that have active-warning systems (see Table 2). The base figure of 4823 potentially preventable accidents includes accidents in which the motor vehicle was struck by the train, i.e., category 4 accidents.

Without specific regulations to require the cleaning of reflectors, Hopkins' no-maintenance scenario is probably the most realistic. However, it certainly would be nice to have some research on the question of the impact of lack of reflector maintenance on reflector brightness.

Hopkins' suggestion for using a single cost estimate with estimates of minimum and maximum benefits to give a more realistic idea of the program's benefit/cost ratio is impossible until better cost data are available on installation costs and, more importantly, until information on grade-crossing visibility is obtained, so that ranges of benefits can be established. At this point, it is impossible to estimate minimum benefits.

REFERENCE

26. R. G. McGinnis. The Benefits and Costs of a Program to Reflectorize the U.S. Fleet of Railroad Rolling Stock. Federal Railroad Administration, 1979.

Publication of this paper sponsored by Committee on Railroad-Highway Grade Crossings.

Accident and Operational Guidelines for Continuous Two-Way Left-Turn Median Lanes

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An investigation was begun to provide highway designers and traffic engineers with more definitive information on the installation of left-turn median lanes. Primary emphasis was on documentation of experiences with continuous two-way left-turn median lanes; however, for purposes of comparison, channelized one-way left-turn median lanes (raised and flush markings) were included. This paper presents a summary of the detailed investigation of the literature on left-turn lanes, the results of a survey of current practices and standards in Texas, results of field studies, and guidelines for use. A literature survey and analysis of questionnaires returned by representatives from Texas cities and the Texas State Department of Highways and Public Transportation suggested areas in which definitive guidelines were required. Based on the analysis of these two phases of the study, field studies were conducted that concentrated on operational characteristics, accident experience, and currently accepted practices. The analysis of the data collected on left-turn-lane sites revealed many characteristics, patterns, and relationships of accidents and operational experiences. A brief summary of the conclusions and findings is included, and recommendations are provided to improve current practices. In the operational characteristics phase of the study, emphasis was placed on the lateral placement of vehicles in the left-turn lane and the entering and maneuvering distances of vehicles within the lane. These suggest the characteristics of driver behavior that can be used by traffic engineers and highway designers in determining the optimum design elements for two-way left-turn lanes.

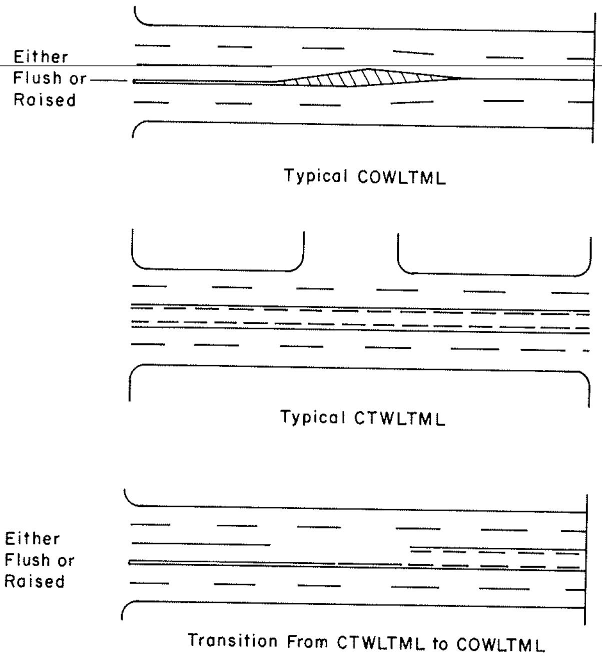
In recent years, there has been increased emphasis on improving the capacity and safety of existing traffic facilities through low-cost improvements or modifications. One concern among highway designers and traffic engineers is the treatment of medians on non-controlled-access highways in urban areas and the development of design and operational standards for median improvements. Although many guidelines have been developed to aid traffic engineers in considering left-turning vehicles, there are still many unanswered questions about how and when special median facilities should be provided.

Basically, three types of left-turn facilities are considered in this study: raised channelized one-way left-turn median lane (raised COWLTML), flush COWLTML, and continuous two-way left-turn median lane (CTWLTML).

A COWLTML (Figure 1) is a median left-turn lane that provides space for speed changes and storage for left-turning vehicles traveling in only one traffic direction to turn at a designated location along a two-direction roadway. A CTWLTML is a left-turn median lane that provides common space for speed changes and storage for left-turning vehicles traveling in either direction and that allows turning movements at any location along a two-way roadway. Raised channelization is generally defined as the use of a curb or other "nontransversible" delineator, while flush channelization generally refers to the use of paint, buttons, tile, or other easily transversible markings.

Although such median lanes have been in operation for some time, very little information has been compiled about their operational differences and about trade-offs between each type of left-turn facility. Therefore, the primary objective of this paper is to present the results of a study that was designed to (a) review previous studies related to traffic operations of left-turn lanes, (b) collect and analyze data for evaluating the operational characteristics of left-turn facilities, (c) identify relationships and characteristics of accidents associated with left-turn-lane facilities, and (d) develop guidelines for design and operational decisions for median treatments. The results presented should enable traffic engineers to better understand the impacts and trade-offs among various types of left-turn facilities in their decision-making process and will facilitate the design of left-turn lanes for individual sites.

Figure 1. Typical types of left-turn lanes.



BASIC DESIGN CONSIDERATION

From a review of pertinent publications, a list of design considerations and implications that focused on access, accidents, and congestion issues was prepared. These three issues are vital considerations in determining the need for a left-turn lane and in determining the type and design details of the facility. The list presented below contains some of the major access considerations that may affect safety, traffic flow, cost, feasibility, and public acceptance of left-turn-lane designs (1-3):

1. What is the abutting retailer's preference in type of access?
2. What is the driver's preference in type of access?
3. How is parking affected?
4. What changes are expected in movement volumes, lane use, traffic composition, etc.?
5. What pedestrian needs exist or are expected?
6. What changes in traffic control are anticipated?
7. What other access does the abutting property have?
8. What controls are there over driveway location, frequency, etc.?
9. What other possible uses of the median area now exist or are anticipated?

Halsey (4) developed a summary of causes of traffic difficulties that lead to traffic accidents and congestion. Items of major importance in left-turn design include angles of movement, velocity differences, acceptable speeds, convergence, divergence (changing number of lanes), and capacity. These basic causes of traffic difficulties manifest themselves in four types of friction: intersectional, marginal, medial, and internal-stream friction. All four are frequently present in left-turn-lane operations.

Several studies (2, 5-7) present principles that are intended as guides to aid the traffic engineer in alleviating friction and minimizing the effects of basic causes of accidents and traffic congestion.

