would turn right onto the arterial, travel farther until a median opening is reached, and then use any one of the previously mentioned maneuvers to travel in the desired direction.

In practice, all three actions illustrated in Figure 3 are possible. U-turns are most likely at low volumes, and one or both of Actions 2 and 3 are possible at high volumes. Since TRAF-NETSIM cannot model U-turns, it is assumed that the other two actions would adequately represent the demand for U-turns at median openings.

Turn percentages at driveways are computed in the following manner: as mentioned earlier, 3 percent of the arterial traffic will turn at each location of the driveways, of which 1.5 percent will turn left and 1.5 percent will turn right. Thus, computing turn percentages is straightforward for TWLTL design because there are no access restrictions to the driveways. However, for NTM design, at locations with left turns, turn percentages are computed according to the logic of Actions 2 and 3.

However, in practice a driver who would turn left at a driveway if the left turns were allowed might adjust his or her route in many ways when left turns are prevented. For example, the driver may choose to travel around the block to take the driveway of choice through a right turn from the arterial or the driver may find an alternative to the desired destination just by turning right in the direction of travel without having to go to the other side of the arterial. It is difficult to incorporate all possible route choices into the simulation analysis. It is assumed that, on the average, drivers tend to increase their travel in an NTM case to reach their desired destinations and the actions presented above adequately represent the additional travel and its operational effects on the system as a whole.

Traffic Volume on Arterial

Through volume is an important variable that affects the performance of the alternative designs. Through volume is chosen as one of the three factors of the three-way factorial experiment explained later. The following three levels of through volume on the arterial are studied for both TWLTL and raised median:

1. Low volume: 600 vph in each direction.
2. Medium volume: 900 vph in each direction.
3. High volume: 1,200 vph in each direction.

Spacing of Median Opening

Median opening spacing has a significant influence on left-turn concentration at median openings: the less spacing, the lower the degree of left-turn concentration. In practice, median spacing varies from case to case. Different highway agencies have different standards for different types of development pattern—urban, suburban, and rural. For this study, a median opening is provided every 660 ft (⅛ mi) in the NTM case. This spacing is commonly used for suburban locations.

Other Input Data

Posted speed limits on the arterial and the driveways are held constant at 40 and 25 mph, respectively. For a raised median, left-turn pockets of 250 ft are provided at median openings. A stop sign is provided at each driveway link entering the arterial. Other input parameters of the model are set to TRAF-NETSIM default values.

APPLICATION OF TRAF-NETSIM

TRAF-NETSIM is a stochastic simulation modeling package to replicate traffic operations in urban road networks. The model is microscopic in nature, that is, it simulates individual vehicles in the system, and it is very detailed in its representation of the dynamics of traffic operations. TRAF-NETSIM is being continually updated and tested; during the past several years the model has been used for a variety of applications. Coding of networks for simulation using TRAF-NETSIM is documented by Yeldin et al. (*3*). Wong (*4*) describes the logic adopted by TRAF-NETSIM and its potential applications. One of the latest features added to the package is the modeling of identical traffic streams (*5*). This feature enables the analyst to conduct controlled simulation experiments using TRAF-NETSIM under identical traffic and other operating conditions and study the variation in output parameters. This study employed a controlled experiment using the identical-traffic-streams feature of TRAF-NETSIM.

The basic approach is to design hypothetical cases and hold all basic TRAF-NETSIM constant while varying only the network geometry to represent either a TWLTL or a median. Network coding for median design fits well within TRAF-NETSIM logic. Yet, because TRAF-NETSIM logic is based on intersection approach, the actual representation of TWLTL operation is not possible. However, Rathi et al. (*6*) indicated that this operation can be simulated by adding several "dummy" nodes between the street blocks. Using this approach, the model can be tricked to represent two-way left-turn lanes as a series of left-turn pockets leading the left-turning traffic into the respective driveways or cross streets.

In a typical TRAF-NETSIM application, a link is defined as the road section between two major intersections and the intersections themselves are represented as nodes. Should there be significant traffic generated by the minor intersections or driveways along this link, a source or sink node can be used to represent such traffic. However, TRAF-NETSIM output does not include measures of effectiveness for source nodes and sink nodes. Because of the microscopic nature of this study, parametric measures are required at each driveway's connection to the arterial. For this reason, each driveway is represented as a link and each arterial-driveway intersection as a node. This representation helps examine the delay and other details at the driveways. Thus, in each case there are two sets of links: arterial links and driveway links.

