Selection of Median Treatments for Existing Arterial Highways

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Median treatments are an important means of reducing accidents and delay on urban arterial highways. Five common median treatments are (a) two-way left-turn lane, (b) continuous left-turn lane, (c) alternating left-turn lane, (d) raised median divider with left-turn deceleration lanes, and (e) median barrier with no direct left-turn access. A benefit-cost comparison of these treatments that considers the accident reduction, delay reduction, and construction cost for median treatments installed in existing arterial highways is reported. The analysis is based on a literature review and reasonable assumptions regarding the effectiveness of the median treatments. The result of the benefit-cost analysis is a selection guide that can be used by a designer to determine the optimal median treatment for an arterial highway based on geometric and operational conditions.

Many urban arterial highways in the United States have serious operational and safety deficiencies. These deficiencies are often the combined result of high and steadily growing traffic volumes and of a high density of driveways resulting from a lack of effective access control. These highways often have nonintersection left-turn movements that are nearly continuous in space and time. If unrestrained, these demands can result in both high accident rates and large delays to through motorists.

Traffic engineers responsible for arterial highways have long recognized the important role of median treatments in alleviating the operational and safety deficiencies described above. Indeed, many of the common safety and operational problems are amenable to solution in no other way. Left-turning vehicles are often the cause of accidents and delays to through vehicles, and only median treatments can alleviate these left-turn problems. Such problems are often continuous on long stretches of arterial highway, and only the continuous solution provided by a median treatment is practical.

Five basic median treatments have the potential to improve traffic operations and safety for continuous sections of existing arterial highways. These are (a) the two-way left-turn lane (TWLTL), (b) the continuous left-turn lane (CLTL), (c) the alternating left-turn lane (ALTL), (d) the raised median divider (RMD) with left-turn deceleration lanes, and (e) the median barrier (MB) with no direct left-turn access. The design and operational characteristics of these treatments are briefly described in the following section. Most of these treatments are currently used by at least some agencies, but the traffic engineer needs a rational basis for selecting a median treatment that is both cost-effective and operationally appropriate for a given highway section. The discussion in this paper provides the framework for a rational method of selecting appropriate median treatments.

DESIGN AND OPERATIONAL CHARACTERISTICS

The five median treatments fall into two distinct categories. The first three treatments use median lanes that do not physically restrict the movement of traffic across the median. The last two techniques use raised medians that limit crossings to those openings selected by the designer. The design and operational characteristics of the five median treatments are discussed below. More detailed descriptions of these techniques can be found in recent reports by Azzeh and others (1) and Glennon and others (2).

Two-Way Left-Turn Lane

The standard design for a two-way left-turn lane specified by the Manual on Uniform Traffic Control Devices (MUTCD) (3, Figure 3-4a) is shown in Figure 1. The major design requirement for this technique is the median width, which should be at least 4.2 m (14 ft).

A two-way left-turn lane is intended to remove left-turning vehicles from the through lanes and store those vehicles in a median area until an acceptable gap in opposing traffic appears. The two-way left-turn lane completely shadows turning vehicles from both through-lane traffic streams. Thus, reductions in the severity and frequency of accidents will result. Frequency is reduced by removing stopped or slow left-turning vehicles from the through lanes, and severity is reduced by allowing additional perception time to reduce left-turn crossing conflicts. Delay to through vehicles is also reduced because left-turning vehicles and queues do not block the through lanes.

The two-way left-turn lane is operationally warranted on arterial highways that have average daily traffic (ADT) volumes higher than 10 000 and traffic speeds faster than 48 km/h (30 mph). The number of driveways should exceed 60 in 1.6 km (1 mile), and there should be fewer than 10 high-volume driveways. Left-turn driveway maneuvers in 1.6 km should total at least 20 percent of the through traffic volume during peak periods. High rates of accidents that involve left-turn maneuvers can also warrant this technique.

Continuous Left-Turn Lane

The standard design for a continuous left-turn lane is shown in Figure 2 (based on MUTCD Figure 3-4b). This technique is similar to the two-way left-turn lane except that it provides individual left-turn lanes for each direction of traffic. Each left-turn lane is continuous except that far-side channelizing islands are placed to prevent through movements at signalized intersections. Left-turn vehicles can be stored in the continuous left-turn lane until an acceptable gap in opposing traffic appears. The continuous left-turn lane completely shadows turning traffic from both traffic streams. Accident frequency is reduced by removing stopped or slow vehicles from the through lanes, and accident severity is reduced by allowing through vehicles additional perception time to avoid left-turn crossing conflicts. Delay to through vehicles is also reduced because left-turn vehicles and queues do not block the through lanes.