Guidelines for Use of Left-Turn Lanes

A list of warrants and guidelines derived from review of the literature has been developed for use in design of left-turn lanes (8). Included is a tabulation of the documented conditions under which left-turn lanes have been installed or programmed for installation. The following items provide a summary of these guidelines:

1. In general, warrants and guidelines for use with CTWLTMLs indicate average daily traffic (ADT) of 10 000-20 000 on facilities that have four through lanes and an ADT of 5000-12 000 on facilities that have two through lanes.
2. Warrants and guidelines for use with COWLTMLs usually indicate only that the ADT volume should exceed 10 000. Volumes at COWLTML sites in the literature ranged from 14 400 to 31 200 vehicles/day on facilities that have four through lanes.
3. Through-lane speeds of 48-80 km/h (30-50 mph) are common on CTWLTML sites.
4. COWLTMLs are commonly used on streets that have through-lane speeds greater than or equal to 48 km/h.
5. CTWLTML widths range from 3 to 4.6 m (10-15 ft).
6. Lane widths of 3.7 m (12 ft) are consistently recommended for COWLTMLs.
7. Land uses along CTWLTML sites are most commonly classified as commercial. Some sites are found in industrial areas that have commercial activity.
8. Land use was not found to be as important a consideration at COWLTML sites as it was at CTWLTML sites.

Sawhill and Neuzil (8) also provide a discussion of an opinion survey of city and state engineers in Texas. Questionnaires were mailed in October 1975 and January 1976 to the 25 district engineers of the State Department of Highways and Public Transportation (SDHPT) and to city engineers in 48 Texas cities ranging in population from approximately 18 000 to 1 233 000 (1970 census figures).

The engineers were asked to weight site characteristics in order of importance in determining the type and need for a left-turn lane and to rank CTWLTMLs, raised COWLTMLs, and flush COWLTMLs according to how well each satisfied certain site characteristics. Demand for midblock left turns was ranked as the most important site characteristic and was followed by (in order of average weight) peak through-traffic speed, number of through lanes, block spacing, pedestrian movements, public (driver's) preference, and abutting retailer's preference.

Although the respondents as a whole showed no distinct preference for left-turn lane type for many street and traffic characteristics, CTWLTMLs were preferred over COWLTMLs in areas of demand for midblock left turns, peak through-traffic volume, strip commercial land use, through-traffic speed of more than 48 km/h, four-through-lane facilities, long block spacings, driver's preference, and abutting retailer's preference. COWLTMLs were preferred over CTWLTMLs by the survey respondents in the areas of restricted sight distance and pedestrian movements. Flush COWLTMLs were usually ranked between CTWLTMLs and raised COWLTMLs. Other results of this survey are summarized below.

1. City engineers in Texas indicated that they desired maximum speed limits in CTWLTMLs to be less than the usual posted speed limits for arterial-street through

lanes, yet speed limits for CTWLTMLs are rarely posted separately.

2. Guidelines suggested for CTWLTML widths range from 3 to 4.6 m (10-15 ft). The survey also indicated that city engineers in Texas desire the CTWLTML width to increase as the through-lane speed increases.

3. Major effects that the survey respondents believed to be due to left-turn-lane installations include substantial (yet sometimes varied) effects on the number of accidents (especially those involving left-turning vehicles), capacity, delay, and travel time at the sites.

4. All engineers in Texas who responded to the survey had an average of about five years' experience with CTWLTMLs. City engineers had about three years' experience with COWLTMLs. District engineers had about six or more years' experience with COWLTMLs.

5. Engineers in Texas have a wide range of opinions on left-turn-lane design practices and conditions for use, but they generally feel that CTWLTMLs are more frequently misused than are COWLTMLs.

6. Approximately half of the district engineers responding to the survey and three-quarters of the city engineers responding use different signs and markings at major intersections than at midblock locations on CTWLTMLs. The most common difference was the transition of the CTWLTML to a COWLTML with inclusion of a gap in the marking for entering the lane.

Related Studies

Studies that are related to left-turn lanes range from studies of individual installations to projects that cover a wide range of improvements. These studies have provided a great deal of valuable information to aid in understanding the effects of left-turn installations; however, application of the findings of these studies to warrants is difficult because the relationships between accidents and site characteristics have not been fully determined. Previous studies related to left-turn lanes may be generally classified as before-and-after (or parallel) accident studies, operational studies (which may also be before-and-after studies), general access studies, and studies that use regression techniques. The summary of findings presented below draws primarily from the more extensive studies.

Operational Studies on CTWLTMLs

Studies on CTWLTMLs have been done by a variety of state and local agencies, but most were focused on accidents and only a few were related to traffic operational aspects. With respect to operational aspects of CTWLTMLs, two major studies were found. One was conducted by Sawhill and Neuzil of the University of Washington (8) and another was conducted by Nemeth of Ohio State University (7).

Sawhill and Neuzil (8) made their operational study in terms of (a) travel distance within a CTWLTML prior to a left-turn maneuver during rush and nonrush hours, (b) general observations and commentary on users' behavior related to CTWLTMLs, and (c) the use of vehicle turn-signal indicators prior to a left-turn maneuver. Their findings include the following observations:

1. Drivers decelerate or stop in the through lane before entering the CTWLTML.
2. Seventeen percent of the out-of-town drivers make their left turns from the through lane without making use of the CTWLTML.
3. Most drivers complete the left-turn entry maneuver into the left-turn lane within 12-15 m (40-50 ft) of beginning the intersection entry.
4. The average travel distance within a CTWLTML for the local driver is 61 m (200 ft) and for the out-of-town driver is 43 m (140 ft). This distance is longer during the rush hour than during the nonrush hour for the local driver, but it is relatively consistent for the out-of-town driver.
5. Automobiles entering the roadway from driveways make little use of the CTWLTML as an acceleration lane; however, truckers do make use of it for their left-turn movement.
6. Few drivers use the CTWLTML as a passing lane.
7. Approximately 80 percent of the drivers use their turn-signal indicators prior to a left turn into a driveway, but only 40 percent signal when entering the roadway from a driveway.

Sawhill and Neuzil also stated that additional research in signing is needed to familiarize the out-of-town drivers with the proper use of the CTWLTML. It was recommended that the width of the median lane be 3-4 m (10-13 ft).

Nemeth (7) initiated four before-and-after operational studies on CTWLTMLs in Ohio. Major study parameters were traffic conflicts, travel time, left- and right-turning volumes, and traffic volume on each lane. Traffic conflict, as defined by Nemeth, is "any instance in which a main-flow vehicle must either swerve or brake to avoid an accident." He further classified the conflicts into cross conflict, opposing conflict, rear-end conflict, and weaving.

