Cost-Effectiveness Methodology for Two-Way Left-Turn Lanes on Urban Four-Lane Roadways

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Two-way left-turn lane (TWLTL) medians are commonly used to solve the safety and operational problems on four-lane undivided roadways caused by conflicts between through and left-turn traffic. Although the potential safety and operational effects of TWLTL medians are well recognized, there are no generally accepted guidelines that define the circumstances under which the costs of TWLTL medians are justified by the benefits they provide. The objectives of the research on which this paper was based were (a) to evaluate the safety and operational effects of TWLTL medians on urban four-lane roadways, (b) to develop a methodology for evaluating the cost-effectiveness of TWLTL medians, and (c) to use this methodology to develop guidelines for their cost-effective use. The cost-effectiveness methodology that was developed is presented in this paper. The formulation of the cost-effectiveness methodology was based on a benefit-cost analysis approach. The benefits were the accident and operational cost savings provided by TWLTL medians. The costs were those of installing and maintaining the medians. A TWLTL evaluation form was designed to facilitate the implementation of the methodology. In addition, a sample problem illustrating the application of the methodology is presented.

The two-way left-turn lane (TWLTL) is commonly used to solve the safety and operational problems that result from conflicts between through traffic and midblock left-turn movements on four-lane undivided roadways. Left turns from a four-lane undivided roadway are made from through traffic lanes, causing through vehicles in these lanes to change lanes or be delayed. But on a roadway with a TWLTL, the deceleration and storage of left-turn vehicles are removed from the through lanes. Thus, conflicts between through and left-turn traffic are eliminated, and through vehicles can pass left-turn vehicles without changing lanes and without delay.

Although the potential safety and operational effects of the TWLTL are recognized by highway engineers, there are no generally accepted guidelines that define the circumstances under which the costs of providing TWLTL medians are justified. Numerous before and after studies of the safety effectiveness of the TWLTL have been conducted. However, empirical data pertinent to the assessment of the operational effectiveness of the TWLTL are lacking. Therefore, previous attempts to develop guidelines for the use of the TWLTL have focused on the safety benefits and have not adequately accounted for the operational effectiveness of the TWLTL.

The overall objective of the research on which this paper was based was to develop guidelines for the use of TWLTL medians on urban four-lane roadways that account for the operational as well as the safety effects of these medians. Specific objectives of the research were (a) to evaluate the safety and operational effectiveness of TWLTL medians on urban four-lane roadways, (b) to develop a methodology for evaluating the cost-effectiveness of the TWLTL, and (c) to apply this methodology to develop guidelines for the cost-effective use of TWLTL medians on urban four-lane roadways. The methodology and guidelines were developed to enable the identification of sections of urban four-lane undivided roadway on which the costs of providing TWLTL medians are justified.

Formulation of the cost-effectiveness methodology was based on a benefit-cost evaluation. The benefits were the accident and operational cost savings provided by TWLTL medians; the costs were those of installing and maintaining TWLTL medians. According to the methodology, if the benefits of a TWLTL exceed its costs, the TWLTL is cost-effective. Otherwise, it is not cost-effective.

The cost-effectiveness methodology is described in this paper. The step-by-step procedure and calculation form that were designed to facilitate the implementation of the methodology are presented. In addition, an example illustrating the application of the methodology is provided. The guidelines developed and other findings of the research are presented elsewhere (*1*).

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ACCIDENT COST SAVINGS

Two procedures are used in the cost-effectiveness methodology to compute the accident cost saving provided by TWLTL medians: one method applies to proposed four-lane roadways that do not have accident histories; and the other, to existing four-lane undivided roadways that have accident histories. A description of both procedures follows.

Proposed Roadways

An analysis of accidents on urban four-lane sections of the state highway system in Nebraska was conducted to determine the safety effects of TWLTL medians (*1*). As a result of this analysis, it was concluded that the accident reductions (Table 1) and the accident severity (Table 2) for four-lane undivided roadways should be used in the cost-effectiveness methodology. The accident reductions (Table 1) represent the number of accidents per mile that would not occur if an urban four-lane roadway with a TWLTL median were built instead of a four-lane undivided roadway. If the TWLTL were not included, these accidents would be expected to occur on the four-lane undivided roadway.

The average cost of these accidents is computed by applying the unit accident severity costs to the accident severity for four-lane undivided roadways shown in Table 2 as follows:

$$AC = 0.0001F + 0.265PI + 0.734PDO \quad (1)$$

where

AC = average cost of an accident on an urban four-lane undivided roadway ($/accident);
F = average cost of a fatal accident ($/accident);

TABLE 1 ANNUAL REDUCTION IN ACCIDENTS PER MILE

	Driveways Per Mile		
ADT	≤45	50	≥55
≤ 8,000	0	0	0
10,000	25	5	0
12,000	50	30	5
≥14,000	75	55	30

TABLE 2 ACCIDENT SEVERITY ON FOUR-LANE UNDIVIDED ROADWAYS

Level of Severity	Percentage of All Accidents
Fatal	0.1
Nonfatal Injury	26.5
Property Damage Only	73.4
	100.0

PI = average cost of a nonfatal injury accident ($/accident); and
PDO = average cost of a property-damage-only accident ($/accident).