SIMULATION EXPERIMENT

Inputs to TRAF-NETSIM are extensive, and it is possible to study a wide range of variations in input parameters. A study design varying all possible inputs would be very complicated. Hence, it is necessary to assume some constant inputs to the model and vary only a manageable number of parameters. Also, the study design is subject to the limitations and capabilities of the TRAF-NETSIM software. As mentioned, the number of inputs is held constant and the number of study variables is limited to three by using a three-way factorial experiment with multiple replications. The three factor (categorical) variables of the experiment are

- Factor 1 (α_j): Driveway density (two levels—low and medium; $j = 1,2$)
- Factor 2 (β_k): Traffic volume on the arterial (three levels—low, medium, and high; $k = 1,2,3$), and
- Factor 3 (γ_l): Two alternative designs (TWLTL and NTM; $l = 1,2$).

The experimental design is shown in Table 1. Figure 4 illustrates the interrelation among the factors and different variables. The measurement of response variables at different levels of the three factors is described in the following discussion. The response variables obtained from TRAF-NETSIM output are three components of delay (total delay, delay to left-turning traffic, and delay to through traffic on the arterial street) and the total fuel consumption. It may be noted that the experimental design created 12 cells of a matrix, each cell representing a particular combination of the three factors.

For generating multiple data replications in each cell of the factorial experiment, the sequence of random numbers is varied in the appropriate input file. In each cell of the factor matrix, four independent replications are made using four different random number seeds to conduct an analysis of variance on the response variables. To ensure generation of identical traffic streams between the two designs in each cell, the same four

TABLE 1 Factorial Experiment Design

Driveway Density, γ_j (j = 1,2) (driveways/mile)	Volume, β_k (k = 1,2,3) (vehicles/hour)	Median Type, α_l (l = 1,2)	
		TWLTL	NTM
Low (32)	Low (600)	$y_{jkl(i)}$	$y_{jkl(i)}$
	Medium (900)	$y_{jkl(i)}$	$y_{jkl(i)}$
	High (1200)	$y_{jkl(i)}$	$y_{jkl(i)}$
Medium - High (64)	Low (600)	$y_{jkl(i)}$	$y_{jkl(i)}$
	Medium (900)	$y_{jkl(i)}$	$y_{jkl(i)}$
	High (1200)	$y_{jkl(i)}$	$y_{jkl(i)}$

$y_{jkl(i)}$ refers to the i th measured value of response variable at the factor level (j,k,l), where $i = 1$ to n ($n = 4$, sample size or number of observations in each cell)

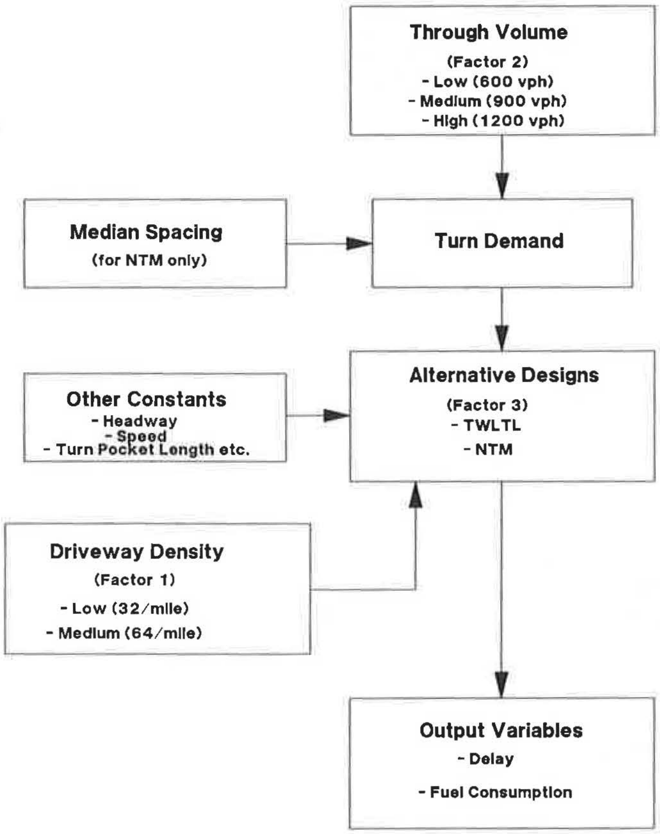

FIGURE 4 Relationships among input variables.