The major design difference between this technique and the two-way left-turn lane is the required median width. A 7.2-m (24-ft) wide median is needed for this technique. This width will accommodate two 3.6-m (12-ft) turning lanes. At locations where 7.2 m (24 ft) is not available for median width, it is advisable that a two-way left-turn lane be considered. Since the

turning lanes are continuous, this technique should be applied over sections at least 0.4 km (0.25 mile) in length.

Alternating Left-Turn Lane

The design of an alternating left-turn lane is shown in Figure 3. The alternating left-turn lane will allow one traffic direction to have the opportunity to cross the median into driveways and, after a specified distance, the left-turn lane is physically opened to the opposing direction of traffic. Thus, both the directions have a unique left-turn lane available for continuous left-turn maneuvers over a limited section of highway. Left-turn access to some driveways is prevented because, when the left-turn lane is available to one traffic direction, the opposing traffic cannot attempt a left turn.

The striping scheme shown in Figure 3 is not readily recognized by today's motorist as delineating a left-turn lane. No striping criteria have been universally adopted for use with a technique such as this. The use of turn arrows should help to reduce confusion.

An important design consideration for the alternating left-turn lane is the configuration of the deceleration taper. In this technique, the deceleration taper not only delineates the correct deceleration path but also serves to separate the left-turn lane for different traffic directions.

Reductions in the frequency and severity of accidents will result from the implementation of this technique. Frequency is reduced by removing stopped or slow-moving vehicles and queues from the through lanes, and severity is reduced by allowing through vehicles additional perception time to avoid left-turn crossing conflicts. Delay to through vehicles will also be reduced because left-turning vehicles will not block the through lanes.

The major advantage of implementing this technique instead of other median treatments lies in the minimum median width required to accommodate the left-turn lane. Since only one lane is used in the median for left-turn movements, the width of the median should be as wide as the turning lane itself. Whereas other treatments require 4.2- to 7.2-m (14- to 24-ft) medians for left-turn movements, this treatment requires only a 3.6-m (12-ft) median. The value of this treatment for application on narrow-median highways is most evident at locations where pavement widening or right-of-way acquisition would be required for the wider medians.

Raised Median Divider With Left-Turn Deceleration Lanes

The raised median divider with left-turn deceleration lanes, shown in Figure 4, promotes safety and through-traffic service by preventing left turns and U-turns across the median except at a few designated locations. Access is provided by left-turn lanes at intersections and major driveways. In addition to preventing left turns at minor driveways, the raised median divider reduces friction in the traffic stream by separating opposing traffic.

This technique reduces the frequency of total conflicts by reducing the number of basic conflict points at all minor driveways. More important, it completely eliminates the more hazardous points of crossing conflict at these driveways. For intersections and major driveways, the frequency and severity of conflicts

Figure 1. Two-way left-turn lane.

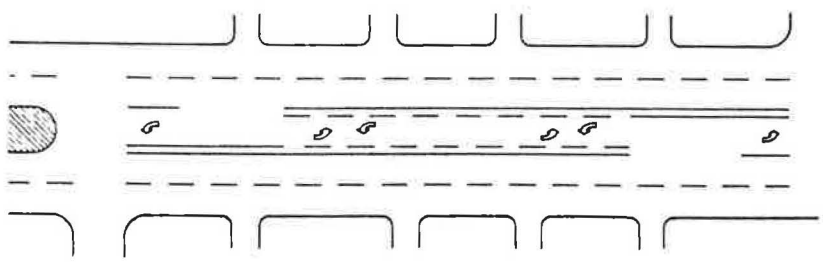


Figure 2. Continuous left-turn lane.

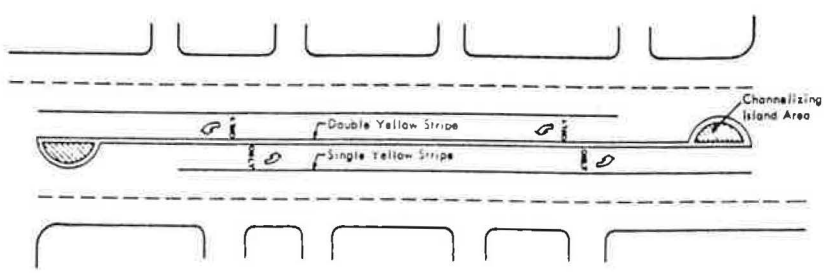
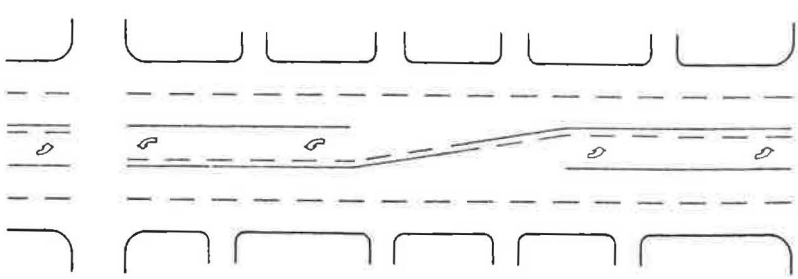