The 1986 unit accident costs used by the Nebraska Department of Roads are $220,000 per fatal accident; $9,300 per nonfatal injury accident; and $1,190 per property-damage-only accident. Substituting these costs in equation 1, the average cost of an accident on a four-lane undivided roadway is $3,560.

Therefore, the annual accident cost savings provided by the installation of a TWLTL on an urban section of proposed four-lane undivided roadway are

$$ACS = \$3{,}560\ RL \quad (2)$$

where

ACS = annual accident cost savings provided by a TWLTL on proposed urban four-lane roadway ($/year);
R = annual accident reduction from Table 1 (accidents/mile/year); and
L = length of the roadway section (miles).

Thus, equation 2 is used in the cost-effectiveness methodology to compute the accident cost savings provided by TWLTL medians on proposed urban four-lane roadways.

Existing Roadways

As a result of the accident analysis conducted in this research (*1*), it was concluded that an accident reduction factor of 30 percent should be used to compute the safety benefits of adding TWLTL medians to existing urban four-lane undivided roadways. Therefore, the annual accident cost savings provided by the installation of a TWLTL on an existing four-lane undivided roadway are

$$ACS = 0.30\,(F \cdot N_F + PI \cdot N_{PI} + PDO \cdot N_{PDO}) \quad (3)$$

where

ACS = annual accident cost savings provided by a TWLTL on existing urban four-lane undivided roadway ($/yr.);

TABLE 3 REGRESSION EQUATIONS FOR PREDICTING REDUCTIONS IN STOPS AND DELAY

Traffic Volume[a] (vph)	Reduction	Equation[b]	R^2
<800	stops	$\ell n\ S = 0.00579\ V_t + 0.0117\ V_\ell - 0.00678D$	0.975
	delay	$\ell n\ D = 0.00845\ V_t + 0.0330\ V_\ell - 0.00561D - 0.0000308P$	0.978
≥800	stops	$\ell n\ S = 0.00610\ V_t + 0.0282\ V_d$	0.996
	delay	$\ell n\ D = 0.00898\ V_t + 0.0652\ V_d$	0.996

[a]Traffic volume in each direction.

[b] S = reduction in stops (number per hour per 1,000 ft.)

D = reduction in delay (seconds per hour per 1,000 ft.)

V_t = average traffic volume per direction (vph)

V_ℓ = sum of left-turn volumes in both directions (vph)

V_d = average left-turn volume per driveway (vph per driveway)

D = driveway density (driveways per mile)

$P = V_t \cdot V_\ell$

F = average cost of a fatal accident (\$/accident);
N_F = average number of fatal accidents per year;
PI = average cost of a nonfatal injury accident (\$/accident);
N_{PI} = average number of nonfatal injury accidents per year;
PDO = average cost of a property-damage-only accident (\$/accident); and
N_{PDO} = average number of property-damage-only accidents per year.

For the 1986 unit accident costs used by the Nebraska Department of Roads, equation 3 becomes the following:

$$ACS = 66{,}000\, N_F + 2{,}790 N_{PI} + 357 N_{PDO} \quad (4)$$

TABLE 4 STOPPING COSTS (*2*)

Vehicle Type	Traffic Volume[a] ≤650 vph[b]	Traffic Volume[a] >650 vph[c]
Passenger Car	21.00	17.75
Single Unit Truck	48.47	43.88
3-S2 Combination Truck	163.99	151.47

Note: Values are dollars per 1,000 stops.
[a]Traffic volume in each direction.
[b]Speed = 40 mph.
[c]Speed = 35 mph.

TABLE 5 UPDATING MULTIPLIERS FOR STOPPING COSTS (*2*)

Vehicle Type	Updating Formula
Passenger Car	$M = 0.0022\ CPI_F + 0.0001\ CPI_O + 0.0033\ CPI_T + 0.0001\ CPI_M + 0.0017\ CPI_D$
Single Unit Truck	$M = 0.0018\ WPI_F + 0.0031\ WPI_T + 0.0002\ CPI_M + 0.0008\ WPI_D$
3-S2 Combination Truck	$M = 0.0008\ WPI_{FD} + 0.0047\ WPI_T + 0.0001\ CPI_M + 0.0003\ WPI_D$

where:

CPI_F - Consumer Price Index - Private Transportation, Gasoline Regular and Premium

CPI_O - Consumer Price Index - Private Transportation, Motor Oil, Premium

CPI_T - Consumer Price Index - Private Transportation, Tires

CPI_M - Consumer Price Index - Private Transportation, Auto Repairs and Maintenance