Of the two sites studied by Nemeth in a before-and-after context, one site involved the conversion of a four-lane arterial into a three-lane roadway, and the other involved restriping a four-lane highway section into a five-lane section. The conclusion of the analysis of the first site was that the conversion resulted in increased travel times, increased weaving, and some reduction in total conflicts. In the second case, an increase in volumes was noted, with an insignificant change in travel speeds. Conflicts attributable to braking were noted to have decreased after some initial increase due to driver confusion about the pavement markings. Recommendations are presented in the form of relevant discussion on such topical areas as adjacent lane use, access conditions and requirements, traffic volume, speed limit, spacing of existing intersections, economic conditions, and safety.

Operational Studies on COWLTMLs

Rowan and Williams (9) performed a study on channelization by measuring the tension of drivers through a highway study section. The study was performed during the three stages of a channelization installation. The first stage had no channelization, and the final stage had a divisional island with a special approach-end treatment. The results were inconclusive, due to the small number of responses and the variability in drivers. Rowan also performed a speed study before and after the installation of divisional island channelization. Those results were also inconclusive.

Shaw and Michael (10) conducted a study to aid in the establishment of warrants for the implementation of left-turn lanes in Indiana. They collected delay and accident-rate data at 11 intersections and used multiple regression techniques to develop equations to predict suburban delay time, rural delay time, suburban accident rates, and rural accident rates in terms of several operational variables. Their final presentation was a cost-benefit analysis in which the cost was the construction cost and the benefits were the reductions in accidents and delay.

Another element considered to be an important left-turn operational characteristic is gap acceptance. Ring and Carstens (11) classified the gap characteristics into types that they termed gap, lag, critical gap, and critical lag. They coupled on-site investigations with arterial modeling in an effort to explain gap-acceptance phenomena surrounding left-turn maneuvers. They concluded that gap acceptance is dependent on following and opposing queue length and that left-turning vehicles adjust speed to minimize the need for complete stops. These behavioral aspects, although difficult to predict, were put in a multiple regression model to estimate the number of vehicles that were forced to stop and the magnitude of delays of the stopped vehicles. The final presentations of Ring and Carstens were two equations for estimating the cost-benefit ratio in which the cost was the construction cost and the benefit was the accident reduction and delay savings.

Another left-turn gap-acceptance study was conducted by Dart (12) at both channelized- and unchannelized-approach signalized intersections. He found that drivers rarely accepted a gap of less than 2 s or rejected a gap longer than 8 s and that there was no appreciable difference between channelized and unchannelized approaches.

Volume Warrants

Volume warrants for left-turn lanes are typically presented in graphical form and relate the percentage of left-turning traffic to other volumes. Ring and Carstens (11) developed a series of graphs for determining whether a left-turn lane is warranted at a rural intersection that also considers the posted speed, the annual accident-cost reduction, and the percentage of trucks. Glennon and others (1) presented a volume warrant chart for sections or intersections that requires the percentage of left turns, advancing volume, and opposing volume.

Accidents at Channelized Intersections

Accident studies related to left-turn lanes at intersections (or high-volume driveways) have found significant decreases in accident rates when one-way left-turn lanes were added. Wilson (13) presented a summary of before-and-after studies that compared channelized left-turn lanes at unsignalized intersections using raised bars, curbs, and paint for channelization. The data showed statistically significant reductions in accident rates for projects that used each type of channelization.

Foody and Richardson (14), in a comparison of intersections with and without left-turn lanes (LTLs), found a great deal of variability in accident rates. The table below shows the comparison of sites Foody and Richardson developed on a basis of signalization and the existence of a left turn lane, in terms of accidents per million vehicles per leg per year. Although significant differences ($p = 0.05$) were shown in comparing total accident rates and those for "all others" (both signalized and nonsignalized), the variability of left-turn accident rates caused the subset averages for the left-turn accident rates to show no statistical difference.

	Nonsignalized		Signalized	
Type of Accident	With LTL (N = 33)	Without LTL (N = 134)	With LTL (N = 61)	Without LTL (N = 135)
Left turn	0.12	1.20	0.37	0.65
All others	0.92	3.15	1.17	1.82
Total	1.04	4.35	1.54	2.47

Shaw and Michael (10) used multiple regression to evaluate delays and accidents at intersections. Equations were developed for estimation of delays and accidents at suburban intersections with left-turn-lane channelization that explained 69 percent of the variation in delay and 61 percent of the variation of accident rates by means of eight and seven variables, respectively. The most important variables in predicting the accident rates were related to ADT, the number of approach lanes, and the average speeds of nondelayed through vehicles.

Accident Experiences on Designated Sections

Glennon and others (1) evaluated numerous access techniques by using information available in the literature and estimating average values of accidents, running times, cost-benefit ratios, and other measures of effectiveness. Table 1 shows the general accident warrants for access control techniques developed for left-turn and total accident rates on routes or at points (1). Estimates of accident reduction were prepared for COWLTMLs and CTWLTMLs. For raised COWLTMLs, it was assumed that accidents would generally be reduced by 50 percent at intersections and major driveways and that at minor driveways all left-turn accidents would be eliminated and there would be a slight increase in right-turn accidents. For flush COWLTMLs, it was assumed that accidents would be reduced by 28 percent, and for CTWLTMLs by 35 percent.

Other references have already shown that there is a great deal of variability in reduction of accidents by channelized lanes. Table 2 shows that there is also a great variability in accident reductions as a result of CTWLTML installations. The variabilities in accident reductions, and their unaccountability, make applications of reductions to a specific proposed installation very difficult.

In summary, no quantitative information related to both COWLTMLs and CTWLTMLs was found in any single reference. Only subjective comments in regard to both types of left-turn lanes were found. Accident analysis for a particular type of left-turn lane was the common approach of the few studies on left-turn lanes. Operational characteristics were mentioned in only a few of those studies; the common study elements were delays and gap acceptance on COWLTMLs and conflicts and entrance distances on CTWLTMLs. Although the previous studies provided valuable information, a more definitive basis for relating accident numbers and rates to site conditions was needed.

METHODOLOGY

The technique selected for an accident or operational study depends primarily on the nature of the available data and the study objectives. In most research applications that deal with design features of roadways, the purpose of accident and operational analysis is to investigate relationships between these parameters and various site or roadway characteristics for a number of chosen cases in order that the effects of certain conditions can be estimated. Four common analysis techniques used in such studies are regression analysis, before-and-after studies, comparison and individual case studies, and performance-standard studies.

In developing guidelines for the use of left-turn lanes, many different basic sets of conditions must be examined. It is also desirable to investigate many different variables within these basic subsets. The before-and-after study approach was impractical in this study

Table 1. Warrants for access control techniques on routes or at points, based on annual number of driveway-related accidents.