random number seeds are used in the appropriate order. (For more information on conducting simulation experiments using TRAF-NETSIM's "identical traffic streams" feature with multiple replications, the reader is referred to Rathi et al. (*5*). Thus, the study required 48 different TRAF-NETSIM runs (12 cells times 4 replications of each cell). To ensure the accuracy of network representation, the Animated NETSIM Graphics (ANETG) package, which is a postprocessor package for TRAF-NETSIM, is used. A typical TRAF-NETSIM run for a 20-min traffic flow simulation required about 30 to 35 min on an IBM-compatible 386 machine with 20-MHz clock speed and a math coprocessor.

Figure 5 is a schematic representation of the sequence of operations for network coding and multiple runs made for the study. Node and link representation of a typical coded network is shown in Figure 6. To avoid the influence of entry links at each end of the arterial, a 500-ft section without any driveway or cross-street connections is inserted between the arterial entry links and the study section. All driveways are coded as links of 100 ft long. As the identity of driveways is maintained as individual links, the turning traffic generated at the driveways is put into the system through entry and exit links connected to the respective locations. Through traffic on the arterial street is also put into the system by entry and exit links connected to the arterial.

Because TRAF-NETSIM is a microscopic simulation model, its output has extensive information, much of which is irrelevant for this study. The huge size of the output files necessitated the development of a postprocessor computer program to extract the information needed. This program was written in BASIC programming language and was custom-made for this study. This postprocessor program delivers only those sections of the TRAF-NETSIM output that are of interest to this study in a format readily appropriate for the Statistical Analysis Software (SAS).

ANALYSIS OF TRAF-NETSIM OUTPUT

The three-factor factorial experiment is analyzed using analysis of variance. However, the choice of response variables and statistical tests is not obvious and required some deliberation.

Selection of Response Variables

The operational differences of the two cross-section designs can be characterized by different variables such as traffic delay, average speed, stop time, queue discharge, fuel consumption, exhaust emissions, and so on. However, many of these variables are interrelated; hence, it is not appropriate to use all these variables for analysis. Variations in delay are sensitive to stop time and time spent in queues. Therefore, delay estimates would adequately represent system performance. On the other hand, fuel consumption statistics are important for estimating vehicle operating costs. Estimates of average delay and fuel consumption are very important for economic evaluation of alternatives. Because of this, the analysis focused on these two variables only.

Intuitively, because through traffic on arterials has uninterrupted right-of-way within the test section, significant differences in delay to the through traffic are not expected. However, the delay to left-turning traffic from the arterial is expected to be significantly different between the two designs. To test this hypothesis, delay data specific to through and left-turning volume, respectively, are extracted from the TRAF-NETSIM output in addition to the combined delay to all vehicles. Thus, the four response variables selected are (a) total delay, (b) delay to left-turning traffic from the arterial, (c) delay to through traffic, and (d) total fuel consumption.

Analysis Focus

Average values of total delay, delay to left-turning arterial traffic, delay to through traffic, and total fuel consumption are computed for the four replications in each cell. These average values are plotted for visualizing any obvious trends. Then each of these response variables is subjected to statistical tests.

Test for Main Effects and Interaction Effects

The purpose of the analysis for main and interaction effects is to verify whether the three factors affect the response variables individually (main effects), collectively (interaction), or both. For this purpose, the following general linear model is used:

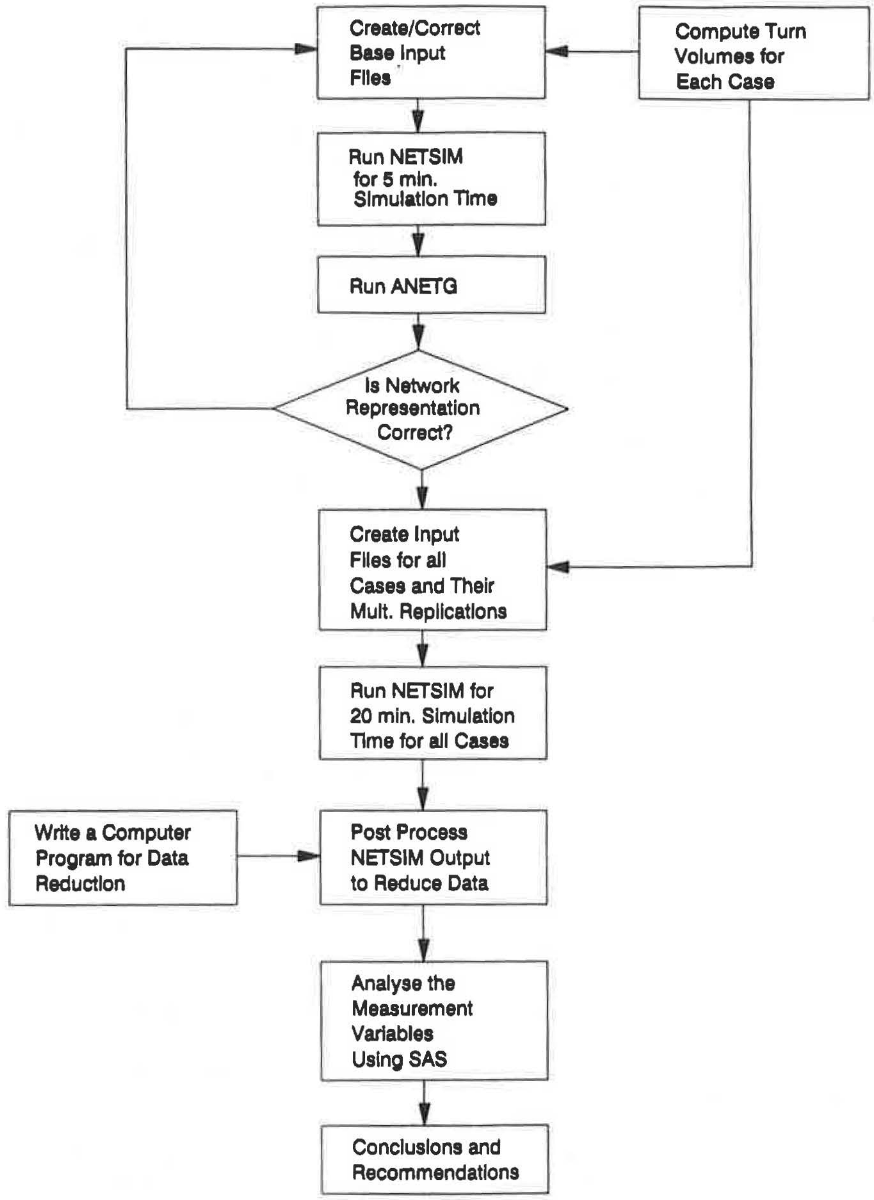

FIGURE 5 Schematic representation of steps in NETSIM runs.

$$y_{jkl(i)} = \mu + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + (\beta\gamma)_{kl} + (\alpha\gamma)_{jl} + (\alpha\beta\gamma)_{jkl} + \varepsilon_{jkl(i)} \quad (1)$$

where

$y_{jkl(i)}$ = ith observed value of the dependent variable in the (jkl)th cell,
α_j, β_k, and γ_l = main effects,
$(\alpha\beta)_{jk}$, $(\beta\gamma)_{kl}$, and $(\alpha\gamma)_{jl}$ = two-factor interaction effects,
$(\alpha\beta\gamma)_{jkl}$ = three-factor interaction effect,
$\varepsilon_{jkl(i)}$ = deviations of the observed $y_{jkl(i)}$ in the (jkl)th cell,
j = levels in median type (1,2),
k = levels in volume (1,2,3), and
l = levels in driveway density (1,2).

Contrasts

The two designs are contrasted by conducting tests of significance for the differences in the mean performance of the two roadway designs at all levels of driveway density and traffic volumes. These contrast tests indicate the levels at which the two designs are significantly different from each other. The generalized form of the tested hypothesis is given in Equation 2.

$$H_0: (\mu_{jk1}) \text{ for TWLTL} = (\mu_{jk2}) \text{ for NTM}$$

$$H_1: (\mu_{jk1}) \text{ for TWLTL} \neq (\mu_{jk2}) \text{ for NTM} \quad (2)$$

where μ_{jk1} and μ_{jk2} are the observed means of the response variable y for TWLTL and NTM, respectively, at levels j and k of the factor variables α_j and β_k.

