Accident Comparison of Raised Median and Two-Way Left-Turn Lane Median Treatments

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It is accepted that the installation of a median will reduce accident occurrence along a previously undivided road. This report provides an accident comparison of raised medians and continuous two-way left-turn lanes used as median treatments on four- and six-lane roads. A statistical comparison of accident rates for the two section types and regression equations to model expected accident experience for each section were developed. Four- and six-lane roadway study sections in Georgia were analyzed separately. The accident rate of raised medians was found to be lower than the rate of two-way left-turn lanes for both four- and six-lane roadway sections. Regression equations were developed for raised median and two-way left-turn lane sections, four- and six-lane sections, total and midblock accidents, and accidents per million vehicle miles and accidents per mile per year. Tables of expected accident rate values were developed from the regression equations. On the basis of expected total accidents per million vehicle miles the tables indicated that for four-lane sections, raised medians had a lower accident rate over the range of data studied. Results from six-lane sections were mixed. The regression equations indicated that raised medians would have lower accident rates for most conditions. However, two-way left-turn lanes had a lower accident rate where few concentrated areas of turns, such as signalized intersections and unsignalized approaches, existed.

This study was intended to provide a basis of comparison between two median treatment types frequently used on arterial roads. Both raised medians and continuous two-way left-turn lanes (TWLTLs) are often used on high-volume four- and six-lane roads. Implementing either type of median treatment will reduce the number of accidents experienced on an undivided road that has the same number of through lanes. This study compares the relative safety of these two median treatments.

A TWLTL is a lane in the center of a road that is dedicated to left turn movements by both directions of traffic. TWLTLs provide excellent service to the land adjoining the roadway by offering an area for deceleration and stopping before a left turn from the road. As a result, TWLTLs reduce the frequency and severity of rear-end collisions and allow drivers additional perception time in making left turns. These lanes are also used by vehicles turning from cross streets and driveways onto the arterial. TWLTLs allow more flexible use of the entire roadway because, for example, temporary work zones can easily be established.

Raised medians facilitate the movement of through traffic along a roadway. Turning movements are concentrated at relatively few points, where they can better be accommodated. This concentration reduces both the total number of conflict points for vehicles turning onto or off of the roadway and the number of driveway maneuvers allowed. Raised medians may also be used for their aesthetic qualities.

The purpose of the study was to provide a quantitative basis for determining whether raised medians or TWLTLs would have a lower accident rate for a given situation. As many study sites as possible throughout the State of Georgia were identified for the study. The study was undertaken in conjunction with the Georgia Institute of Technology School of Civil Engineering. The Georgia Department of Transportation (GaDOT) provided information that could not be readily collected in the field.

The study was limited to roads with either four or six travel lanes. Data for these two types of sites were analyzed independently. Accident data were obtained for fatal, injury, and property-damage-only accidents occurring along each section. Full data analysis was performed for both total and midblock accident occurrence.

PREVIOUS RESEARCH

A Federal Highway Administration (FHWA) report by Azzeh et al. (*1*) advocated the use of either TWLTLs or raised medians to reduce accidents and delay caused by an undivided roadway. When accident reductions for raised medians and those for TWLTLs are compared, it appears that TWLTLs would be safer for low and moderate levels of development (measured as having fewer than 60 commercial driveways per mile). Raised medians would be considered safer for high levels of development. The relative safety of the two median types remained constant for all average daily traffic (ADT) levels studied (fewer than 5,000, 5,000 to 15,000, and more than 15,000 vehicles per day).

The same report included general comments about each median type. A TWLTL is attractive because it keeps left turning vehicles from through traffic while providing maximum left-turn access. A TWLTL should be used, in lieu of an undivided road, when there are frequent rear-end conflicts caused by left-turning vehicles and on moderate- to high-volume highways that have few cross streets and many driveways.

Raised medians reduce the number of conflicting vehicle maneuvers at driveways. However, there will be some increase in other conflicts because of indirect left-turn maneuvers when

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drivers move vehicles into minor driveways. Raised medians are used on major arterials with a moderate to high number of driveways per mile. A cross-street spacing of one-half mile or greater is desired.

Perhaps the most often quoted report is Parker's 1983 Virginia study (*2*). Regression equations were produced for the accident occurrences of raised median, traversable median (including TWLTL), and undivided highway sections. General guidelines were also presented for using the various median types. The report indicated that if stopping sight distance is less than AASHTO standards, a TWLTL should not be used. A raised median should not be used where speeds exceed 45 mph unless the curb face is mountable. Raised medians are desirable when access points are limited to major intersections, there are large pedestrian volumes, or a grid pattern permits circuitous flow of traffic without disrupting residential traffic. Additionally, TWLTLs should not be used when access is required on only one side of the street.

Harwood and St. John (*3*) listed characteristics and appropriate implementations of raised medians and TWLTLs. Raised medians discourage new strip development, whereas TWLTLs may encourage such development. However, raised median sections increase travel time for drivers who wish to turn left if median openings are not provided. They also reduce operational flexibility, such as allowing for emergency vehicle operations, lane closures, and work zones. Raised medians are best suited to major arterials with a high volume of through traffic and limited access points and are also appropriate when a highway agency makes a conscious choice to favor the traffic movement function through an area.