Figure 3. Alternating left-turn lane.



associated with left-turn vehicles are reduced by allowing deceleration and shadowing of these vehicles in left-turn lanes.

The median divider usually reduces the total number of driveway maneuvers. However, the maximum reduction in the frequency of conflicts is moderated by increases in right-turn volumes at minor driveways where desired left turns are accomplished through indirect, circuitous paths.

The construction of a raised median divider often requires widening of the existing roadway. Where insufficient right-of-way has been dedicated, additional right-of-way will need to be purchased. The minimum required roadway width is 16.8 m (56 ft). This width accommodates four 3.3-m (11-ft) through lanes and a 3.6-m (12-ft) median. A more desirable design allows four 3.6-m (12-ft) through lanes and a 4.8-m (16-ft) median for a total roadway width of 19.2 m (64 ft) (Figure 4).

The most important design element for the raised median divider is the median width, which must be adequate to completely shadow left-turning vehicles from through vehicles. The desirable minimum median width is 4.2 m (14 ft). This width provides a 3.6-m (12-ft) deceleration storage lane and a 0.6-m (2-ft) raised median at median openings. However, a 4.8-m (16-ft) median width is recommended, and a 6.6-m (22-ft) width is required if U-turns are permitted.

The required minimum deceleration length is that distance required if a vehicle is to make a comfortable stop from the average running speed on the highway. The storage length should be sufficient to store the maximum expected vehicle queue. As a minimum, storage length for at least two passenger automobiles should be provided. The spacing of median openings is dictated by the length of the deceleration lane, which varies from 90 to 300 m (300 to 1000 ft) for design speeds from 48 to 72 km/h (30 to 45 mph).

Median Barrier With No Direct Left-Turn Access

The final median treatment considered here is the median barrier with no direct left-turn access. This design has no left-turn deceleration lanes, but instead left turns are accomplished by means of indirect left-turn ramps—cloverleaf loops or jughandles—at median openings. Figures 5 and 6 show these two basic designs. The cloverleaf design (Figure 5) is recommended when the distance between major driveways or intersections is less than 1.6 km (1 mile). The jughandle design (Figure 6) is recommended when major driveways or intersections are spaced at 1.6 km or more. This treatment incorporates a New Jersey type of barrier or a simple barrier curb in the median and eliminates all direct left turns and U-turns along the highway.

The median barrier with no direct left-turn access reduces the number of basic conflict points and totally eliminates the more hazardous crossing conflicts at driveways in much the same way the raised median divider does. Furthermore, the frequency of rear-end conflicts on the through lanes is expected to decrease as a result of the elimination of direct left turns. On the other hand, the frequency of right-turn conflicts at minor driveways will probably increase in proportion to the number of indirect left turns. The reduction in points of crossing conflict at driveways is partially offset by the creation of additional basic conflict points at indirect left-turn locations. However, this trade-off is minimized if these locations are signalized.

A much narrower median is required for this treat-

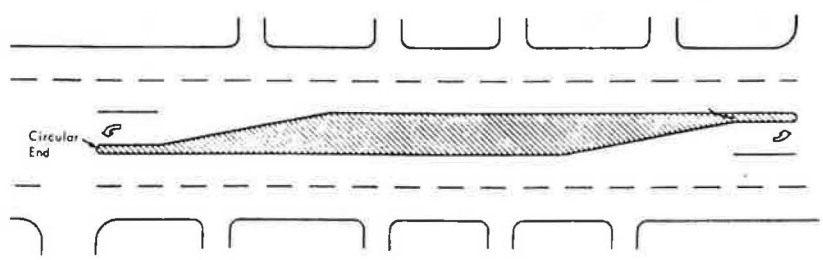


Figure 4. Raised median divider with left-turn deceleration lanes.