CPI_D - Consumer Price Index - Private Transportation, Automobiles, New

WPI_F - Wholesale Price Index - Regular Gasoline to Commercial Users (Code No. 05710203.05)

WPI_{FD} - Wholesale Price Index - Diesel Fuel to Commercial Users (Code No. 05730301.06)

WPI_T - Wholesale Price Index - Truck Tires (Code No. 07120105.07)

WPI_D - Wholesale Price Index - Motor Truck (Code No. 141106)

OPERATIONAL COST SAVINGS

Operational cost savings provided by TWLTL medians are the savings in road-user stopping and travel time costs that result from the reductions in stops and delay provided by TWLTL medians. A computer simulation study (*1*) was conducted to determine these reductions. The regression equations (Table 3), which were determined in the computer simulation study, are used in the cost-effectiveness methodology to predict the reductions in stops and delay provided by TWLTL medians. The calculation of the operational cost savings using these predicted reductions, described below, is based on economic analysis procedures published by AASHTO (*2*).

TABLE 6 VALUES OF TIME (*2*)

Vehicle Type	$/vehicle-hour
Passenger Car	0.35[a]
Single Unit Truck	7.00
3-S2 Combination Truck	8.00

[a]For low time savings, average trips, and 1.56 adults per vehicle.

Stopping Costs Savings

The savings in stopping costs are computed from the reductions in stops provided by TWLTL medians. The hourly stopping costs savings are computed as follows:

$$SCS = 0.00528\ \Delta S \cdot L \sum_{i=1}^{3} P_i S_i M_i \qquad (5)$$

where

SCS = stopping costs savings provided by a TWLTL on an urban four-lane roadway ($/hour);

TWO-WAY LEFT-TURN LANE EVALUATION FORM[a]

Project .... Analyst .... Date ....

Location: On .... From .... To ....

Length .... miles Number of Driveways[b] .... Driveways Per Mile ....

ADT .... vpd Truck Percentages: Single Unit .... % 3-S2 Combinations .... %

Step 1. Calculate Daily Reductions in Stops and Delay.

(1[c]) Directional Volume Range (vph)	(2) No. of Hours Per Day in Range	(3) Average Directional Volume in Range (vph)	(4[d]) Average Left-Turn Volume in Range (vph)	(5) Reduction in Stops from Table A1 (stops/hr)	(6) Reduction in Delay from Table A2 (sec/hr)	(7) Stops Reduction (stops) (5) X (2)	(8) Delay Reduction (seconds) (6) X (2)
0-100							
101-200							
201-300							
301-400							
401-500							
501-600							
601-700							
					Subtotal A		
701-800							
801-900							
901-1,000							
1,000-1,100							
Total	24				Subtotal B		
						Total	

[a]Applicable to four-lane roadways only.

[b]Total number of driveways on both sides of roadway.

[c]Directional volume equals total volume divided by two.

[d]Total left-turn volume in both directions per 1,000 ft. of section length.

FIGURE 1 Two-way left-turn-lane evaluation form.

S = reduction in stops from Table 3 (number/hr/1,000 ft);

L = length of roadway section (miles);

P_i = proportion of vehicle type i in the traffic stream (%/100%);

S_i = stopping cost for vehicle type i from Table 4 ($/1,000 stops); and

M_i = updating multiplier for vehicle type i from Table 5.

The stopping costs in Table 4 are those published by AASHTO (*2*) for the year 1975. Three vehicle types are included: passenger cars, single-unit trucks, and 3–S2 combination trucks. The speeds used to determine the stopping costs shown for each level of traffic volume are the same speeds used in the computer simulation study (*1*) and were intended to approximate the speed-volume relationships on urban arterial roadways (*3*). A speed of 40 mph was used for traffic volumes of 650 vph or less; a speed of 35 mph was used for traffic volumes greater than 650 vph.

The updating multipliers in Table 5 enable the 1975 stopping costs in Table 4 to be updated to the current year. These multipliers are computed according to the AASHTO (*2*) procedures based on changes in consumer and wholesale price indices (*4*).

Step 2. Calculate Cost Per Stop.

① Vehicle Type[a]	② Proportion of Traffic	③ Stopping Cost[b] ($/stop)	④ Updating Multiplier from Table A3	⑤ Cost Per Stop ($/stop) ② X ③ X ④
(a.) Directional Volume ≤700 vph				
PC		0.02100		
SU		0.04847		
3-S2		0.16399		
			Total A	
(b.) Directional Volume >700 vph				
PC		0.01775		
SU		0.04388		
3-S2		0.15147		
			Total B	

[a]PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b]Source: Reference 30.

Step 3. Calculate Hourly Time Cost.

① Vehicle Type[a]	② Proportion of Traffic	③ 1975 Value of Time[b] ($/veh-hr)	④ Current Year CPI[c]	⑤ 1975 CPI[c]	⑥ Hourly Time Cost ($/hour) ② X ③ X ④ / ⑤
PC		0.35		156.1	
SU		7.00		156.1	
3-S2		8.00		156.1	
				Total	

[a]PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b]Source: Reference 30.
[c]Consumer Price Index.