Two-way left-turn lanes generally reduce delay to left-turning vehicles and enhance operational flexibility. However, they do not provide any refuge area for pedestrians. Inappropriate use of TWLTLs by drivers may cause vehicular conflicts. Harwood and St. John indicated that TWLTLs should be used when there are low to moderate volumes of through traffic.

DATA COLLECTION

Site Selection

Roadway sections that had a continuous TWLTL or a continuous curb-and-gutter raised median were considered for the study. Other than the following restrictions, there were no predefined limits on the range of data to be expected from these sites. The parameters used for selection were

- ADT at least 9,500 vehicles per day,
- Location on a state route,
- A constant four- or six-through lane cross section, and
- Free access to the road at grade (uncontrolled access).

To ensure that the study incorporated only urban type sections, ADT values were kept above 9,500 and there was free access to the road. Sites located on a state route enabled collection of accident data that were uniformly reported.

Some of the sites chosen were suggested by Vargas (*4*). The remaining sites were determined through computer searches of the GaDOT road inventories. These inventories provided the preliminary information needed to identify potential sites, including number of through lanes, ADT, access control, type of median treatment, and lane widths.

In the Atlanta metropolitan area, 16 suitable TWLTL sites were identified; however, only 4 raised median sites were located. Several potential sites were eliminated because of depressed or flush medians along portions of the site length. Broadening the search area to encompass the entire state resulted in the addition of 15 raised median sites and 4 TWLTL sites.

The 20 of the TWLTL sites have a total length of 74.86 miles. The 19 raised median sites have a total length of 47.60 miles. Each site was subdivided into sections wherever possible. Sections for analysis were established for lengths greater than 0.75 miles to ensure that the data for all sections would be representative of actual conditions. Short analysis sections would tend to yield highly fluctuating data. The researchers also wanted to define the analysis sections so that reported ADT values would remain constant through the section. Analyzing sections with a relatively constant ADT was a secondary consideration in establishing the analysis sections. Table 1 provides a summary of basic site and section characteristics.

Data Collected

Data for the analysis sections were obtained from three sources:

- Road inventories from GaDOT Planning Data Services,
- Field collection, and
- Accident data from GaDOT Traffic and Safety Division.

TABLE 1 SITE AND SECTION CHARACTERISTICS

	TWLTL	Raised Medians
Number of Sites		
4 Lane sections	17	13
6 Lane sections	3	6
Totals	20	19
Number of Sections		
4 Lane sections	42	15
6 Lane sections	8	17
Totals	50	32
Site Lengths		
4 Lane sections	62.48	24.68
6 Lane sections	12.38	22.92
Totals	74.68	47.60
Million Vehicle Miles per year		
4 Lane sections	691.48	228.25
6 Lane sections	149.05	264.42
Totals	840.53	492.68

Road inventories provided ADT and mileage points reported to the nearest one 1/100th of a mile and were used to further subdivide sites into analysis sections. Accident data were obtained in summary form, which indicated fatal accidents, injury accidents, and total accidents for each analysis section. The data were provided for the total length of the analysis section and for midlock portions of the section. Accident data were available for 1984, 1985, and 1986 on all but two sites; for each of these, data were available for only two years. Data collected in the field for each section consisted of the number of driveways, signalized intersections, unsignalized approaches (streets), and, for raised median sections, median openings other than at signalized intersections.

Data Summary

The accident data obtained from GaDOT were used to calculate accidents per million vehicle miles (MVM) and accidents per mile per year. The number of accidents per million vehicle miles was believed to be the best indicator for comparison between median types because of the great variation of ADT present in the sites analyzed. However, the numbers of accidents per mile per year were calculated for use in comparing this study with other research.

Table 2 summarizes the accident calculations for injury accidents, fatality accidents, and total accidents. No determination was made of the number of injuries or fatalities associated with each section because these numbers are dependent on variables outside the scope of this research.

The summary rates presented in Table 2 were not obtained by averaging the accident rates for individual sections, which would have created an error because the site lengths and ADTs vary. Instead, accidents per MVM were obtained for each section type by summing the number of accidents per year and dividing that number by the total number of million vehicle miles traveled per year. Accidents per mile per year were found by dividing the total number of accidents per year by the sum of the analysis section lengths for each cross-section type.

TABLE 2 SUMMARY OF ACCIDENT DATA

	Total Accidents			Midblock Accidents		
	TWLTL	RM	% Diff	TWLTL	RM	% Diff
Accidents / MVM						
4 Lane sections	8.99	7.67	-14.7%	3.50	1.34	-61.7%
6 Lane sections	10.82	8.15	-24.7%	4.19	1.92	-54.2%
Accidents / Mi / Yr						
4 Lane sections	99.45	70.91	-28.7%	38.78	12.39	-68.1%
6 Lane sections	130.26	94.07	-27.8%	50.46	22.13	-56.1%
Injury Accidents / MVM						
4 Lane sections	2.00	1.70	-15.0%	0.81	0.32	-60.5%
6 Lane sections	3.61	1.90	-47.4%	1.09	0.43	-60.6%
Injury Accidents / Mi / Yr						
4 Lane sections	22.14	15.76	-28.8%	8.91	2.92	-67.2%
6 Lane sections	43.46	21.87	-49.7%	13.14	4.93	-62.5%
Fatal Accidents / MVM						
4 Lane sections	0.01	0.03	-66.7%	0.01	0.01	0.0
6 Lane sections	0.03	0.03	0.0	0.02	0.01	-50.0%
Fatal Accidents / Mi / Yr						
4 Lane sections	0.14	0.29	-51.7%	0.06	0.08	-25.0%
6 Lane sections	0.38	0.39	-2.6%	0.30	0.10	-66.7%

The data obtained from road inventories and field collection were converted to a per mile basis (signals per mile, for example). Table 3 summarizes the site data.