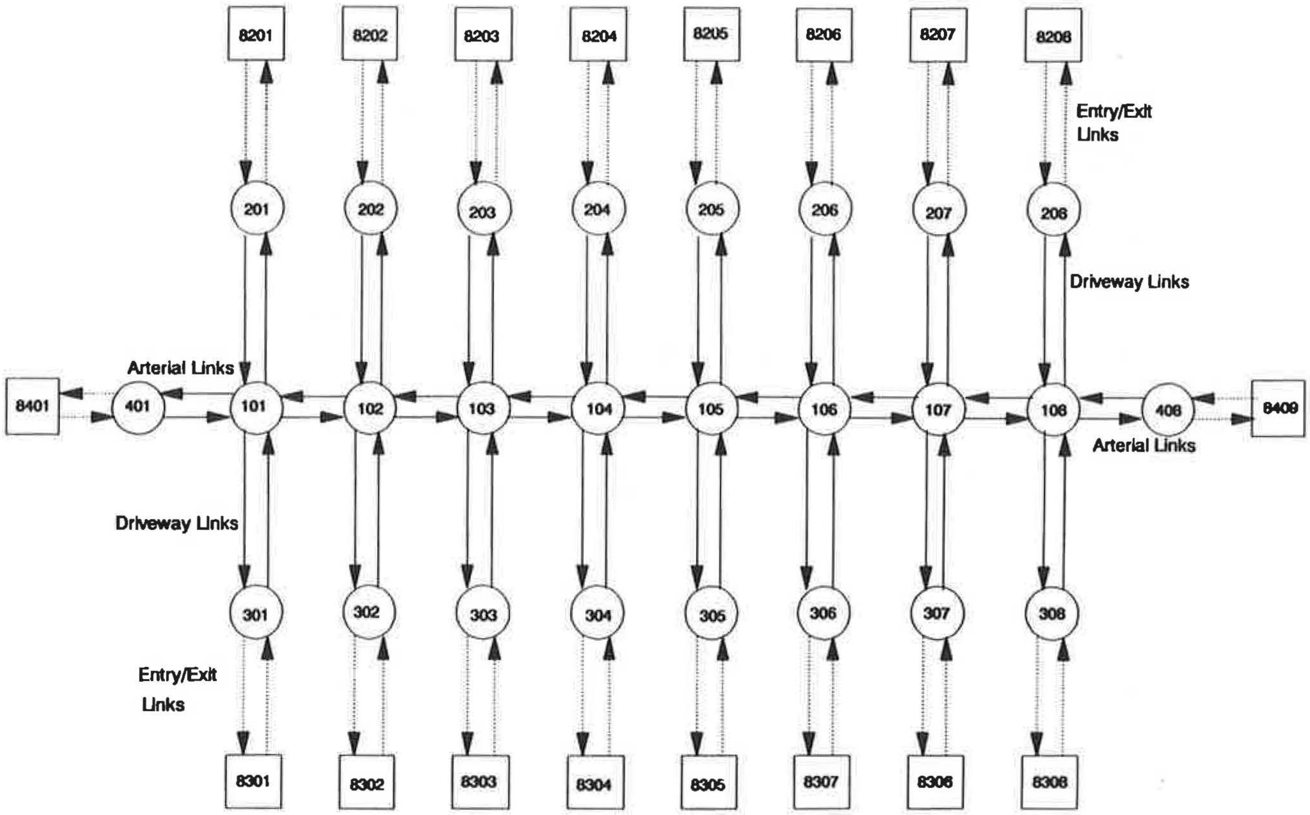

FIGURE 6 Node-link representation for low driveway density.

Estimates

In addition to the previous analyses, estimates of the differences in total delay and fuel consumption between the two designs are also obtained.

RESULTS

The average delay and fuel consumption for the NTM design are found to be consistently higher than those for TWLTL cross section. An example of this trend is illustrated in Figure 7. After examining similar trends for delay to left-turning and through traffic on the arterial and fuel consumption, it appeared that the difference in delay or fuel consumption increased at higher levels of driveway density and traffic volume. The differences in the rates of increase observed in the plots indicated that there may be some interaction among the three study variables. However, detailed analysis did not support this notion.