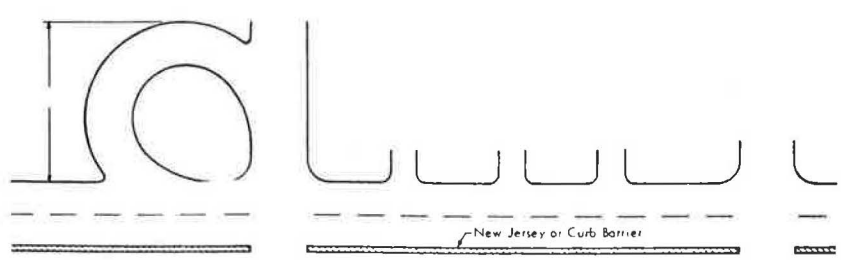


Figure 5. Median barrier with indirect left-turn ramp (cloverleaf loop).

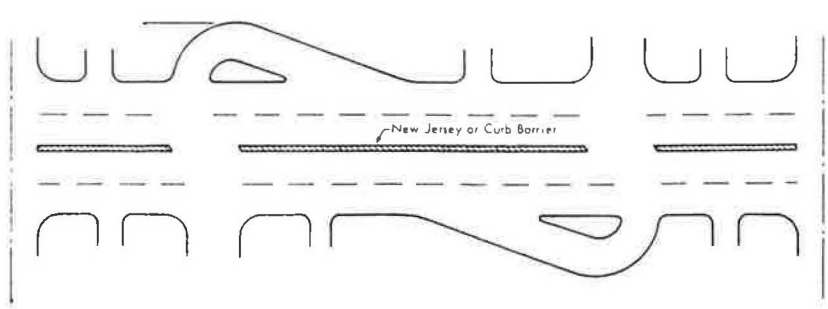


Figure 6. Median barrier with indirect left-turn ramp (jughandle).

ment than for the raised median divider because this treatment eliminates the left-turn deceleration lanes. The desirable median width for the barrier is 1.8 m (6 ft), which is sufficient to accommodate a 0.6-m (2-ft) wide barrier with a 0.6-m (2-ft) clearance on each side. However, a right-of-way width of more than 45 m (150 ft) is needed at the jughandle or cloverleaf sites, and this requirement alone may render this design impractical at many locations.

EFFECTIVENESS OF MEDIAN TREATMENTS

The selection of the optimal median treatment should be based on its effectiveness in reducing both accidents and delay. Unfortunately, the effectiveness of most median treatments has not been evaluated consistently. This lack of proven evaluations does not eliminate the need to make rational choices among the available median treatments and should not deter the use of the best available information to compare alternatives. Estimates of effectiveness can be developed from the available literature and reasonable assumptions. The effectiveness of the five median treatments in reducing both accidents and delay is considered below.

Accident Reduction

The effectiveness of median treatments in reducing accidents can be estimated by (a) estimating the accident experience of typical arterial highways, commercial driveways, and signalized intersections; (b) estimating the number of driveways and intersections per kilometer on typical arterial highways; and (c) determining the number of accidents per kilometer per year that would be reduced by each median treatment. Level of development and highway, driveway, and crossroad ADT—measurements used in the tables throughout this paper—are defined below:

Item	Definition
Level of development	
Low	< 30 driveways
Medium	30-60 driveways
High	> 60 driveways
Highway ADT	
Low	< 5000 vehicles/d
Medium	5 000-15 000 vehicles/d
High	> 15 000 vehicles/d
Driveway ADT	
Low	< 500 vehicles/d
Medium	500-1500 vehicles/d
High	> 1500 vehicles/d
Crossroad ADT	
Low	< 500 vehicles/d
Medium	500-1500 vehicles/d
High	> 1500 vehicles/d

Table 1 gives expected annual accident frequency for a 1.6-km (1-mile) section of arterial highway for three ADT levels and three levels of development. The values are based on regression equations developed by Mulinazzi and Michael (4). The derivation of these values from the Mulinazzi and Michael regression equations is documented by Azzeh and others (1).

Annual accident frequencies for typical commercial driveways are given in Table 2. A prediction equation for the expected accident experience of four-way, unsignalized intersections on divided highways was developed in a study by McDonald (5). A commercial driveway is essentially a three-way intersection that has only 9 conflict points whereas a four-way intersection has 32 conflict points. The accident predictions in Table 2 were obtained by multiplying the accident frequencies from McDonald's equations by $^{9}/_{32}$. Accidents probably do not correspond directly with the numbers of conflict points, and some particular maneuvers definitely have a higher frequency of conflicts under certain conditions. However, the procedure is valuable in making comparisons.