Data were plotted in the form of scatter diagrams. Each of the independent variables was plotted against accidents per MVM and against accidents per mile per year for each of the section types so that the data could be checked for outliers. The relevant scatter diagrams plot total accidents per MVM against the independent variables found to be significant in the regression analysis. Figures 1–4 show that none of the data points used in developing the regression equations (for accidents per MVM) appears to be an outlier.

DATA ANALYSIS AND RESULTS

Comparison of Accident Rates

The accident data were tested to determine the error level at which there was a significant difference between two-way left-turn lane and raised median accident rates. Table 4 lists the alpha error at which the two accident rates were found to be significantly different. The figures indicate the alpha error associated with the conclusion that raised medians are safer than TWLTLs. The last two columns also indicate whether the two rates are statistically significant at different alpha values of 0.10 and 0.05.

The calculations were based on a one-sided student's t-distribution. The assumption that $\mu_T = \mu_{RM}$ (mean of TWLTL accident rates equals mean of raised median accident rates) was tested, with the alternate hypothesis being that $\mu_T > \mu_{RM}$ (mean of TWLTL accident rates is greater than mean of raised median accident rates). With the initial hypothesis, any difference in accident rates is due to chance alone. The alternate hypothesis, for which the alpha error has been calculated, states that the difference in rates is not attributable to chance alone and that the mean of TWLTL accident rates is higher than the accident rate for raised median cross sections.

There is never certainty, statistically speaking, that rates of finite sample sizes are definitely different. However, some

TABLE 3 SUMMARY OF SITE DATA

		TWLTL		RAISED MEDIAN	
		6 Lane	4 Lane	6 Lane	4 Lane
ADT	Minimum	23712	9500	20360	10180
	Maximum	47685	52240	47180	59070
	Mean	32769	30542	31994	24605
	Stnd Dev.	8308	9881	7969	10866
Drives/mi	Minimum	36.90	10.08	18.18	5.00
	Maximum	144.34	103.53	106.40	76.74
	Mean	71.29	50.16	45.62	33.75
	Stnd Dev.	33.96	21.67	22.84	19.30
Signals/mi	Minimum	1.07	0.00	0.00	0.00
	Maximum	5.66	7.06	4.76	8.14
	Mean	2.63	2.10	2.25	2.26
	Stnd. Dev.	1.54	1.56	1.08	1.97
Openings/mi	Minimum	---[1]	---	0.00	1.14
	Maximum	---	---	7.43	13.79
	Mean	---	---	2.89	3.98
	Stnd. Dev.	---	---	1.91	3.37

[1] Openings per mile not applicable to two-way left-turn lane sections.

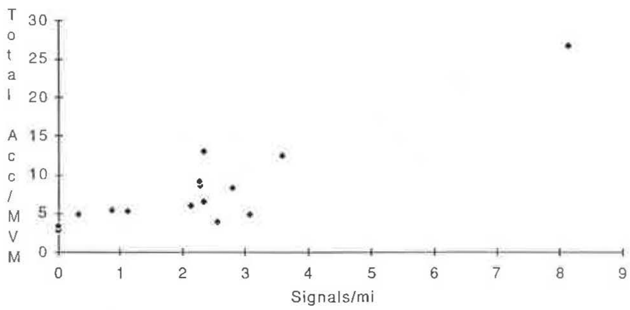

FIGURE 1 Raised median four-lane sections.

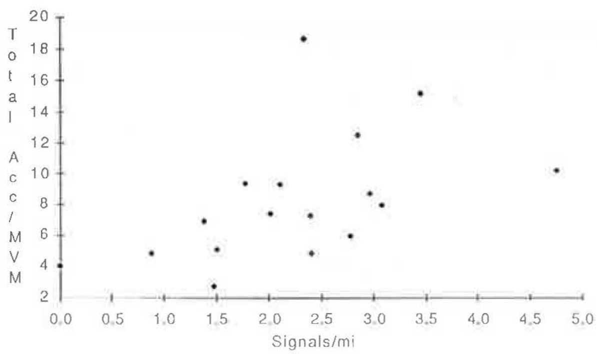

FIGURE 2 Raised median six-lane sections.

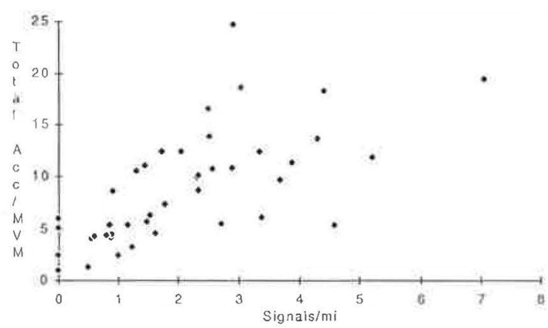

FIGURE 3 TWLTL four-lane sections.