FIGURE 1 ***continued***

Travel Time Costs Savings

The savings in travel time costs are computed from the reductions in delay provided by TWLTL medians. The hourly travel time costs savings are computed as follows:

$$TCS = 0.00147\ \Delta D\ L\ \frac{CPI}{156.1} \sum_{i=1}^{3} P_i T_i \qquad (6)$$

where

TCS = travel time costs savings provided by a TWLTL on an urban four-lane roadway ($/hour);
ΔD = reduction in delay from Table 3 (sec/hr/1,000 ft);
L = length of roadway section (mi);
CPI = consumer price index;
P_i = proportion of vehicle type i in the traffic stream (%/100%);
T_i = value of time for vehicle type i from Table 6.

The values of time in Table 6 are those established by AASHTO (*2*) for the year 1975. However, the results of equation 6 are updated to the current year by the ratio (CPI/156.1), which is the current consumer price index divided by the 1975 consumer price index.

The value of time shown in Table 6 for passenger cars was computed from the information given by AASHTO (*2*) for low time savings on average trips (i.e., $0.21 per person/hr and 1.56 persons per vehicle). These categories were used because (a) all delay reductions found in the computer simulation study were in the low time savings range (0–5 min per vehicle), and (b) the effects of TWLTL medians apply to all trip types (*1*).

Annual Operational Cost Savings

The annual operational cost savings provided by TWLTL medians are computed by summing the hourly stopping and travel time costs savings from equations 5 and 6 as follows:

$$OCS = 365 \sum_{i=1}^{24} (SCS_i + TCS_i) \qquad (7)$$

where

OCS = annual operational cost savings provided by a TWLTL on an urban four-lane roadway ($/yr);

Step 4. Calculate Annual Operational Cost Savings.

(a) Stops:

.... (Subtotal A, Col. 7, Step 1) X .... (Total A Col. 5, Step 2)
\+ .... (Subtotal B, Col. 7, Step 1) X .... (Total B Col. 5, Step 2) = ... (Daily Stopping Costs Savings ($/day))

(b) Delay:

.... (Total Col. 8, Step 1) X .... (Total Col. 6, Step 3) ÷ 3,600 (sec/hour) = ... (Daily Delay Costs Savings ($/day))

(c) Total:

[........ (a) + ... (b)] X 365 (days/year) = ... (Annual Operational Cost Savings ($/year))

FIGURE 1 ***continued***

SCS_i = stopping costs savings from equation 5 for the ith hr of an average day ($/hr); and

TCS_i = travel time costs savings from equation 6 for the ith hr of an average day ($/hr).

In equation 7, stopping and travel time costs savings are computed for each of the 24 hr in an average day. However, these savings are not computed for any hours with traffic volumes outside the traffic volume range (100–1,100 vph in each direction) of the regression equations in Table 3. The stopping and travel time costs savings are assumed to be zero for hours with volumes less than 100 vph in each direction. The cost-effectiveness methodology is not applicable to roadways with hourly directional volumes above 1,100 vph.

TWLTL COST

The TWLTL cost used in the cost-effectiveness methodology is the additional cost of right-of-way, construction, and maintenance required by providing a TWLTL on an urban four-lane roadway. The annual cost of the TWLTL is computed as follows:

$$C = (FC - SV) \cdot CRF_{i,n} + \frac{SV \cdot i}{100} + M \qquad (8)$$

where

C = annual cost of providing a TWLTL on an urban four-lane roadway ($/year);

FC = initial cost of the TWLTL, which includes additional right-of-way and construction costs ($);

SV = salvage value of the TWLTL ($);

$CRF_{i,n}$ = capital recovery factor for interest rate i and project life of n years; and

M = annual cost of maintaining the TWLTL ($/year).

Step 5. Calculate Annual Accident Cost Savings.

(a) Existing Four-Lane Undivided Roadway With Accident History:

① Accident Severity	② Number of Accidents	③ Unit Accident Cost Savings[a] ($/accident)	④ Accident Cost Savings ($) 2 X 3
Fatal		$66,000	
Nonfatal Injury		2,790	
Property-Damage-Only		357	
		Total	

.... ÷ .... = ...

Total Col. 4 ÷ No. of Years of Accident History = Annual Accident Cost Savings ($/year)

(b) Proposed Four-Lane Roadway Without Accident History:

.... X .... X $3,560 = ...

Annual Accident Reduction from Table A4 (accidents/year) X Length of Section (miles) X Average Accident Cost[b] ($/accident) = Annual Accident Cost Savings ($/year)

[a]Based on 30% reduction in accidents and 1986 unit accident costs used by Nebraska Department of Roads ($220,000 per fatal accident; $9,300 per nonfatal injury accident; and $1,190 per property-damage-only accident).