Table 1. Annual accident frequency for 1.6 km (1 mile) of typical arterial highway.

Level of Development	Accidents for Three Levels of Highway ADT: Low	Medium	High
Low	12.6	25.1	37.9
Medium	20.2	39.7	59.8
High	27.7	54.4	81.7

Table 2. Annual accident frequency for a typical commercial driveway.

Driveway ADT	Accidents for Three Levels of Highway ADT: Low	Medium	High
Low	0.26	0.45	0.62
Medium	0.63	1.1	1.5
High	0.97	1.7	2.3

Table 3. Annual accident frequency for a typical four-way, signalized intersection.

Crossroad ADT	Accidents for Three Levels of Highway ADT: Low	Medium	High
Low	1.1	1.9	2.6
Medium	1.9	3.2	4.4
High	2.5	4.2	5.8

Annual accident frequencies for four-way signalized intersections on arterial highways are given in Table 3. These data are based on the work of Webb (6).

For evaluation purposes, 1.6 km (1 mile) of a typical arterial highway is assumed to have two signalized intersections. The assumed distribution of driveways per 1.6 km for each level of development is given below:

Level of Development	Number of Driveways by Driveway Volume: High	Medium	Low
High	0	10	65
Medium	2	8	35
Low	2	5	8

Two-way left-turn lanes have been evaluated by several agencies: Two studies have been conducted in Michigan (7, 8), one in Sacramento, California (9), one in Seattle (10), and one by a technical council of the Institute of Transportation Engineers (11). The results of a before-and-after study of 11.6 km (6.6 miles) of two-way left-turn lanes in Michigan (12) are given below:

Type of Accident	Number of Accidents: Before	After	Change (%)
Left turn	94	52	-45
Rear end	238	90	-62
Right angle	92	105	+14
Sideswipe	42	39	-7
Other	66	70	+6
Total	532	356	-33

This table illustrates the effectiveness of this treatment in reducing left-turn and rear-end accidents. Although increases in head-on accidents might be expected in the median lane because of conflict with opposing vehicles, the literature discounts such occurrences as infrequent. Based on all of the studies identified above, the total number of accidents on an arterial street can be expected to decrease by 35 percent after installation of a two-way left-turn lane on a four-lane arterial street. The expected accident reductions for 1.6 km (1 mile) of an arterial street have been calculated from Table 1 and are given in Table 4.

No operational studies on the continuous left-turn lane were found in the literature. Therefore, the two-way left-turn lane was used as the basis for comparison, and two operational differences between the two-way left-turn lane and the continuous left-turn lane were considered. First, the continuous left-turn lane has a separate left-turn lane for each direction of travel, which should reduce some conflicts that result from opposing vehicles using the same lane. On the other hand, motorists turning left from the continuous left-turn lane must cross the left-turn lane for the opposite direction, which therefore increases the conflict area. It seems reasonable to assume that these two effects cancel one another and therefore that the effectiveness for the continuous left-turn lane is the same as that for the two-way left-turn lane (Table 4).

Alternating left-turn lanes operate somewhat differently from two-way and continuous left-turn lanes. In addition to reducing rear-end and left-turn conflicts, alternating left-turn lanes may reduce the frequency of left-turn maneuvers by discouraging left-turn access at driveways where there are opposing left-turn deceleration lanes. One study (13) indicates a 28 percent decrease in accidents as a result of converting a section of highway to alternating left-turn operation. To completely evaluate the effectiveness of this treatment, several assumptions were made about its operational characteristics. Included in these assumptions is that left-turn access will be provided to all medium- and high-volume driveways but to only half of the low-volume driveways. The installation of left-turn lanes for these driveways is assumed to reduce their accident experience by 50 percent. For half of the low-volume driveways where the left-turn access is denied, accident experience is assumed to be reduced by 60 percent. Finally, it is assumed that the installation of the median lane makes it possible to install left-turn lanes at two signalized intersections and that the accident experience at these intersections is reduced by 50 percent. Detailed explanation and justification of these assumptions are provided by Azzeh and others (1). The resulting estimates of accident reduction for this treatment are given in Table 4.

The raised median divider is evaluated by using assumptions similar to those made for the alternating left-turn lane, but this treatment is even more restrictive operationally. The treatment is assumed to prevent left turns at all low-volume driveways and to result in a 60 percent accident reduction at these driveways. It is also assumed that left-turn deceleration lanes are installed at all medium- and high-volume driveways and at signalized intersections. This results in a 50 percent decrease in accidents at these locations. The overall accident reduction for the installation of a raised median divider is given in Table 4.