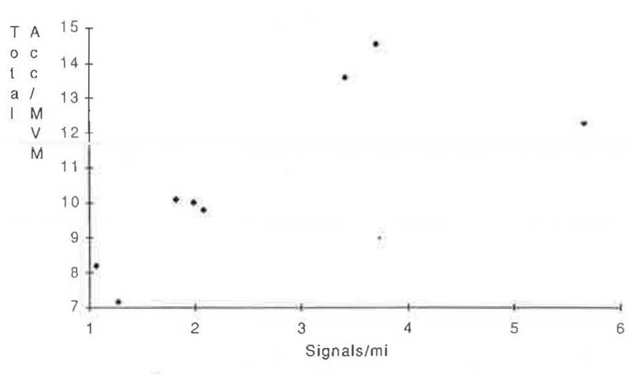

FIGURE 4 TWLTL six-lane sections.

of the extremely low alpha errors found in this study are as close as could reasonably be expected to ascertaining a difference in accident rates for the two cross-section types analyzed.

As expected, raised medians were found to be safer in terms of the number of midblock accidents. However, this determination should not be a decisive factor in comparison of the two median types. Raised medians shift many conflicts from midblock locations to surrounding intersections. Conceptually, the minimization of total accidents, not just midblock accidents, should be important in comparing the effects of median type.

As mentioned, the number of accidents per million vehicle miles (MVM) is preferred to the number of accidents per mile per year as an indicator of relative safety. The use of the accident per MVM rate accounts for differences among sites in traffic volumes and, therefore, in differences in the opportunity for accidents.

Elimination of the study of accidents per mile per year reduces the most useful comparisons to those of total accidents per MVM for four- and six-lane sections. The rates indicate that raised medians had a lower accident experience than TWLTLs for the range of variable data tested. However, the question of determining an acceptable alpha error is crucial because the difference in accident rates for four-lane sections has a high alpha error.

Regression Models

Regression equations were developed to model data obtained for each section type. Four basic section types were analyzed (raised median and TWLTL, each with four- and six-lane sections). Additionally, data were further subdivided by total and midblock accidents and accidents per MVM and accidents per mile per year. This grouping led to the development of 16 regression equations.

Regression equations were found by using three Biomedical computer program (BMDP) statistical software on the Georgia Tech mainframe computer (Cyber B). Data were initially tested with BMDP9R and BMDP2R to determine which variables were significant in the regression analysis. These two programs serve to eliminate variables that are redundant or have a high correlation to significant variables. BMDPIR was then used to find the final regression equation based on the variable sets found by the first two programs.

BMDP9R is an "all-possible-subset" regression program. In other words, the program will test all of the possible combinations of data, from single variables to all of the independent variables. The best set of variables is then chosen from the tested combinations on the basis of Mallow's C_p. This statistic provides a measure of whether the regression equation has enough information in it. Use of this indicator serves to maximize both the squared multiple correlation (R^2) and the F ratio (also called F statistic). Neither of these statistics, when used individually, provides an accurate description of an equation's utility. Although it is desirable to maximize R^2, excess variables in an equation tend to inflate this value. Although the F ratio does not describe the relationship between the regression and residual sum of squares, as R^2 does, this statistic reacts inversely with the addition of unnec-

TABLE 4 SIGNIFICANT DIFFERENCE OF ACCIDENT RATES BETWEEN TWLTL AND RAISED MEDIANS

Section type	Accident type	Alpha-error at point of significant difference	Significant difference at alpha-error =0.10	=0.05
Total Accidents				
4 Lane sections	Acc/MVM	0.2168	no	no
	Acc/mile/yr	0.0980	yes	no
6 Lane sections	Acc/MVM	0.0549	yes	no
	Acc/mile/yr	0.0883	yes	no
Midblock Accidents				
4 Lane sections	Acc/MVM	0.0009	yes	yes
	Acc/mile/yr	0.0128	yes	yes
6 Lane sections	Acc/MVM	<0.0005	yes	yes
	Acc/mile/yr	0.0224	yes	yes

essary variables. The F ratio is used with the R^2 statistic to find the best regression equation.

BMDP2R was then used to find what it considered to be the best set of variables. BMDP2R, a stepwise regression program, attempts to enter a variable into an equation and then seeks to remove a variable based on the equation's F ratio. Often this process results in a smaller variable list than those suggested by other programs.

All of the suggested variables combinations from the two programs were used with BMDP1R (a multiple linear regression program) to find the final regression equation for each section type. When alternate variable lists were compared, the equation that produced the best combination of R^2 and F ratio was chosen.

Table 5 lists the variables selected as significant for regression equations for each section type, along with the corresponding R^2 and F ratio values. Regression equations were found that fit total accidents well for almost all section types. Raised median six-lane section accidents per MVM were the exception. On the other hand, half of the midblock accident models fit poorly, which probably indicates that the type of data obtained was not adequate to explain midblock accidents.

Regression equations developed are linear. That is, they are of the form

$$y = aX_1 + bX_2 + \cdots + f$$

Table 6 lists regression coefficients for the variables. As can be seen all of the total accident equations rely on the number of signals per mile. Further, all of the total accident per mile per year equations (and none of the total accident per MVM equations) incorporate ADT.