Item	Left-Turn Accidents Low ADT (<5000 vehicles/day)	Left-Turn Accidents Medium ADT (5000-15 000 vehicles/day)	Left-Turn Accidents High ADT (>15 000 vehicles/day)	Total Accidents Low ADT (<5000 vehicles/day)	Total Accidents Medium ADT (5000-15 000 vehicles/day)	Total Accidents High ADT (>15 000 vehicles/day)
Level of development (driveways/km)						
Low (<48)	2.66	5.18	7.70	3.8	7.4	11.0
Medium (48-96)	7.91	15.47	23.03	11.3	22.1	32.9
High (>96)	10.50	20.58	30.66	15.0	29.4	43.8
Driveway ADT (vehicles/day)						
Low (<500)	0.18	0.31	0.43	0.26	0.44	0.62
Medium (500-1500)	0.44	0.77	1.05	0.63	1.10	1.50
High (>1500)	0.68	1.19	1.61	0.97	1.70	2.30

Note: 1 km = 0.6 mile.

Table 2. Results of before-and-after studies on CTWLTMLs.

Source	Sections	Total Length (km)	Through Lanes	Date Installed	Before Period (years)	After Period (years)	Change in Number of Accidents (%) Total	Left Turn	Rear End	Right Angle	Side-swipe	Other
Sawhill and	1	1.66	4	1958	4	4	-26	+140	-28			-30
Neuzil (8)	1	2.4	4	1961	3	1	-6	-29	-19			+16
Conradson and Al-Ashari (15)	4	10.6	4	1964-1969	1	1	-33	-45	-62	+14	-7	+6
Busbee (16)	1	2.7	4	1974	1	1	-38	-90				

Note: 1 km = 0.6 mile.

due to the limited availability of time. Before-and-after and comparative parallel studies have already been conducted in many areas and can help provide information on possible accident reductions. The performance-standard study approach is undesirable due to difficulties in establishing standards for comparison and to the large number of variables. Since we wished to study operational as well as accident relationships, two study approaches were taken: regression analysis for accidents and comparison and individual case study for operations.

The identification of important variables was undertaken in an extensive review of related literature, and consideration was given to how the data would be used. The literature expressed the data in many different forms and, in some cases, provided statistical parameters, such as means, standard deviations, significance, and levels, that aided in predicting the variability and relative importance of each variable. Transformations used in the studies also provided hints of possible transformations of data for the regression analysis.

Selection of data to be collected was based on the relative importance of the data and the degree of difficulty anticipated in collecting the data. Collection of data that would not generally be available or easily obtained by the traffic engineer was not considered practical. It was considered desirable to be able to separate accidents by location, type, severity, cause, etc., in order that accident characteristics might be more easily compared for different lane types and accident groupings. Site data were tabulated by block or subblock, in order that the sites could be examined at different levels of detail. Vehicle kilometers for the block were calculated and summed over the total length of each section when several blocks were combined. Several dummy variables were used in the analysis as simple tests of whether the existence of signals on the ends of the midblock sites, the existence of parking, or the existence of three-leg intersections could account for differences between sites. The total number of variables was 63.

Accident Study Data Analysis

Accident data for left-turn-lane sites were analyzed by using standard regression techniques. Purposes of the analysis were (a) to provide insight into the characteristics of the sites and accidents that were being used in the analysis and (b) to describe existing field applications of various left-turn lane types.

Equations Developed

Sections were formed by combining midblock and intersection data in a manner that provided as much homogeneity as possible for lane-type markings, parking, lane widths, etc., at each site. Features such as railroad tracks and highly skewed intersections were avoided. The sections averaged approximately 0.72 km (0.45 mile) in length; extremely long sections that remained homogeneous rarely occurred, and extremely short sections were avoided.

The sections were analyzed with and without the inclusion of intersection accidents. This enabled an examination of the effects of intersection accidents on the total number of accidents, thereby providing another means of comparing lane types with the evaluation of the variability of other factors with and without intersection accidents included. The inclusion of intersection accidents generally improved the predictability of equations concerning accidents and accident severity and lessened the predictive ability of the equations related to the critical accident rate and the average damage scale. [Full details of the 46 equations are available on request from the authors.]

Ten equations were developed by using individual midblock sites (short sections between two adjacent intersections), excluding all intersection accidents. Due to the poor predictability of accidents at midblock sites and the large numbers of variables entering the equations (up to 11), individual midblock sites were quickly dropped from the analysis. Separation of the midblock sites by lane type did little to improve the equations.

The sites were examined with combinations of lane types and with separation of the CTWLTML sections. COWLTML sections were too few in number for an adequate regression analysis. The predictive abilities of the equations generally improved slightly when the CTWLTML sections were considered by themselves, indicating that some differences probably exist between characteristics of the CTWLTML sites and those of the COWLTML sites.

Checks of Regression Assumptions

Plots of residuals versus dependent and independent variables were examined to identify inadequacies of the models and to provide clues for possible variable transformations that might improve the equations. The plots of residuals versus dependent variables for the single midblock sites exhibited linear residual patterns, with positive residuals on one end of the dependent variable range and negative residuals on the other. These patterns, which resulted from the large number of site variables that had zero values on the short sections and from a mixture of lane types, rendered the midblock-site equations inadequate for predictive purposes. Similar patterns were observed for the equations developed by using mixed lane types. Although the patterns were not as strong as in the case of the midblock sites, the equations would still be judged inadequate. These patterns illustrate further that there are differences between the CTWLTML sites and the COWLTML sites.

Residual patterns similar to those related to the midblock-site equations were also observed for equations predicting the severity index, critical rate, and average damage scale, for reasons similar to those previously discussed. For the section equations developed from the CTWLTML sites, the residual patterns were extremely slight or exhibited the normal absence of pattern. The equation that was chosen for predictive purposes on CTWLTML sections presented no residual problems.

Regression Analysis Results

Examination of the regression equations, residual plots, extreme cases, etc., revealed many important relationships between accident and site characteristics. The following is a summary of the most important findings of the regression analysis, with a concentration on CTWLTML equations.

Important Variables

In order to identify the variables that are of greatest importance in relation to accidents at the study sites, a maximum level of five independent variables per equation was set.

Dependent Variables

The best dependent variables for prediction of all types of accidents on CTWLTML sections appeared to be (in order of value) the number of accidents per mile, the number of accidents, and the number of accidents per million vehicle miles. [Customary units are retained in the names of the variables since customary units were used in developing the equations.] The left-turn accident variables followed the same pattern. The amounts of variability explained by the equations were generally higher for the CTWLTML sections when the intersection accidents were included.

The severity index and average damage scale were very unpredictable, as was expected. The equations for prediction of the severity index and average damage scale also were found inadequate, due to previously mentioned residual plot patterns. The critical accident rate was used as a dependent variable to aid in spotting unusual conditions. (The R^2 values, however, are somewhat misleading, since the critical rate was developed by using vehicle miles, the primary independent variable for predicting the critical rate.)