Table 2 summarizes the probabilities of Type I error resulted from the tests of significance on main effects and interaction effects. Table 3 summarizes the probabilities of Type I error for the contrast tests on the differences in the performance variables between the TWLTL and NTM. A null hypothesis (H_0) is rejected in favor of the alternative hypothesis (H_1) if the probability of Type I error is less than the specified α (5 percent, or 0.05). It may be noted that the lower the probability of Type I error, the stronger is the support in favor of the alternative hypothesis. For example, a probability of error of 0.0001 in rejecting the H_0 (that the effect of driveway density on total delay is not significant) indicates that the alternative hypothesis H_1 (that driveway density influences the delay) is significant. In such situations, stating that H_1 is significant at $\alpha = 0.05$ is an understatement of the strong evidence in favor of H_1. However, a 5 percent significance level is used as a benchmark for acceptance criteria, and the reader is advised to be aware of this phenomenon.

The expected differences in total delay and fuel consumption between NTM and TWLTL as quantified by TRAF-NETSIM model are listed in Tables 4 and 5. The results of this analysis lead to the following conclusions:

- Driveway density, traffic volume, and median design have significant influence on total delay, delay to left-turning traffic from the arterial and through traffic on the arterial, and fuel consumption on the road network.
- For left-turn delay, there is no convincing evidence in support of significant pairwise and three-way interaction effects of median design with driveway density and traffic volume.
- For delay to through traffic on the arterial, the pairwise interactions are found to be significant, and there is not much evidence in support of the existence of a three-way interaction.
- For total delay and fuel consumption, two-way and three-way interactions are found to be significant.
- Average total delay for the NTM cross section is observed to be consistently more than that for the TWLTL cross sections. The difference is greater at higher levels of driveway