Expected Value Tables

Tables of expected accident rates, developed from the regression analysis, list the accident rates estimated by the regression equations. The tables cover only data ranges that were present at the sections studied. This approach has led to different variables value ranges for four- and six-lane sections. For instance, ADTs range from 20,000 to 50,000 for six-lane sections, but four-lane section ADTs range from 10,000 to 50,000.

However, in some places, the tables give rates at combinations of independent-variable values that were not observed at the sections studied. The table of expected accidents per MVM on four-lane sections has no rates that were not covered by the data obtained. This situation results from the limited number of independent variables found to be significant in the corresponding regression equations. On the other hand, the table for accidents per MVM on six-lane sections has several areas that were not found in the study sections. In this table, all of these were predicted TWLTL rates because of the paucity of TWLTL six-lane sections. For all values of ADT, data range combinations that were not found in the field were

- One signal per mile, 30 drives per mile, and 6 approaches per mile;

TABLE 5 VARIABLE SETS USED IN REGRESSION EQUATIONS

Section type		Variable sets	Multiple R^2	F Ratio
TOTAL ACCIDENTS				
TWLTL 6 Lanes	-Acc/mi/yr	ADT, Drives/mi, Signals/mi, Apprch/mi	0.9861	53.088
	-Acc/MVM	Signals/mi, Apprch/mi Drives/mi	0.9572	29.823
TWLTL 4 Lanes	-Acc/mi/yr	ADT, Signals/mi, Apprch/mi	0.6018	19.146
	-Acc/MVM	Signals/mi	0.4443	31.980
R. Med. 6 Lanes	-Acc/mi/yr	ADT, Signals/mi	0.6242	11.629
	-Acc/MVM	Signals/mi	0.2639	5.378
R. Med. 4 Lanes	-Acc/mi/yr	ADT, Signals/mi	0.7670	19.752
	-Acc/MVM	Signals/mi	0.7990	51.661
MIDBLOCK ACCIDENTS				
TWLTL 6 Lanes	-Acc/mi/yr	ADT	0.8294	29.167
	-Acc/MVM	ADT	0.6281	10.131
TWLTL 4 Lanes	-Acc/mi/yr	ADT, Drives/mi, Apprch/mi	0.4772	11.563
	-Acc/MVM	Drives/mi, Apprch/mi	0.3939	12.671
R. Med. 6 Lanes	-Acc/mi/yr	ADT	0.2768	5.741
	-Acc/MVM	Openings/mi, Signals/mi	0.0749	0.567
R. Med. 4 Lanes	-Acc/mi/yr	ADT, Signals/mi	0.7579	18.781
	-Acc/MVM	Drives/mi, Signals/mi	0.7175	15.236

- One signal per mile, 60 drives per mile, and 4 or 6 approaches per mile;
- One or 2 signals per mile and 90 drives per mile;
- Two signals per mile, 30 drives per mile, and 4 or 6 approaches per mile;
- Three signals per mile and 30 drives per mile;
- Three signals per mile, 60 drives per mile, and 6 approaches per mile; and
- Three signals per mile, 90 drives per mile, and 4 or 6 approaches per mile.

The tables use the same variable format—even if some of the variables do not affect the accident rate—to facilitate comparisons and promote clarity. The purpose of the tables is not to show an absolute accident rate; rather, they are intended to present trends in the data and the relative difference between median types.

Tables 7 and 8 present the expected total accidents per MVM for four- and six-lane sections, respectively. Table 7 reveals that raised medians are safer than TWLTLs over the range of data studied for four-lane sections. However, it is significant that the difference between accident rates drops from 26 to 3 percent as the number of signalized intersections increases from one per mile to four per mile. The accident rates were calculated from regression equations that were dependent only on the number of signals per mile.

Table 8 gives the expected total accident rates for six-lane sections. As can be seen, accident rates for TWLTLs and raised medians did not depend on the same variables. In an effort to provide a common basis for comparison, Table 9 was created. Table 9 is similar to Table 8 in all respects, except that raised median accidents were modeled as being dependent on the same variables as TWLTL accidents. A regression equation was derived through computer analysis, as with the

TABLE 6 REGRESSION EQUATION COEFFICIENTS

Total Accidents

Section	Accident Type	ADT	Coefficients: Drives per mi	Signals per mi	Apprch per mi	Open. per mi	Constant
TWLTL 6 Lanes	Acc/Mi/Yr	0.0050848	-0.89517	32.37220	6.48221	- - -	-73.91125
	Acc/MVM	0	-0.08593	3.08711	0.44833	- - -	7.53150
TWLTL 4 Lanes	Acc/Mi/Yr	0.0038777	0	22.68622	-8.85380	- - -	-21.86862
	Acc/MVM	0	0	2.29131	0	- - -	4.01780
Raised Median 6 Lanes	Acc/Mi/Yr	0.00455	0	22.46702	0	0	-96.48022
	Acc/MVM	0	0	1.96196	0	0	3.85559
Raised Median 4 Lanes	Acc/Mi/Yr	0.0019168	0	16.13910	0	0	-14.79288
	Acc/MVM	0	0	2.72091	0	0	1.91835