The median barrier with no direct left-turn access is similarly evaluated. The barrier is assumed to eliminate left turns at all driveways. Although this results in a 50 percent reduction in driveway accidents, an accompanying increase in accidents is associated with the two signalized, indirect left-turn locations. The net accident reduction for installation of a median barrier is given in Table 4.

Table 4. Annual reduction in accidents from median treatments for 1.6 km (1 mile) of typical arterial highway.

Level of Development	ADT	Annual Number of Accidents Reduced				
		TWLTL	CLTL	ALTL	RMD	MB
Low	Low	4.4	4.4	1.7	2.2	-2.7
	Medium	8.8	8.8	3.2	4.1	-4.0
	High	13.3	13.3	5.1	6.3	-5.0
Medium	Low	7.1	7.1	3.5	5.8	1.8
	Medium	13.9	13.9	7.1	11.2	4.7
	High	20.9	20.9	11.6	17.2	8.1
High	Low	9.7	9.7	6.4	10.7	6.3
	Medium	19.0	19.0	13.3	20.7	13.6
	High	28.6	28.6	21.0	31.2	21.3

Table 5. Annual reduction in delay from median treatments for 1.6 km (1 mile) of typical arterial highway.

Level of Development	ADT	Annual Reduction in Delay (h)				
		TWLTL	CLTL	ALTL	RMD	MB
Low	Low	0	0	0	0	0
	Medium	0	0	0	0	0
	High	0	0	0	0	0
Medium	Low	0	0	0	0	0
	Medium	2 628	2 628	2 628	2 628	0
	High	6 935	6 935	6 935	6 935	0
High	Low	0	0	0	0	0
	Medium	6 059	6 059	6 059	6 059	0
	High	17 046	17 046	17 046	17 046	0

Delay Reduction

No comparative data on the effectiveness of the five median treatments in reducing delay are available. However, four of the treatments have a very similar effect on delay. The two-way left-turn lane, the continuous left-turn lane, the alternating left-turn lane, and the raised median divider with left-turn deceleration lanes all reduce delay by removing left-turning vehicles from the through lanes to a sheltered area in the median. This results in an increase of the average running speed of through traffic. The effectiveness of these treatments in reducing delay was estimated by assuming a value for this increase in average running speed. The following assumptions were made to estimate reductions in delay for typical four-lane highways:

1. Arterials with low traffic volumes or low levels of development would not experience any increase in running speed.
2. Average running speeds on arterials without median treatments are assumed to be as given below (1 km/h = 0.62 mph):

Highway ADT	Level of Development	Average Running Speed (km/h)
Medium	Medium	56
Medium	High	48
High	Medium	48
High	High	40

3. For a medium level of development, there is an increase of 8 km/h (5 mph) in average running speed during the 2 h of each day that show the highest traffic volume. These hours are assumed to include 20 percent of all through vehicles.
4. For a high level of development, there is an in-

crease of 8 km/h (5 mph) in average running speed during the 4 h of each day when traffic volume is highest. These hours are assumed to include 35 percent of all through vehicles.

The estimated effectiveness of reduction in delay that results from these assumptions is given in Table 5.

Installation of the fifth median treatment—the median barrier with no direct left-turn access—will also result in an increase in average running speed. However, this saving is probably offset by the increase in travel time for indirect left-turning vehicles and the increased delay if the indirect crossings are signalized. For evaluation purposes, these effects are assumed to be equal and offsetting so that the net reduction in delay is zero (this assumption may be unrealistic on extremely high-volume highways where median barriers may be far more desirable than suggested by the following analysis).

COST OF MEDIAN TREATMENTS

The effectiveness of median treatments should be evaluated in relation to their costs. For this reason, construction costs have been estimated for the installation of each of the five median treatments for 1.6 km (1 mile) of a typical existing arterial highway. Three construction options, presented in order of increasing cost, are considered separately for each median treatment:

1. Option 1 assumes that the existing roadway is wide enough to permit installation of the median treatment without additional widening.
2. Option 2 assumes that pavement widening is necessary but that no additional right-of-way must be acquired.
3. Option 3 assumes that both pavement widening and right-of-way acquisition are necessary to install the median treatment.