[b]Based on 1986 unit accident costs used by Nebraska Department of Roads and accident severity of four-lane undivided roadways (0.1% fatal; 26.5% nonfatal injury; and 73.4% property-damage-only accidents).

FIGURE 1 ***continued***

The user of the cost-effectiveness methodology must determine the initial cost, salvage value, capital recovery factor, and maintenance cost to be used in equation 8.

PROCEDURE

In the cost-effectiveness methodology, the sum of the annual accident and operational cost savings provided by the TWLTL is compared to the annual cost of the TWLTL. If the annual cost savings are greater than the annual cost, the TWLTL is cost-effective; if the savings are less than the annual cost, the TWLTL is not cost-effective. When the annual cost savings and the annual cost are equal, the results indicate indifference relative to the cost-effectiveness of the TWLTL.

The cost-effectiveness methodology is organized into an eight-step procedure. A TWLTL evaluation form that contains the step-by-step approach was designed to facilitate the implementation of the procedure. The evaluation form and the tables used in conjunction with it are presented in Figure 1. The following is an explanation of each step in the evaluation procedure shown in Figure 1.

Step 1: Calculate Daily Reductions in Stops and Delay

The daily reductions in stops and delay that are provided by the TWLTL are calculated by summing the reductions

Step 6. Calculate Total Annual Cost Savings.

.... + ... = ...

Annual Operational Cost Savings from Step 4 ($/year) + Annual Accident Cost Savings from Step 5 ($/year) = Total Annual Cost Savings ($/year)

Step 7. Calculate Annual TWLTL Cost.

First Cost: $.................... Project Life .... yrs.

Salvage Value: $.................... Interest Rate .... %

[.................... First Cost ($) − .... Salvage Value ($)] X .... Capital Recovery Factor

\+ .... Salvage Value ($) X .... Interest Rate (%) ÷ 100%

\+ .... Annual Maintenance Cost ($/year) = ... Annual TWLTL Cost ($/year)

Step 8. Compare Savings to Cost.

B: .... Total Annual Cost Savings from Step 6 ($) vs. C: .... Annual TWLTL Cost from Step 7 ($)

Conclusion:

B > C, TWLTL cost-effective. ....

B < C, TWLTL not cost-effective. ....

B = C, Indifference. ....

FIGURE 1 ***continued***

during each hour of an average day during which the mean directional volume (i.e., total volume divided by two) is greater than 100 vph. Although these reductions could be computed for each hour individually, acceptable results can be obtained by grouping the hours of the day into 100-vph directional volume ranges and then computing the reductions for the hours in each range using the average of the hourly directional volumes in the range. The reductions in stops and delay are assumed to be zero during the hours when the mean directional volume is less than 100 vph. Two subtotals are computed for reductions in stops because a 40-mph speed is assumed in computing stopping costs for hours with mean directional volumes of 700 vph or less, and a 35-mph speed is assumed for hours with mean directional volumes above 700 vph. The methodology is not applicable to roadways with mean directional volumes greater than 1,100 vph.

Step 2: Calculate Cost Per Stop

The cost per stop is calculated as the weighted average of the stopping costs of the passenger cars, single-unit trucks, and 3–S2 combination trucks in the traffic stream. The unit stopping costs are 1975 stopping costs published by AASHTO (*2*). The updating multipliers enable the 1975 stopping costs to be updated to the current year in accordance with the AASHTO (*2*) procedures.

Step 3: Calculate Hourly Time Cost

The hourly time cost is calculated as the weighted average of the hourly time costs of the passenger cars, single-unit trucks, and 3–S2 combination trucks in the traffic stream. The unit values of time are 1975 values published by AASHTO (*2*) updated to the current year by means of the consumer price index in accordance with the AASHTO (*2*) procedures.

Step 4: Calculate Annual Operational Cost Savings

The annual operational cost savings are calculated by applying the unit costs computed in steps 2 and 3 to the daily reductions in stops and delay computed in step 1.

Table A1. Equations for predicting reductions in stops.

Traffic Volume[a] (vph)	Equation[b]
<800	$\Delta S = 5.28\ L \cdot e^{(5.79\ V_t + 11.7\ V_1 - 6.78D)/1{,}000}$
≥800	$\Delta S = 5.28\ L \cdot e^{(6.10\ V_t + 28.2\ V_d)/1{,}000}$

[a] Average traffic volume per direction (total traffic volume/2).

[b] ΔS = reduction in stops (stops/hour).
L = length of roadway section (miles).
V_t = average traffic volume per direction (vph).
V_1 = total left-turn volume in both directions per 1,000 ft. of section (vph).
V_d = average left-turn volume per driveway (vph per driveway).
D = driveway density (driveways per mile).

Table A2. Equations for predicting reduction in delay.