Midblock Accidents

Section	Accident Type	ADT	Coefficients: Drives per mi	Signals per mi	Apprch per mi	Openings per mi	Constant
TWLTL 6 Lanes	Acc/Mi/Yr	0.0033571	0	0	0	- - -	-60.86993
	Acc/MVM	0.0001292	0	0	0	- - -	-0.36498
TWLTL 4 Lanes	Acc/Mi/Yr	0.0016209	0.52512	0	-8.74647	- - -	4.19088
	Acc/MVM	0	0.05632	0	-0.61905	- - -	3.29801
Raised Median 6 Lanes	Acc/Mi/Yr	0.0009661	0	0	0	0	-8.13549
	Acc/MVM	0	0	0.16643	0	-0.10956	1.86028
							-19.32438
Raised Median 4 Lanes	Acc/Mi/Yr	0.0010357	0	2.51833	0	0	0.98599
	Acc/MVM	0	-0.04567	0.78479	0	0	

other regression models. This model was originally not used because the additional variables do not provide enough information to be statistically significant.

With regard to six-lane section total accidents, the expected-value tables indicate that raised medians are safer for all ADT levels except when there is 1 signalized intersection per mile and at least 75 driveways per mile or when there are 2 signalized intersections per mile, at least 80 driveways per mile, and 5 or fewer unsignalized approaches per mile.

These results should be viewed in light of the aforementioned independent variable combinations not covered by study data. Specifically, rates for the conditions where TWLTLs were found to be safer represent an extrapolation from variable combinations present in the study sections. Of course, the same holds true for many of the conditions for which raised medians were found to be safer.

For four-lane total accidents per MVM, raised medians were found to be safer for all conditions.

COMPARISON WITH PAST RESEARCH

Parker's 1983 Virginia study (*2*) presented expected-value tables and a set of general guidelines, all developed from a study of four-lane roads. The expected-value tables in that report indicate that with ADTs from 10,000 to 30,000, TWLTLs have a lower number of accidents per mile when there are fewer than 30 driveways per mile and fewer than 5 streets per mile.

The expected-value table for accidents per mile for four-lane sections in the current study revealed a different relationship. Drives per mile was not found to be significant for either median type. Further, ADT is definitely significant. At an ADT of 10,000, TWLTLs are safer except when the number of approaches per mile is low. At an ADT of 30,000, raised medians are safer except with seven or more approaches per mile and two or fewer signals per mile.

The relative safety of TWLTLs under conditions of few signals per mile and a high number of approaches is probably attributable to the characteristics associated with less developed areas. Under such conditions, there are probably few points of concentrated left-turn vehicle manuevers. Such points seem to adversely affect TWLTL safety. The correlation between ADT and accidents per mile per year is to be expected. As opposing traffic increases, left-turn movements should become safer at concentrated and controlled points such as those found with raised medians.

Parker's general guidelines were also found to apply to the sections studied in this project only when the number of accidents per mile per year was under consideration. Parker recommends a TWLTL median when there are fewer than 12 streets per mile and the number of driveways per mile exceeds 50. Although the results of this project agree with these guide-

TABLE 7 TOTAL ACCIDENTS/MVM EXPECTED: FOUR-LANE SECTIONS

Signals per mile	Drives per mile	Approach per mile	ADT = 10,000 TWLTL	ADT = 10,000 RM	ADT = 30,000 TWLTL	ADT = 30,000 RM	ADT = 50,000 TWLTL	ADT = 50,000 RM
1	25	2	6.31	4.64	6.31	4.64	6.31	4.64
		4	6.31	4.64	6.31	4.64	6.31	4.64
		6	6.31	4.64	6.31	4.64	6.31	4.64
		8	6.31	4.64	6.31	4.64	6.31	4.64
	50	2	6.31	4.64	6.31	4.64	6.31	4.64
		4	6.31	4.64	6.31	4.64	6.31	4.64
		6	6.31	4.64	6.31	4.64	6.31	4.64
		8	6.31	4.64	6.31	4.64	6.31	4.64
2	25	2	8.60	7.36	8.60	7.36	8.60	7.36
		4	8.60	7.36	8.60	7.36	8.60	7.36
		6	8.60	7.36	8.60	7.36	8.60	7.36
		8	8.60	7.36	8.60	7.36	8.60	7.36
	50	2	8.60	7.36	8.60	7.36	8.60	7.36
		4	8.60	7.36	8.60	7.36	8.60	7.36
		6	8.60	7.36	8.60	7.36	8.60	7.36
		8	8.60	7.36	8.60	7.36	8.60	7.36
3	25	2	10.89	10.08	10.89	10.08	10.89	10.08
		4	10.89	10.08	10.89	10.08	10.89	10.08
		6	10.89	10.08	10.89	10.08	10.89	10.08
		8	10.89	10.08	10.89	10.08	10.89	10.08
	50	2	10.89	10.08	10.89	10.08	10.89	10.08
		4	10.89	10.08	10.89	10.08	10.89	10.08
		6	10.89	10.08	10.89	10.08	10.89	10.08
		8	10.89	10.08	10.89	10.08	10.89	10.08
4	25	2	13.18	12.80	13.18	12.80	13.18	12.80
		4	13.18	12.80	13.18	12.80	13.18	12.80
		6	13.18	12.80	13.18	12.80	13.18	12.80
		8	13.18	12.80	13.18	12.80	13.18	12.80
	50	2	13.18	12.80	13.18	12.80	13.18	12.80
		4	13.18	12.80	13.18	12.80	13.18	12.80
		6	13.18	12.80	13.18	12.80	13.18	12.80
		8	13.18	12.80	13.18	12.80	13.18	12.80

lines on the basis of the number of accidents per mile per year, a TWLTL median would not be recommended for a four-lane road on the basis of accidents per MVM.