Independent Variables

The most consistently important independent variables were weekday ADT, number of signals (or number of signals per mile), number of driveways (or number of driveways per mile), and city size. Other important variables were vehicle miles of travel (per weekday), percentage of commercial land use, and the existence of curbside parking. The relationships indicated that independent variables expressed as rates are most appropriately associated with dependent variables that are also expressed as rates.

ADT has frequently been related to accident rates, since it is a measure of both exposure and congestion. Vehicle miles of travel is a measure of interaction between the ADT and the section length. The number of signals and number of driveways are logical entries since both are indirect measures of level of development and conflicting movements. It is also important to note that the number of signals on the site is important even when intersection accidents are not included. The inclusion of a signal variable illustrates the importance of signal effects on accidents that do not actually occur at intersections. The city-size variable may be a measure of the differences in traffic characteristics of the cities in which the sections were located.

As might be expected, percentage of land use classified as commercial appeared to influence accident numbers and rates. Commercial-land-use influences appeared to be more prevalent on the CTWLTML sections in the prediction of left-turn accidents, illustrating the importance of commercial land use in generating midblock left turns and the greater need for left-turn provisions in commercial areas. The high colinearity between percentage of commercial land use and number of driveways per mile (0.671) generally deterred both variables from entering the same equation.

It is also important to note the absence of other variables that were considered to be important in the literature. Lane widths were not shown to be of major importance in the analysis, which may be primarily due to the fact that the average—3.6 m (11.7 ft)—is adequate. Similarly, there is no evidence from the analysis that present speed limits are unsafe or that posted speed limits for CTWLTMLs significantly reduce accident numbers or rates.

Prediction of Accident Rates

CTWLTMLs

The best dependent variable for predicting accident rates on CTWLTML sections is the number of accidents per mile. This equation also provides logical independent variables that consistently demonstrate relationship to accidents. These independent variables are weekday ADT, number of signals per mile, number of driveways per mile, and city size. The equation developed is

$$\text{Number of accidents per mile} = -43.5 + 0.002\,03(\text{ADT}) + 0.000\,175(\text{city population}) + 0.491(\text{number of driveways per mile}) + 9.20(\text{number of signals per mile}) \quad (1)$$

The standard error for the residuals is approximately 33 accidents/mile, the F_{reg} is approximately 34, and the value of R^2 is approximately 0.75.

Although the equation shows that the number of accidents per mile increases with each of the independent variables, Table 3 better illustrates the magnitude of the expected accident rates. The average observed accident-per-mile rate for the CTWLTML sites with intersection accidents included is 77.9 accidents/mile. The average rate for the values in Table 3 is 79.5 accidents/mile.

Non-CTWLTMLs

Although there were too few non-CTWLTML sites for a regression analysis, comparison of these sites with the CTWLTML sites can provide some insight into differences in the lane types. Table 4 presents a tabulation of COWLTML and reversible-lane-site accident rates in comparison with estimated accident rates for CTWLTML sites with the same characteristics. This expedient comparison shows a consistent overestimation of accident rates on raised COWLTML sites by the accident-rate equation developed for CTWLTML sites. The comparison also illustrates part of the reason why equations developed for all lane types in combination were not satisfactory.

Operational Study Data Collection

Five operational situations were selected to represent typical left-turn installations. These situations were (a) short blocks, (b) offset intersections, (c) offset driveways, (d) one-side left-turns only, and (e) other commonly used situations. Selection of sites for operational study involved reviewing locations in several cities and making an inventory of those sites that fitted selection criteria. These criteria were based on land use, type of left-turn facility, average daily traffic volume, posted speed limit, and type of delineation. Twenty sites were selected in Austin and Fort Worth, Texas. Nine of the 14 sites in Austin are CTWLTMLs; 4 of these are CTWLTMLs that have transitions from CTWLTMLs to either raised or flush COWLTMLs at the intersection. The five other Austin sites are either raised or flush COWLTMLs. The remaining six sites, in Fort Worth, have either an extreme width or a different delineation. A brief summary of the characteristics of the sites is shown in Table 5.

Various operational characteristics mentioned in the literature were considered in the data selection process. The data requirements adopted for this study were entrance distance, maneuvering distance, lateral placement, traffic volume, and conflicts.

Entrance distance is the distance from an intersection to where a vehicle enters the turn lane before making a left-turn maneuver. These data apply to CTWLTML facilities, since the COWLTML has specific openings provided for left-turn entry. The entrance distance for each car that entered each CTWLTML facility was recorded by two observers, who noted the distance from the stopping line of the intersection at which the left front wheel touched the CTWLTML line. Maneuvering distance is the distance required for the left-turning vehicle to fully enter the left-turn lane. The spot where the left front wheel touched the CTWLTML and the spot where the right rear wheel touched the CTWLTML were estimated by the same two observers. The distance between these spots is the maneuvering distance.

Lateral placement is the lateral position of the vehicle within the lane. Data were collected through the use of a movie camera set on the roadside as far as possible from the roadway (in order to minimize influence on the driver). One still photograph was also taken whenever a vehicle entered the median left-turn facility. Three reference markers were used; two outside markers located the outer edges and the third marker located the center of the left-turn lane.

A clipboard counter was used to record the combined total for the through-lane volume, left-turn volume, and opposing volume. These volume counts were made simultaneously with the distance data collection and used as relative descriptors of the site. Conflict data include any friction caused by vehicles turning left over the study section. Only the peak period was observed, since the higher volume would normally generate more conflicts.

Theoretically, five types of conflicts were identified as pertinent to the operation of CTWLTMLs: (a) head-on conflict, (b) conflict between a vehicle in the CTWLTML and a left-turning vehicle from a minor street as it enters the CTWLTML, (c) conflict between a vehicle in the CTWLTML and a vehicle that starts to enter the CTWLTML, (d) conflict between a left-turning vehicle from the through lane (not using the CTWLTML) and a straight-through vehicle, and (e) conflict between a vehicle in the CTWLTML and a left-turning vehicle from the through lane.

In a flush COWLTML, fewer types of conflicts are possible, since fewer choices are available to the drivers. These consist of the following: (a) conflict between a left-turning vehicle and a straight-through vehicle in the through lane, (b) conflict between a left-turning vehicle in the left-turn lane and a left-turning vehicle from the opposite direction, and (c) conflict between a left-turning vehicle and a straight-through vehicle in the opposite direction.

On a raised COWLTML, even fewer conflict types are possible, since conflicts with the opposite stream of traffic are eliminated. The only possible type of conflict is one between a left-turning vehicle and a through vehicle in the through lane.