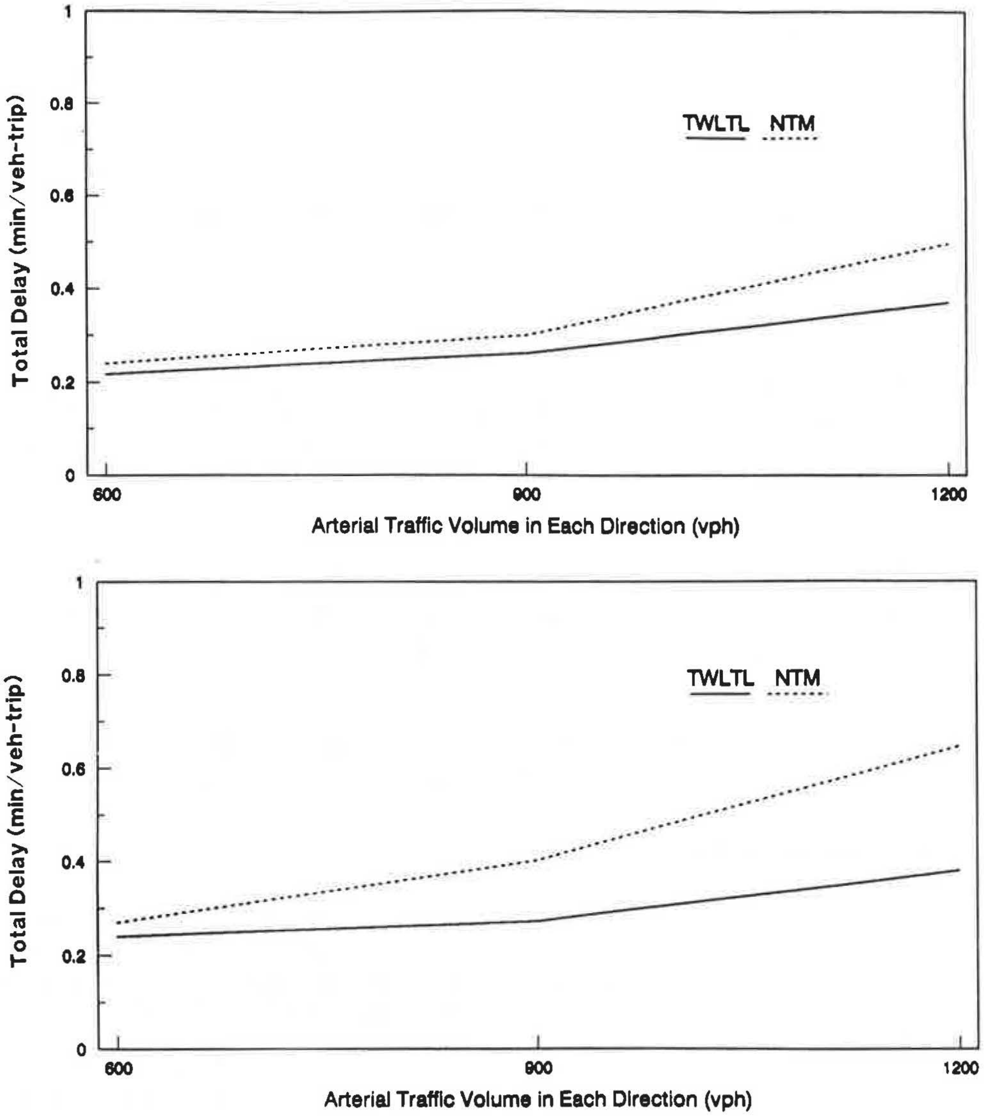

FIGURE 7 Networkwide delay for two designs; low driveway density, *top*, and medium driveway density, *bottom*.

TABLE 2 Summary of Statistical Tests for Main Effects and Interaction Effects

Variable	Null Hypothesis Tested (H_0)	Dependent Variable			
		Network Delay	Left-turn Delay	Through Delay	Fuel Consumption
Main Effects					
Driveway Density	$\alpha_j=0$	0.0001	0.0001	0.0001	0.0001
Volume	$\beta_k=0$	0.0001	0.0001	0.0001	0.0001
Median	$\gamma_l=0$	0.0001	0.0001	0.0001	0.0001
Interactions					
Density-Volume	$(\alpha\beta)_{jk}=0$	0.0013	0.0340	0.0001	0.0001
Volume-Median	$(\beta\gamma)_{kl}=0$	0.0001	0.1663*	0.0027	0.0001
Density-Median	$(\alpha\gamma)_{jl}=0$	0.0001	0.4953*	0.0001	0.0001
Density-Volume-Median	$(\alpha\beta\gamma)_{jkl}=0$	0.0001	0.3699*	0.0934*	0.0001

Note: Figures indicate probability of Type I error.

*Indicates that the is <u>not</u> significant at α = 0.05.

TABLE 3 Summary of Contrast Tests on Difference Between TWLTL and NTM

Driveway Density (α_i)	Volume Level (vph) (β_k)	Null Hypothesis	Dependent Variable			
			Network Delay	Left-turn Delay	Through Delay	Fuel Consumption
Low	Low Medium High	$\mu_{111} = \mu_{112}$ $\mu_{121} = \mu_{122}$ $\mu_{131} = \mu_{132}$	0.1033* 0.0085 0.0001	0.0365 0.0006 0.0001	0.0001 0.0001 0.0001	0.0001 0.0001 0.0001
Medium	Low Medium High	$\mu_{211} = \mu_{212}$ $\mu_{231} = \mu_{222}$ $\mu_{231} = \mu_{232}$	0.0322 0.0001 0.0001	0.0130 0.1591* 0.0934*	0.0001 0.0001 0.0001	0.0001 0.0001 0.0001

Note: Figures indicate probability of Type I error.

*Indicates that the is not significant at $\alpha = 0.05$.

density and through volumes. Additionally, the difference is found to be statistically significant at all levels.

- Delay to left-turning traffic on the arterial is 8.6 percent less for a TWLTL than an NTM design at low driveway density with low traffic volume, followed by 12.6 percent for medium and 13.9 percent for high traffic volumes. At medium driveway density with low traffic volume, TWLTL experiences 5.4 percent less left-turn delay than NTM design. However, the potential for delay reduction to left-turning traffic by employing a TWLTL design in preference to NTM design is not significant for cases with medium to high driveway density and moderate to high traffic volumes.
- Through traffic on the arterial is observed to experience more delay with NTM design than TWLTL design under all driveway densities and traffic volume levels tested. This difference exists even though the logic in coding the network assigned an uninterrupted right-of-way to this traffic. This can be attributed to the fact that there are more vehicle miles of travel with the NTM design than for TWLTL because of the added travel due to U-turns.
- Average fuel consumption for the NTM cross section is also observed to be consistently higher than that for the TWLTL cross section. The difference is found to be statistically significant at all levels.