Traffic Volume[a] (vph)	Equation[b]
<800	$\Delta D = 5.28\ L \cdot e^{(8.45\ V_t + 33.0\ V_1 - 5.61\ D - 0.0308P)/1{,}000}$
≥800	$\Delta D = 5.28\ L \cdot e^{(8.98\ V_t + 65.2\ V_d)/1{,}000}$

[a] Average traffic volume per direction (total traffic volume/2).

[b] ΔD = reduction in delay (seconds per hour).
L = length of roadway section (miles).
V_t = average traffic volume per direction (vph).
V_1 = total left-turn volume in both directions per 1,000 ft. of section length (vph).
V_d = average left-turn volume per driveway (vph per driveway).
D = driveway density (driveways per mile).
P = $V_t \cdot V_1$

FIGURE 1 *continued*

Step 5: Calculate Annual Accident Cost Savings

One of two procedures is used to calculate the annual accident cost savings. If the TWLTL is being added to an existing four-lane roadway with an accident history, the annual accident cost savings is computed on the basis of a 30-percent reduction in the average number of fatal and nonfatal injury and property-damage-only accidents per year during the accident history. If the TWLTL is being added to a proposed four-lane roadway without an accident history, the annual accident cost savings is computed on the basis of a predicted reduction in accidents per year. The unit accident costs are 1986 costs used by the Nebraska Department of Roads.

Step 6: Calculate Total Annual Cost Savings

The total annual cost savings are the sum of the annual operational cost savings computed in step 4 and the annual accident cost savings computed in step 5.

Step 7: Calculate Annual TWLTL Cost

The annual cost of TWLTL is the sum of the capital recovery cost of the TWLTL and the annual cost of maintaining the TWLTL.

Step 8: Compare Savings to Cost

The final step in the procedure is to determine whether or not the TWLTL being evaluated is cost-effective. This determination is based on a comparison of the TWLTL median's benefits, which are the total annual cost savings computed in step 6, to its annual cost, which is computed in step 7. If its benefits are greater than its cost, the TWLTL is cost-effective. If its benefits are less than its cost, the TWLTL is not cost-effective. If its benefits are equal to its cost, the results of the evaluation are indifferent relative to the cost-effectiveness of the TWLTL.

SAMPLE PROBLEM

A sample problem, which illustrates the application of the cost-effectiveness methodology, follows. This sample illus-

Table A3. Updating multipliers for stopping costs.[a]

Vehicle Type	Updating Formula	1986 Multiplier
Passenger Car	$M = 0.0022\ CPI_F + 0.0001\ CPI_O + 0.0033\ CPI_T + 0.0001\ CPI_M + 0.0017\ CPI_D$	1.643
Single Unit Truck	$M = 0.0018\ WPI_F + 0.0031\ WPI_T + 0.0002\ CPI_M + 0.0008\ WPI_D$	1.796
3-S2 Combination Truck	$M = 0.0008\ WPI_{FD} + 0.0047\ WPI_T + 0.0001\ CPI_M + 0.0003\ WPI_D$	1.562

where:

CPI_F – Consumer Price Index – Private Transportation, Gasoline Regular and Premium

CPI_O – Consumer Price Index – Private Transportation, Motor Oil, Premium

CPI_T – Consumer Price Index – Private Transportation, Tires

CPI_M – Consumer Price Index – Private Transportation, Auto Repairs and Maintenance

CPI_D – Consumer Price Index – Private Transportation, Automobiles, New

WPI_F – Wholesale Price Index – Regular Gasoline to Commercial Users (Code No. 05710203.05)

WPI_{FD} – Wholesale Price Index – Diesel Fuel to Commercial Users (Code No. 05730301.06)

WPI_T – Wholesale Price Index – Truck Tires (Code No. 07120105.07)

WPI_D – Wholesale Price Index – Motor Truck (Code No. 141106)

[a]Source: Reference 30.

Table A4. Annual reduction in accidents per mile.

ADT	Driveways Per Mile		
	≤45	50	≥55
≤ 8,000	0	0	0
10,000	25	5	0
12,000	50	30	5
≥14,000	75	55	30

FIGURE 1 ***continued***

trates the use of the methodology to evaluate the addition of a TWLTL to an existing four-lane undivided roadway.

Traffic congestion, caused by conflicts between left-turn and through traffic, is being experienced during several hours each day on a 1,000-ft section of an urban four-lane undivided street that serves commercial development. The ADT on the street is 18,000 vpd with 18 percent single unit and 10 percent combination trucks. Within the 1,000-ft section, there are five driveways. Throughout much of the day, the left-turn volume into these driveways is about 10 percent of the traffic volume on the section. During the past 3 yr, there have been 14 accidents on the section: 6 nonfatal injury and 8 property-damage-only accidents.

Addition of a TWLTL is being considered to improve the safety and efficiency of traffic operations on the street. Therefore, the cost-effectiveness of installing and maintaining a TWLTL on this section is to be determined.

The completed Two-Way Left-Turn Lane Evaluation Form for this problem is presented in Figure 2. The evaluation was conducted using 1986 cost data. A brief explanation of each step of the evaluation follows.