Operational Study Data Analysis

Data were analyzed by means of variance techniques to ascertain the effects of different lane widths, different delineation systems, and different types of left-turn facilities. Results of the analyses provided some basic information on the proper width of the left-turn lane, the proper delineation system, and other related operational characteristics that can be used to develop criteria for the left-turn-lane design. Lateral placement of the vehicle in the left-turn median lane, as well as entering and maneuvering distances, was analyzed in three interrelated efforts. In the lateral placement study, the effects of lane widths, pavement markings, types of median turn lane, and location of the raised island were investigated. For the entrance distance, a study was made on (a) entrance distance during peak and off-peak periods, (b) entrance distance at midblock and intersection locations, (c) entrance-distance behavior for different types of pavement markings, and (d) entrance-distance behavior for different types of through lanes. The maneuvering-distance portion of the study was concerned with the same general locations and configurations as the entering-distance study.

Accident Analyses

1. Comparisons of general accident statistics for raised COWLTML sites and CTWLTML sites reveal similar patterns by hour of day, number of vehicles involved, and severity.
2. Raised COWLTML sites have a greater proportion

Table 3. Estimated accidents per lane on four-lane urban streets [average section length = 0.71 km (0.44 mile)].

Signals per Mile	Driveways per Mile[a]	ADT <15 000 (avg = 10 540) Population 50 000	250 000	400 000	ADT = 15 000-20 000 (avg = 17 500) Population 50 000	250 000	400 000	ADT >20 000 (avg = 24 500) Population 50 000	250 000	400 000
>3 (avg = 4.63)	>60	72.3	107.3	133.5	86.4	121.4	147.6	100.6	135.6	161.8
	40-60	53.9	88.9	115.1	68.0	103.0	129.2	82.2	117.2	143.4
	<40	40.4	75.4	101.6	54.5	89.5	115.7	68.7	103.7	129.9
1-3 (avg = 2.0)	>60	48.1	83.1	109.3	62.2	97.2	123.4	76.4	111.4	137.6
	40-60	29.7	64.7	90.9	43.8	78.8	105.0	58.0	93.0	119.2
	<40	16.2	51.2	77.4	30.8	65.3	91.5	44.5	79.5	105.7
0	>60	29.7	64.7	90.9	43.8	78.8	105.0	58.0	93.0	119.2
	40-60	11.3	46.3	72.5	25.4	60.4	86.6	39.6	74.6	100.8
	<40	0.0	32.8	59.0	11.9	46.9	73.1	26.1	61.1	87.3

[a]Average values used in developing the table are for >60: 87.7; for 40-60: 50; for <40: 22.7.

Table 4. Comparison of accident rates by lane type.

Lane Type	Number of Through Lanes	ADT	Population	Signals per Mile	Driveways per Mile	Actual Accidents per Mile	Estimated CTWLTML Accidents per Mile	Error[a] (Actual - CTWLTML)
Raised COWLTML	6	29 562	407 000	4.17	39.6	166.7	145.5	+21.2
	6	31 134		4.65	39.5	127.9	153.2	-25.3
	6	32 706		3.13	84.4	253.1	317.5	-64.4
	4	15 483		0.0	16.1	41.9	67.1	-25.2
	4	13 921		0.0	31.3	12.5	71.4	-58.9
	4	13 591		0.0	0.0	9.4	55.4	-46.0
	4	14 477		0.0	81.8	65.9	97.3	-31.4
	4	14 477		0.0	100.0	76.3	106.3	-30.0
	4	14 477		2.1	62.5	64.9	107.0	-42.4
	4	8 323	283 700	0.0	17.0	36.2	31.4	+4.8
	6	13 660		3.2	35.5	29.0	81.0	-52.0
Flush COWLTML	4	17 197	407 000	0.0	23.3	46.4	74.1	-27.6
Reversible	2	13 223	283 700	2.0	56.0	66.0	78.9	-12.9
	2	11 367		2.9	5.9	35.3	59.2	-23.9

[a]Average error = 29.7 (SD = 24.3); average error (raised) = -31.8 (SD = 26.1); average error (four-lane, raised) = -33.4 (SD = 20.3).

Table 5. Summary of selected sites for operational study.

Location	Type of Left-Turn Lane	ADT[a]	Speed Limit (km/h)	Delineation
Austin				
5th and Lamar	CTWLTML	31 110	56	Single line of white buttons; yellow square buttons at intersection approach.
6th and Lamar	CTWLTML	31 110	56	Single line of white buttons; yellow square buttons at intersection approach.
45th and Lamar	CTWLTML and raised COWLTML	25 780	64	Standard CTWLTML marking[b] at midblock; opening; raised island at approach.
45th and Guadalupe	CTWLTML and flush COWLTML	23 210	56	Standard CTWLTML with buttons; opening; yellow square buttons at approach.
Anderson and Burnet	CTWLTML	22 570	64	Standard CTWLTML with buttons; large round buttons at approach.
Denson and Airport	CTWLTML	19 060	72	Standard CTWLTML with buttons.
Barton Spring and Lamar	CTWLTML and raised COWLTML	29 940	64	Single line of white buttons; raised island at approach.
Riverside and Congress	CTWLTML and flush COWLTML	21 340	56	Standard CTWLTML at midblock; opening; yellow square buttons at approach; six lanes with parking on one side.
32rd and Red River	CTWLTML	12 240	48	Standard reversible lane[b] marking; two lanes; reversible lane during peak period.
45th and Lamar	Raised COWLTML	21 680	64	Standard COWLTML with raised island.
19th and Lamar	Raised COWLTML	25 790	56	Standard COWLTML with raised island on the right side.
45th and Guadalupe	Flush COWLTML	20 730	56	Standard COWLTML with buttons.
Congress and 19th	Flush COWLTML	25 040	48	Standard COWLTML.
26th and Guadalupe	COWLTML	26 980	56	Continuous one-way with buttons.
Fort Worth				
Cockell and Berry	CTWLTML	19 500	56	Single line with buttons; double line with buttons at intersection; six lanes.
Wichita and Mansfield	Raised COWLTML	14 500	64	Raised island; metallic buttons 30 cm in diameter on the other side.
Bigham and Camp Bowie	Raised COWLTML	28 700	56	Raised island; ceramic buttons 20 cm in diameter on the other side.
Guliford and Camp Bowie	Raised COWLTML	32 200	56	Raised island; ceramic buttons 20 cm in diameter on the other side.
University and West Settlement	Flush COWLTML	16 700	48	Ceramic buttons 20 cm in diameter on both sides.
East Vickery and South Main	Flush COWLTML	8 000	48	Metallic buttons 30 cm in diameter on both sides.

Note: 1 km = 0.6 mile; 1 cm = 0.4 in.
[a]Obtained from 1975 volume count furnished by the Texas Department of Highways and Public Transportation.
[b]See Manual on Uniform Traffic Control Devices (17).

of intersection and intersection-related accidents than CTWLTML sites—75 percent and 55 percent for raised COWLTML sites and CTWLTML sites, respectively. CTWLTML sites have a higher proportion of driveway and nonintersection accidents.