The estimated construction costs for each median treatment and construction option are given below:

Median Treatment	Cost ($) Option 1 (existing paved median)	Option 2 (pavement widening required)	Option 3 (pavement widening and right-of-way acquisition required)
Two-way left-turn lane	8 200	280 200	501 000
Continuous left-turn lane	12 800	403 200	783 600
Alternating left-turn lane	10 200	282 200	503 000
Raised median divider	97 600	369 600	590 400
Median barrier	185 200	304 000	398 800

These estimates were determined from the following unit costs (1 m = 3.3 ft, 1 m^2 = 10.76 ft^2, and 1 km = 0.62 mile):

Construction Item	Unit Cost for Construction and Overhead ($)
Pavement striping (reflective)	2.10/m
Pavement (0.3 m thick)	24.70/m^2
Driveway patchback	24.70/m^2
Curb and gutter	26.70/m
Median barrier (New Jersey type)	66.70/m
Relocation of structures (one side of roadway)	6250/km
Right-of-way acquisition	33.30/m^2

These unit costs are based on data gathered in 1975. Naturally, they are expected to rise as time passes, but the benefit-cost comparisons in the next section should still be valid since the costs of accidents and delay time are presumably rising as well. The service lives of all capital items are estimated at 20 years except for pavement striping for which the life is estimated at 2 years.

BENEFIT-COST RATIOS FOR MEDIAN TREATMENTS

The five median treatments have been compared on the basis of their benefit-cost ratios. For purposes of this study, the benefit-cost ratio (BC) is defined as

$$BC = [(AR)(AC) + (DR)(DC)]/CC\,[CRF]_i^n \qquad (1)$$

where

AR = annual number of accidents reduced,
AC = average cost per accident = $2800 (14),
DR = annual hours of delay reduced,
DC = average cost per hour of delay = $4.50 (1, 15),
CC = total construction cost,
$[CRF]_i^n$ = capital recovery factor at i percent for n years,
i = minimum attractive rate of return = 7 percent, and
n = service life = 2 years for pavement striping and 20 years for other capital items.

The benefit-cost ratio for each median treatment for each construction option is given in Table 6. Benefit-cost ratios less than 1.0 are not shown because these median treatments are not warranted under the specified conditions.

SELECTION OF MEDIAN TREATMENTS

The benefit-cost analysis presented provides a basis for selecting appropriate median treatments for arterial highways. The objective should be to select a median treatment that is not merely warranted but optimal. This objective can be accomplished by using Table 7, which summarizes the results of the benefit-cost analysis in the form of a selection guide for median treatments and construction options. The table contains a series of median treatments and construction options for each possible combination of daily traffic volume and level of development at the site under consideration. Treatment-option combinations are given in order of descending benefit-cost ratio. The optimal median treatment is the highest treatment on the list that is operationally warranted and physically feasible at the site under consideration. The width requirements of median treatments are very important in making a choice; for example, an alternating left-turn lane is preferable to a two-way left-turn lane only if construction option 1 (no widening) can be used when the two-way left-turn lane would require construction option 2 (widening).

A great many useful general conclusions about the selection of median treatments can be drawn from Table 7. For instance, at sites that have 5000 (low) ADT and driveway density of <30 in 1.6 km (1 mile), the only warranted median treatments are construction option 1 for the two-way and continuous left-turn lanes. By contrast, on highways that have >15 000 (high) ADT and driveway density of >60 in 1.6 km, all median

Table 6. Benefit-cost ratios for median treatments.

		Level of Development								
		Low			Medium			High		
Median Treatment	Construction Option	Low ADT	Medium ADT	High ADT	Low ADT	Medium ADT	High ADT	Low ADT	Medium ADT	High ADT
TWLTL	1	2.7	5.4	8.2	4.4	11.2	19.8	6.0	17.7	34.6
CLTL	1	1.7	3.5	5.3	2.8	7.2	12.7	3.8	11.4	22.1
ALTL	1	-	1.6	2.5	1.7	5.6	11.3	3.2	11.4	24.0
RMD	1	-	1.3	1.9	1.8	4.7	8.6	3.3	9.3	17.9
MB	1	-	-	-	-	-	1.3	1.0	2.2	3.4
TWLTL	2	-	-	1.2	-	1.7	3.0	-	2.7	5.2
CLTL	2	-	-	-	-	1.2	2.0	-	1.8	3.6
ALTL	2	-	-	-	-	1.0	2.0	-	2.1	4.3
RMD	2	-	-	-	-	1.2	2.3	-	2.5	4.7
MB	2	-	-	-	-	-	-	-	1.3	2.1
TWLTL	3	-	-	-	-	-	1.8	-	1.6	3.1
CLTL	3	-	-	-	-	-	1.1	-	1.0	2.0
ALTL	3	-	-	-	-	-	1.2	-	1.2	2.6
RMD	3	-	-	-	-	-	1.4	-	1.5	3.0
MB	3	-	-	-	-	-	-	-	1.0	1.6

Table 7. Selection guide for median treatments.