Step 1: Calculate Daily Reductions in Stops and Delay

The hourly distribution of directional volumes shown in column 2 (Figure 2) was determined from traffic counts conducted at the site. During 4 hr of the day, directional volumes are not greater than 100 vph. Therefore, according to the cost-effectiveness methodology developed in this research, the reductions in stops and delay are assumed to be zero during these 4 hr. The average values of directional

TWO-WAY LEFT-TURN LANE EVALUATION FORM[a]

Project ..... *Example I* ..... Analyst ..... *R. A. Jones* ..... Date ..... *8/1/86* .....

Location: On ..... *Hwy. A* ..... From ..... *First St.* ..... To ..... *Fourth St.* .....

Length ..... *0.19* ..... miles Number of Driveways[b] ..... *5* ..... Driveways Per Mile ..... *26* .....

ADT ..... *18,000* ..... vpd Truck Percentages: Single Unit ..... *18* ..... % 3-S2 Combinations ..... *10* ..... %

Step 1. Calculate Daily Reductions in Stops and Delay.

(1c)	(2)	(3)	(4d)	(5)	(6)	(7)	(8)
Directional Volume Range (vph)	No. of Hours Per Day in Range	Average Directional Volume in Range (vph)	Average Left-Turn Volume in Range (vph)	Reduction in Stops from Table A1 (stops/hr)	Reduction in Delay from Table A2 (sec/hr)	Stops Reduction (stops) (5) X (2)	Delay Reduction (seconds) (6) X (2)
0-100	4						
101-200	2	119	24	2.2	4.8	4	10
201-300	3	256	50	6.7	26.5	20	80
301-400	1	387	76	19.2	113.2	19	113
401-500	1	472	92	38.0	255.8	38	256
501-600	2	555	108	74.0	525.8	148	1,052
601-700	3	621	122	127.7	895.4	383	2,686
					Subtotal A	612	
701-800	6	733	144	197.7	4,737.6	1,186	28,426
801-900	2	819	160	365.6	12,634.9	731	25,270
901-1,000							
1,000-1,100							
Total	24				Subtotal B	1,917	
						Total	57,893

[a] Applicable to four-lane roadways only.

[b] Total number of driveways on both sides of roadway.

[c] Directional volume equals total volume divided by two.

[d] Total left-turn volume in both directions per 1,000 ft. of section length.

FIGURE 2 Example of completed two-way left-turn-lane evaluation forms.

volume and left-turn volume, shown in columns 3 and 4 (Figure 2), were computed from the traffic count data.

Step 2: Calculate Cost per Stop

The cost per stop was computed for the traffic composition of 72 percent passenger cars, 18 percent single-unit trucks, and 10 percent combination trucks. This cost was updated using the 1986 multipliers given in Table A3 of Figure 1. One cost per stop was computed for the 12 hr during which the directional volume was 700 vph or less. Another cost per stop was computed for the 8 hr during which the directional volume was above 700 vph.

Step 3: Calculate Hourly Time Cost

The hourly time cost was computed for the traffic composition of 72 percent passenger cars, 18 percent single-unit trucks, and 10 percent combination trucks. It was updated using the 1986 consumer price index of 362.3.

Step 4: Calculate Annual Operational Cost Savings

Utilizing the results of the previous steps, an operational cost savings of nearly $240/day was computed. Based on

Step 2. Calculate Cost Per Stop.

① Vehicle Type[a]	② Proportion of Traffic	③ Stopping Cost[b] ($/stop)	④ Updating Multiplier from Table A3	⑤ Cost Per Stop ($/stop) ②X③X④
(a.) Directional Volume ≤ 700 vph				
PC	0.72	0.02100	1.643	0.0248
SU	0.18	0.04847	1.796	0.0157
3-S2	0.10	0.16399	1.562	0.0256
			Total A	0.0589
(b.) Directional Volume > 700 vph				
PC	0.72	0.01775	1.643	0.0210
SU	0.18	0.04388	1.796	0.0142
3-S2	0.10	0.15147	1.562	0.0237
			Total B	0.0589

[a]PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b]Source: Reference 30.

Step 3. Calculate Hourly Time Cost.

① Vehicle Type[a]	② Proportion of Traffic	③ 1975 Value of Time[b] ($/veh-hr)	④ Current Year CPI[c]	⑤ 1975 CPI[c]	⑥ Hourly Time Cost ($/hour) ②X③X④/⑤
PC	0.72	0.35	362.3	156.1	0.585
SU	0.18	7.00	362.3	156.1	2.924
3-S2	0.10	8.00	362.3	156.1	1.857
				Total	5.366

[a]PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b]Source: Reference 30.
[c]Consumer Price Index.

FIGURE 2 *continued*

365 days/yr, this amounts to an annual operational cost savings of $87,500/yr.