3. The most frequently noted factors contributing to accidents on CTWLTML and raised COWLTML sites are unsafe speed and failing to yield right-of-way. Together these factors accounted for 56 percent and 24 percent of the two-vehicle cases for CTWLTML sites and raised COWLTML sites, respectively. Following too closely is a contributing factor in 42 percent of the two-vehicle accidents for raised COWLTML sites, compared with 14 percent for CTWLTML sites. The analysis of factors contributing to accidents illustrates the effects of the greater freedom of movement possible with CTWLTMLs, which allow continuous access to abutting property.

4. Analysis of factors related to accidents on the study sites indicated that the percentage of cases involving driveway maneuvers on CTWLTML sites was twice that on raised COWLTML sites. CTWLTML sites had only small percentages of midblock accidents involving vehicles slowing or stopping to make left turns.

5. The best dependent variable for estimation purposes was found to be the number of accidents per mile.

6. Little success was found in predicting accident severities or damage measures.

7. The most consistently important independent variables for prediction of accidents and rates were weekday ADT, number of signals (or signals per mile), number of driveways (or driveways per mile), and city size. Secondary variables were vehicle miles, percentage of commercial land use, and the dummy variable for existence of parking.

8. Independent variables notably absent from the equations were those related to lane widths plus speed limits.

9. A "best" predictive equation was selected and a table was developed that illustrated the effects of the independent variables on the number of accidents per mile on CTWLTML sites.

Operational Analyses

In regard to the operational analyses, the following findings [more completely documented in Walton and others (18)] were developed.

Lateral Placement

1. In reference to CTWLTMLs, lane widths of 3.4 m (11 ft) and 3.7 m (12 ft) have no significant adverse effect on traffic operations, but lane widths of approximately 4.6 m (15 ft) or more created some confusion among drivers.

2. In reference to flush COWLTMLs, lane widths of 3.2 m (10 ft 6 in) to 3.8 m (12 ft 6 in) showed no significant operational variation.

3. Lane widths of 2.6 m (8 ft 6 in) to 3.2 m for COWLTMLs produced significant variations.

4. Standard CTWLTML markings and white single-line button markings were interpreted differently by drivers, and the use of paint or buttons for delineation showed some operational variation in terms of driver response and vehicle positioning.

5. Raised COWLTMLs with paint markings and flush COWLTMLs with 30-cm (12-in) diameter metallic buttons on both sides of the lane were comparable in terms of vehicle queueing in the lane.

6. There were significant differences between CTWLTMLs and flush COWLTMLs with 30-cm diameter metallic buttons on both sides of the lane.

7. In a raised COWLTML, drivers tend to position the vehicle away from the raised barrier.

Entrance Distance

1. Traffic volume, especially the left-turning and the adjacent through-lane traffic volume, has a significant effect on entrance distance.

2. Entrance distances to left turns at midblock and at intersection approaches are different.

3. The type of lane delineation has significant effects on entrance distance.

4. Entrance distance varies with the number of through lanes.

5. There is a wide range of entrance distances on CTWLTMLs. The majority of drivers observed entered the CTWLTML 45-75 m (150-250 ft) from the intersection, while very few drivers entered the lane less than 30 m (100 ft) from the intersection.

Maneuvering Distance

1. Although there is a range of maneuvering distances, a large number of observed drivers completed the left-turn entry in 15 m (50 ft).

2. Traffic volume and the number of through lanes were found to influence maneuvering distance.

3. Maneuvering distances are shorter at midblock than at intersection approaches.

CONCLUSIONS AND RECOMMENDATIONS

The study findings suggest a wide range of guidelines for consideration by highway designers and traffic engineers. The guidelines refer to urban arterials and are recommended for use in addition to standard traffic engineering practice. These guidelines should, however, provide a higher level of user confidence and a basis for comparing information gained from other sources.

CTWLTMLs are an effective and efficient means of providing an enhanced level of service on many urban arterials. They are especially effective in locations of strip commercial development and frequent driveway openings that experience moderate left-turn demand. Raised and flush COWLTMLs are effective at major intersections that experience high left-turn demand.

CTWLTML lane widths and posted speed limits of the urban arterial were found to be adequately accounted for in standard practice by highway designers and traffic engineers. In other words, a minimum of a 3.4-m (11-ft) lane, with a 3.7-m (12-ft) requirement desirable for CTWLTML facilities, is recommended. Any lane width over 4.6 m (15 ft) was found to create some driver confusion regardless of the speed of the through traffic or the legal speed limit. Therefore, the following provides a summary of recommended guidelines found in this study for left-turn median lanes.

1. Existing site conditions should be carefully inventoried and assessed when considering left-turn-lane improvements or installations. The findings of this or any other study should be considered only as guides, not warrants, for left-turn-lane improvements or installations.

2. The text table on page 00, along with Wilson (13), may be used for estimating improvements in accident rates due to left-turn channelization at individual intersections.

3. Table 1 should be used as a general guide for consideration of access control techniques.

4. Existing accident locations, contributing factors, and related factors should be used as guides in deter-

mining the potential effectiveness of left-turn lane types.
5. Table 3 and Equation 1 should be used as guides for determining the potential effectiveness of a CTWLTML.

In general, CTWLTMLs provide for increased flexibility, e.g., the inherent characteristic of additional storage space for short blocks. The fear of conflicts and a resultant increase in accidents after implementation is unfounded. In fact, most "anticipated" conflicts rarely occur; if they occur, they are handled with typical driver judgement. It was observed that the signing and pavement-marking procedures in the Manual on Uniform Traffic Control Devices (MUTCD) (17), sections 3B-12 and 2B-17 (as amended in Volumes 1-8), are effective in informing drivers of CTWLTML operations. We believe that signing contributes marginally to driver awareness and that pavement markings (lane delineation and symbol messages) are mandatory. Speed limits imposed on many CTWLTML locations serve little purpose because of the characteristic use of the facility.

In regard to raised or flush COWLTMLs, no significant driver-conflict problems were observed. Adequate storage space for the left-turning queue was the primary design element that created any concern.

In reference to raised lane markers (e.g., ceramic or metallic buttons), other minor observations of interest are that 1.3-cm (0.5-in) high square buttons and 7.6-cm (3-in) high, 20-cm (8-in) buttons installed at the intersection approach to separate opposing traffic were not observed to be very effective in prohibiting left turns from the opposing traffic and that 30-cm (12-in) metallic buttons are effective in separating through-lane traffic and left-turn-lane traffic. However, there are several disadvantages: (a) the buttons are difficult to maintain and clean, (b) they can create hazards to motorcyclists, and (c) they may force motorists who entered the left-turn lane by mistake to turn at the intersection. Few vehicles were observed returning to the through lane at the intersection and few vehicles entered the left-turn lane by crossing through the space between buttons.