	ADT					
	Low		Medium		High	
Level of Development	Median Treatment	Construction Option	Median Treatment	Construction Option	Median Treatment	Construction Option
Low	TWLTL	1	TWLTL	1	TWLTL	1
	CLTL	1	CLTL	1	CLTL	1
			ALTL	1	ALTL	1
			RMD	1	RMD	1
					TWLTL	2
Medium	TWLTL	1	TWLTL	1	TWLTL	1
	CLTL	1	CLTL	1	CLTL	1
	RMD	1	ALTL	1	ALTL	1
	ALTL	1	RMD	1	RMD	1
			TWLTL	2	TWLTL	2
			RMD	2	RMD	2
			CLTL	2	CLTL	2
			ALTL	2	ALTL	2
					TWLTL	3
					RMD	3
					MB	1
					ALTL	2
					CLTL	3
High	TWLTL	1	TWLTL	1	TWLTL	1
	CLTL	1	ALTL	1	ALTL	1
	RMD	1	CLTL	1	CLTL	1
	ALTL	1	RMD	1	RMD	1
	MB	1	TWLTL	2	TWLTL	2
			RMD	2	RMD	2
			MB	1	ALTL	2
			ALTL	2	CLTL	2
			CLTL	2	MB	1
			TWLTL	3	TWLTL	3
			RMD	3	RMD	3
			MB	2	ALTL	3
			ALTL	3	MB	2
			MB	3	CLTL	3
			CLTL	3	MB	3

treatments and construction options are warranted. Generally, median treatments that require pavement widening are warranted only for highways that have traffic volumes >5000 vehicles d. Median treatments that require both pavement widening and right-of-way acquisition are warranted for only two types of sites: (a) highways that have traffic volumes >5000 vehicles d and driveway densities >60 in 1.6 km and (b) highways that have traffic volumes >15 000 vehicles d and driveway densities >30 in 1.6 km.

The two-way left-turn lane (option 1) is the most desirable median treatment in all cases considered. The median treatments decrease in benefit-cost ratio in about the order that they have been presented throughout this paper. The continuous left-turn lane is dominated by the two-way left-turn lane; i.e., in all cases where a continuous left-turn lane could be used, a two-way left-turn lane would be better. This finding results from the assumption that the continuous left-turn lane has the same effectiveness as the two-way left-turn lane but a higher cost. Therefore, the continuous left-turn lane should not be used unless there is direct evidence that it is more effective than the two-way left-turn lane.

The selection guide given in Table 7 provides an excellent basis for choosing among alternative median treatments when no better information is available. However, the user should be aware of the limitations of the guide imposed by the methods used in its development. The benefit-cost ratios are based on typical values of construction cost, accident reduction, and delay reduction. The estimates for accident and delay reduction for several median treatments are based on assumptions that appear reasonable but cannot be completely supported by research results within the current state of the art. If the user can estimate these quanti-

ties for a particular site, a more reliable evaluation will result. In this case, however, the benefit-cost procedure of this paper provides a useful framework for evaluating the available alternatives.

The user should also recognize that some important considerations are beyond the scope of an economic analysis but may well have an important impact on the final decision. For example, the economic analysis does not completely reflect the role of operational flexibility in evaluating median treatments. An arterial highway with a two-way left-turn lane is far more flexible operationally than a highway with a median barrier. Such flexibility makes routine operation less restrictive since left-turns are not prohibited, and the treatment has better service capability under transient conditions such as roadway construction or a traffic accident. In this case, both the economic and operational considerations favor the same median treatment, but in other situations there may be trade-offs to be made by the decision maker. In short, the economic analysis is an extremely important part of the selection of an optimal median treatment, but other less quantifiable factors also deserve consideration.

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Highway Design Consistency and Systematic Design Related to Highway Safety

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This paper proposes a more systematic approach to highway design for achieving consistent designs to meet the needs of drivers. It is intended as a catalyst toward promoting optimal improvements of existing facilities. Its nature is conceptual. The topics covered include (a) a critique of current practices; (b) the evolution of highway design; (c) objectifying the design process; (d) consistency of design in relation to driver expectancy; (e) application to achieve design consistency; and (f) developing a cost-effectiveness methodology.

For almost 4 decades, highway designers have relied on criteria presented in a series of design policies of the