Harwood and St. John (*4*), within subjective guidelines such as the need to accommodate pedestrians, suggested that TWLTL should be used instead of raised medians when the number of driveways per mile exceeded 45 and when there were low to moderate volumes of through traffic. Some of the expected-value tables developed in this report suggest the same thing. For TWLTLs to be safer, the number of driveways per mile should be high. Although accidents per MVM remained constant with changing ADTs, accidents per mile per year preclude the use of TWLTLs at higher ADT levels.

The relative safety of TWLTLs and raised medians may be inferred from the Azzeh et al. FHWA report (*1*). As discussed previously, the application of the FHWA work is based on anticipated accident reduction from a previously undivided roadway. The accident-rate reductions were determined for a four-lane highway. From the comparison of expected accident reductions for each median type, for all ADT ranges, TWLTLs were expected to be safer when land development was low to moderate. Low to moderate land development was used to describe areas with several concentrated sources of traffic and few low-volume driveways. The implication of the FHWA report is that for high-development areas, which are assumed to have no high-volume driveways and a large number of low-volume driveways, raised medians are safer. Further, when more high-volume driveways and fewer low-volume driveways are present, TWLTLs would be safer. This implication is contrary to the results obtained in the current study and in other studies (*2,3*). The unusual results obtained from the FHWA report most likely mean that the relative safety of median types cannot be inferred from the accident-reduction rates of those median types.

CONCLUSIONS

This study provides a comparison of accident rates occurring in situations with raised medians and two-way left-turn lanes (TWLTLs). Regression equations have also been developed to model accident occurrence for each median type. In all,

TABLE 8 TOTAL ACCIDENTS/MVM EXPECTED: SIX-LANE SECTIONS

Signals per mi	Drives per mile	Approach per mile	ADT = 20,000 TWLTL	ADT = 20,000 RM	ADT = 30,000 TWLTL	ADT = 30,000 RM	ADT = 40,000 TWLTL	ADT = 40,000 RM	ADT = 50,000 TWLTL	ADT = 50,000 RM
1	30	2	8.94	5.82	8.94	5.82	8.94	5.82	8.94	5.82
		4	9.83	5.82	9.83	5.82	9.83	5.82	9.83	5.82
		6	10.73	5.82	10.73	5.82	10.73	5.82	10.73	5.82
	60	2	6.36	5.82	6.36	5.82	6.36	5.82	6.36	5.82
		4	7.26	5.82	7.26	5.82	7.26	5.82	7.26	5.82
		6	8.15	5.82	8.15	5.82	8.15	5.82	8.15	5.82
	90	2	3.78	5.82	3.78	5.82	3.78	5.82	3.78	5.82
		4	4.68	5.82	4.68	5.82	4.68	5.82	4.68	5.82
		6	5.57	5.82	5.57	5.82	5.57	5.82	5.57	5.82
2	30	2	12.02	7.78	12.02	7.78	12.02	7.78	12.02	7.78
		4	12.92	7.78	12.92	7.78	12.92	7.78	12.92	7.78
		6	13.82	7.78	13.82	7.78	13.82	7.78	13.82	7.78
	60	2	9.45	7.78	9.45	7.78	9.45	7.78	9.45	7.78
		4	10.34	7.78	10.34	7.78	10.34	7.78	10.34	7.78
		6	11.24	7.78	11.24	7.78	11.24	7.78	11.24	7.78
	90	2	6.87	7.78	6.87	7.78	6.87	7.78	6.87	7.78
		4	7.77	7.78	7.77	7.78	7.77	7.78	7.77	7.78
		6	8.66	7.78	8.66	7.78	8.66	7.78	8.66	7.78
3	30	2	15.11	9.74	15.11	9.74	15.11	9.74	15.11	9.74
		4	16.01	9.74	16.01	9.74	16.01	9.74	16.01	9.74
		6	16.90	9.74	16.90	9.74	16.90	9.74	16.90	9.74
	60	2	12.53	9.74	12.53	9.74	12.53	9.74	12.53	9.74
		4	13.43	9.74	13.43	9.74	13.43	9.74	13.43	9.74
		6	14.33	9.74	14.33	9.74	14.33	9.74	14.33	9.74
	90	2	9.96	9.74	9.96	9.74	9.96	9.74	9.96	9.74
		4	10.85	9.74	10.85	9.74	10.85	9.74	10.85	9.74
		6	11.75	9.74	11.75	9.74	11.75	9.74	11.75	9.74