Step 5: Calculate Annual Accident Cost Savings

The street in this problem is an existing four-lane undivided roadway with an accident history. Therefore, computation of the annual accident cost savings of $6,532 was based on a 30-percent reduction in accidents.

Step 6: Calculate Total Annual Cost Savings

The sum of the annual operational and accident cost savings is $94,000. More than 90 percent of this total is operational cost savings.

Step 7: Calculate Annual TWLTL Cost

The estimated first cost of the TWLTL is $200,000. In accordance with the policy of the agency for which the analyst works, a zero salvage value and a 6-percent interest rate were used. Because substantial traffic impacts are expected to result from future development planned along other sections of the street, a project life of only 5 yr was used. The estimated annual maintenance cost of $1,000/yr includes pavement repair, pavement markings, and snow removal that would be required by the TWLTL.

Step 8: Compare Savings to Cost

The total annual cost savings are greater than the annual cost of the TWLTL. Therefore, the TWLTL is cost-effective. In fact, it is cost-effective solely on the basis of the

Step 4. Calculate Annual Operational Cost Savings.

(a) Stops:

612 (Subtotal A, Col. 7, Step 1) X *0.0661* (Total A Col. 5, Step 2)

\+ *1,917* (Subtotal B, Col. 7, Step 1) X *0.0589* (Total B Col. 5, Step 2) = *153.36* (Daily Stopping Costs Savings ($/day))

(b) Delay:

57,893 (Total Col. 8, Step 1) X *5.366* (Total Col. 6, Step 3) ÷ 3,600 (sec/hour) = *86.29* (Daily Delay Costs Savings ($/day))

(c) Total:

[*153.36* (a) + *86.29* (b)] X 365 (days/year) = *87,500* (Annual Operational Cost Savings ($/year))

FIGURE 2 ***continued***

Step 5. Calculate Annual Accident Cost Savings.

(a) Existing Four-Lane Undivided Roadway With Accident History:

①	②	③	④
Accident Severity	Number of Accidents	Unit Accident Cost Savings[a] ($/accident)	Accident Cost Savings ($) ② X ③
Fatal	0	$66,000	0
Nonfatal Injury	6	2,790	16,740
Property-Damage-Only	8	357	2,856
		Total	19,596

19,596	÷	*3*	=	*6,532*
Total Col. 4		No. of Years of Accident History		Annual Accident Cost Savings ($/year)

(b) Proposed Four-Lane Roadway Without Accident History:

....	X	....	X	$3,560	=	....
Annual Accident Reduction from Table A4 (accidents/year)		Length of Section (miles)		Average Accident Cost[b] ($/accident)		Annual Accident Cost Savings ($/year)

[a] Based on 30% reduction in accidents and 1986 unit accident costs used by Nebraska Department of Roads ($220,000 per fatal accident; $9,300 per nonfatal injury accident; and $1,190 per property-damage-only accident).

[b] Based on 1986 unit accident costs used by Nebraska Department of Roads and accident severity of four-lane undivided roadways (0.1% fatal; 26.5% nonfatal injury; and 73.4% property-damage-only accidents).

FIGURE 2 ***continued***

operational cost savings. However, it is not cost-effective solely on the basis of the accident cost savings.

CONCLUSION

The methodology presented in this paper provides a practical, quantitative procedure for evaluating the cost-effectiveness of TWLTL medians on urban four-lane roadways. However, factors other than cost-effectiveness must also be considered before making the final decision to install a TWLTL. Even though it may be evaluated as cost-effective, a TWLTL may not be appropriate in a particular case because of other factors such as inadequate sight distance, high pedestrian volume, classification as a major arterial street, short block lengths, inappropriate driveway configuration, and availability of adequate, indirect left-turn access. The results obtained by using the cost-effectiveness methodology must be considered in light of these other factors.

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Step 6. Calculate Total Annual Cost Savings.

87,500 + *6,532* = *94,000*

Annual Operational Cost Savings from Step 4 ($/year)		Annual Accident Cost Savings from Step 5 ($/year)		Total Annual Cost Savings ($/year)
87,500	+	6,532	=	94,000

Step 7. Calculate Annual TWLTL Cost.

First Cost: $ *200,000* Project Life *5* yrs.

Salvage Value: $ *0* Interest Rate *6* %

[*200,000* First Cost ($) − *0* Salvage Value ($)] X *0.23740* Capital Recovery Factor

\+ *0* Salvage Value ($) X *6* Interest Rate (%) ÷ 100%

\+ *1,000* Annual Maintenance Cost ($/year) = *48,500* Annual TWLTL Cost ($/year)

Step 8. Compare Savings to Cost.

B: *94,000* Total Annual Cost Savings from Step 6 ($) vs. C: *48,500* Annual TWLTL Cost from Step 7 ($)

Conclusion:

B > C, TWLTL cost effective. ✓

B < C, TWLTL not cost effective. ......

B = C, Indifference. ......

FIGURE 2 ***continued***

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