The figures in Tables 4 and 5 may be used for estimating additional delay and excess fuel consumption for arterials with NTM design over arterials with TWLTL designs. These estimated differences can be useful for benefit-cost analysis when such an analysis is needed to choose between the two designs. Based on Tables 4 and 5, estimates of annual savings in delay are computed and are presented in Table 6. It must be pointed out that the results should be applied only within the range of volumes studied, that is, 600 to 1,200 vph in each direction [approximately 12,000 to 24,000 average daily traffic (ADT)] and the intermediate values may be obtained from linear interpolation.

CONCLUSIONS

This study attempted to identify the differences in the operational characteristics of two alternative roadway designs—namely, continuous two-way left-turn lanes and discontinuous nontraversable medians—by using a simulation technique. The analysis using TRAF-NETSIM identified the differences in the operational characteristics of the two designs.

The results suggest that driveway density, traffic volume on the arterial, and the type of design (TWLTL or NTM) have significant effect on the performance measures such as total delay, fuel consumption, and delay to left-turning traffic and through traffic on the arterial. At low driveway density and low traffic volume, the difference in total delay between the two designs is not significant. At higher driveway densities, no significant difference in delay to left-turning traffic on the arterial can be expected between TWLTL and NTM. However, TWLTL design is found to cause less delay to through traffic and be more fuel efficient at all levels of driveway density and traffic volume.

TABLE 4 Estimated Reduction in Total Delay for TWLTL over NTM Design

Driveway Density (driveways/mile)	Volume (vph)	Difference in Delay (min/veh-trip)	95% Confidence Interval	
			Lower	Upper
Low (32)	600 900 1,200	N.S. 0.0375 0.1275	N.A. 0.0111 0.1011	N.A. 0.0639 0.1539
Medium (64)	600 900 1,200	0.0300 0.1300 0.2675	0.0036 0.1036 0.2411	0.0564 0.1564 0.2939

Note: These reductions would be attained if a TWLTL is used instead of an NTM
N.S. - Not Significant, N.A. - Not Applicable

TABLE 5 Estimated Reduction in Fuel Consumption for TWLTL over NTM Design

Driveway Density (driveways/mile)	Volume (vph)	Difference in Fuel Consumption (gal/100 veh-miles)	95% Confidence Interval	
			Lower	Upper
Low (32)	600	0.7848	0.6986	0.8709
	900	0.5768	0.4906	0.6629
	1,200	0.9116	0.8254	0.9977
Medium (64)	600	1.7615	1.6753	1.8476
	900	1.7035	1.6173	1.7896
	1,200	2.4538	2.3676	2.5399

Note: These reductions would be attained if a TWLTL is used instead of an NTM

TABLE 6 Average Annual Savings in Delay and Fuel Consumption

Driveway Density (driveways/mile)	Volume (ADT)	Annual Savings	
		Delay (hrs)	Fuel (gal.)
Low (32)	12,000	None	17,187
	18,000	821	24,411
	24,000	8,103	35,485
Medium - High (64)	12,000	2,190	38,576
	18,000	5,475	57,483
	24,000	11,315	83,220

Note: These reductions would be attained if a TWLTL is used instead of an NTM (assuming a peak-hour factor of 10 percent and one-half mile arterial section)

SCOPE FOR FURTHER RESEARCH

The study used constant values for several input parameters such as spacing of median openings, left-turn demand, and posted speed limit on the arterial to keep the number of cases within a manageable limit. The values for most of these parameters vary in practice. Further research should focus on studying the operational differences between the two designs by varying speed, left-turn demand, and spacing of median openings for NTM along with varying driveway density and traffic volumes. Of particular interest is the effect of arterial volumes above 1,200 vph in each direction. The results presented here show that the difference in delay increases with increasing volume between 600 and 1,200 vph. It would be interesting to see if this gap continues to widen as volumes increase to the 1,800-to-2,000-vph range.

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