TABLE 9 TOTAL ACCIDENTS/MVM EXPECTED USING SAME VARIABLES: SIX-LANE SECTIONS

Signals per mi	Drives per mile	Approach per mile	ADT = 20,000 TWLTL	ADT = 20,000 RM	ADT = 30,000 TWLTL	ADT = 30,000 RM	ADT = 40,000 TWLTL	ADT = 40,000 RM	ADT = 50,000 TWLTL	ADT = 50,000 RM
1	30	2	8.94	5.34	8.94	5.34	8.94	5.34	8.94	5.34
		4	9.83	5.77	9.83	5.77	9.83	5.77	9.83	5.77
		6	10.73	6.20	10.73	6.20	10.73	6.20	10.73	6.20
	60	2	6.36	5.36	6.36	5.36	6.36	5.36	6.36	5.36
		4	7.26	5.78	7.26	5.78	7.26	5.78	7.26	5.78
		6	8.15	6.21	8.15	6.21	8.15	6.21	8.15	6.21
	90	2	3.78	5.37	3.78	5.37	3.78	5.37	3.78	5.37
		4	4.68	5.80	4.68	5.80	4.68	5.80	4.68	5.80
		6	5.57	6.23	5.57	6.23	5.57	6.23	5.57	6.23
2	30	2	12.02	7.15	12.02	7.15	12.02	7.15	12.02	7.15
		4	12.92	7.58	12.92	7.58	12.92	7.58	12.92	7.58
		6	13.82	8.00	13.82	8.00	13.82	8.00	13.82	8.00
	60	2	9.45	7.16	9.45	7.16	9.45	7.16	9.45	7.16
		4	10.34	7.59	10.34	7.59	10.34	7.59	10.34	7.59
		6	11.24	8.02	11.24	8.02	11.24	8.02	11.24	8.02
	90	2	6.87	7.18	6.87	7.18	6.87	7.18	6.87	7.18
		4	7.77	7.60	7.77	7.60	7.77	7.60	7.77	7.60
		6	8.66	8.03	8.66	8.03	8.66	8.03	8.66	8.03
3	30	2	15.11	8.95	15.11	8.95	15.11	8.95	15.11	8.95
		4	16.01	9.38	16.01	9.38	16.01	9.38	16.01	9.38
		6	16.90	9.81	16.90	9.81	16.90	9.81	16.90	9.81
	60	2	12.53	8.97	12.53	8.97	12.53	8.97	12.53	8.97
		4	13.43	9.40	13.43	9.40	13.43	9.40	13.43	9.40
		6	14.33	9.82	14.33	9.82	14.33	9.82	14.33	9.82
	90	2	9.96	8.98	9.96	8.98	9.96	8.98	9.96	8.98
		4	10.85	9.41	10.85	9.41	10.85	9.41	10.85	9.41
		6	11.75	9.84	11.75	9.84	11.75	9.84	11.75	9.84

50 TWLTL and 32 raised median sections were studied, lending stability to the analysis performed.

Comparisons were made for total and midblock accidents, four- and six-lane sections, accidents per million vehicle miles (MVM) and accidents per mile per year, and injury, fatal, and all accidents occurring. Although the comparisons of all of these combinations are interesting, total accidents per MVM is considered to give the best indication of the relative safety of a median type. The comparison of accidents occurring on six-lane sections showed, with a low statistical error, raised medians to be safer than TWLTLs. The accident comparison for four-lane sections also showed raised medians to be safer, but with a higher statistical error.

The relative safety of raised medians probably resulted from the range of ADTs used. With higher volumes of opposing traffic, left-turn movements seem to be safer at concentrated points, such as those provided by raised medians. When turns are concentrated at certain points, the area in which conflicts occur is greatly reduced. The turns may also be better accommodated at concentrated points; by using traffic signals, for example.

Regression equations were developed for 16 conditions: raised medians and TWLTLs, four- and six-lane sections, total and midblock accidents, and accidents per mile per year and accidents per MVM. Total accidents per MVM were used to accurately reflect the relative safety of the sections. The following are regression equations developed for the four sections:

TWLTL 6-lane:

$$\text{accidents/MVM} = 3.087 * S - 0.086 * D + 0.448 * A + 7.532$$

TWLTL 4-lane:

$$\text{accidents/MVM} = 2.291 * S + 4.018$$

Raised median 6-lane:

$$\text{accidents/MVM} = 1.962 * S + 3.856$$

Raised median 4-lane:

$$\text{accidents/MVM} = 2.721 * S + 1.918$$

Where

S = Signals per mile;
D = Driveways per mile; and
A = Approaches per mile.

Tables presenting the expected accident rates were generated for all regression models developed. The expected-value tables for the regression equations produced results comparable to the accident-rate comparison performed earlier.

For four-lane sections, raised medians were always safer than TWLTLs. However, the difference in rates was found to decrease with increasing numbers of signals per mile. For six-lane sections raised medians were, again, found to be safer except under certain conditions. TWLTLs were safer when all the following conditions were met: high numbers of driveways per mile (at least 75), low numbers of signals per mile (2 or fewer), and low numbers of approaches per mile (a maximum of 5 or 6, depending on signals per mile).

Results of this study compared fairly well with those of other research when viewed using the parameters of the other studies. The general guidelines developed in other research appear to be applicable, especially in relation to the six-lane sections studied. For TWLTLs to be safer than raised medians, traffic should be low with few concentrated sources of traffic entering or leaving the road.

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