The CTWLTML, as is appreciated by most practitioners, is an excellent option and is recommended for use where these guidelines suggest it as an effective alternative.

ACKNOWLEDGMENT

The contents of this report reflect our views, and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Discussion

Stanley L. Ring, Department of Civil Engineering, Iowa State University, Ames

The authors have made a significant contribution toward a better understanding of the use of CTWLTMLs. Although this technique for improving traffic operations is more frequently used now than it was in the past, a surprisingly small amount of significant research has been conducted on the subject. The authors' review of the literature contains a number of studies done in the 1960s.

The development of a "best" regression equation to predict accident rates was a basic objective of the study. The authors document the final equation selected with suitable supportive information for the readers. It would appear, however, that a word of caution regarding the application of Equation 1 should be given. The uniqueness of the study sites and the operating characteristics of the traffic flow are related to the specific model presented. In view of this applicable environmental constraint, the reader should be cautioned in making applications to other environments.

Also, it should be noted that a relatively large negative intercept constraint exists in Equation 1. Again, a word of caution regarding the extension of the predicting range beyond the data would be in order.

The operational study phase provided some useful results. I was, however, somewhat concerned with the procedure for measuring vehicle entrance and maneuvering distance and lateral placement. Observations from the side of the road "as far as possible from the roadway (in order to minimize influence on the driver)" would appear to introduce considerable judgment decisions and estimating because of visual shortcomings and parallax. A number of photographic or video studies from elevated positions have been made in similar situations and have yielded more reliability.

It has been reported that, in certain locations, vehicles entering the roadway from an entrance tend to use the CTWLTML for storage or for merging with adjacent through traffic at a more convenient angle. In some cases, trucks especially benefit from these facilities. It would have been helpful if this aspect were observed and reported for the reader's total knowledge of benefits.

Other questions arose in regard to increased potential for U-turns, signal progression as an independent variable, and changes in total vehicle delay. Answers may be available in the detailed project report, or they may have been beyond the scope of this study. These questions may be related to the limitations of the manual observation technique.

The authors are to be commended overall for an excellent study.

John C. Glennon, Overland Park, Kansas

I would like to commend the authors on their paper. It offers a significant contribution to our knowledge about left-turn median treatments. I have no other direct comments about the paper, but I would like to recommend further operational studies. My observation is that several jurisdictions around the country are still reluctant to try the two-way left-turn median. Although some jurisdictions may be afraid of increased accidents, more are probably reluctant because of the lack of convincing evidence on significant benefits.

It seems clear that two-way left-turn medians would offer substantial delay reductions where traffic volumes are moderate to high in strip commercial areas. Yet no studies have clearly shown the capacity improvement value of two-way left-turn medians under various traffic-flow and commercial-development conditions. The studies I recommend, therefore, would be aimed at delineating the traffic operational benefits of two-way left-turn medians under various conditions.

Zoltan A. Nemeth, Department of Civil Engineering, Ohio State University, Columbus

Let me begin by congratulating the authors of this valuable contribution to the very limited literature on CTWLTMLs. With the exception of a few states and cities, this ingenious traffic engineering device is not being used to its full potential. In fact, it is not being used at all in many cities, although the date of the first installation goes back to at least 1950, when it was introduced in Michigan. There are various misconceptions underlying the resistance, and every bit of evidence regarding the safety and effectiveness of CTWLTMLs should be shared with the traffic engineering community.

Every traffic engineer recognizes that urban arterials usually perform two conflicting functions, namely the provision of access to abutting land uses and the provision of flow for through traffic. By permitting parking in the curb lane, for example, access is being favored, while the removal of curb parking increases the level of service for the traffic flow. CTWLTMLs can do both: They improve access to driveways and reduce delay to through traffic.

The main purpose of my comments is to support some of the findings of this paper. The basis for my comments is mostly the information gathered in two different surveys of traffic engineers around the country: an earlier one in connection with sponsored research (7) and a recent one in connection with the work of a committee I chair for the Institute of Transportation Engineers (this survey resulted in 106 responses from 29 states).

My comments will be directed at three areas of the subject paper.

1. Among the findings of the accident analysis is the information that "unsafe speed," "failing to yield the right-of-way," and "following too closely" are the major contributing factors in 70 percent of the accidents at CTWLTML sites. These factors are among the contributing factors commonly listed on standard accident reporting forms and, in general, are not very useful for the purposes of cause-and-effect accident studies. The more important conclusion is that "CTWLTML sites had only small percentages of midblock accidents involving vehicles slowing or stopping to make left turns."

I would like to add that, among the traffic engineers who responded to the above-mentioned surveys, only 11 percent indicated that accident problems were experienced at CTWLTMLs. Furthermore, all but one of the respondents who reported accident problems also indicated that some problems existed with improper use of the median lane. In contrast, only 50 percent of the total survey population reported problems with improper use. In other words, few CTWLTMLs have accident problems and those that do also have problems with improper use. As one of the respondents to the survey explained, "motorists sometimes stop in the median lane at an angle, with the rear of the car protruding into the through lane. This causes some rear-end accidents, which most often do not involve the left-turning vehicles themselves."

Also, sideswipe accidents occur when some drivers enter the CTWLTMLs too early and travel down the lane only to be struck by another driver entering the CTWLTML nearer to the left-turn point.

Sometimes right-angle collisions occur between vehicles entering the CTWLTML from the through lane and vehicles exiting from a driveway and making a left turn into or across the CTWLTML.

Generally, the responses indicate that the incidence of other types of accidents (especially head-on collisions) was very rare.

Some other improper uses reported in the surveys include turning improperly from the through lanes, passing slower vehicles for many blocks in the CTWLTML before turning left, truckers stopping for loading or unloading, bicyclists using it as a bike way. Improper uses that are due to unfamiliarity will, of course, diminish in time. At the beginning, however, education of the public is important, and the cooperation of the enforcement agencies is needed. (In an extreme case of noncooperation, one respondent reported that, in an early use, the police considered CTWLTMLs to be median divider islands and ticketed left-turning vehicles.)

I would like to add that CTWLTMLs can, in case of emergency, provide a path for emergency vehicles, a detour lane during blocking of through lanes by construction or vehicle breakdown, or even a place for storing snow removed from the through lanes.

2. The accident prediction equation (Equation 1) includes only four independent variables, and they are readily available. This should make it easy for others to test the equation and compare results. It was surprising at first to find that operating speeds were not included among the independent variables. A closer look at the study-site characteristics revealed, however, that speed limits ranged mostly from 48 to 64 km/h (30-40 mph) [only one site had a 72-km/h (45-mph) speed limit]. In this range, apparently, speed has no significant effect on accident statistics. It would have been interesting to see the effect of higher operating speed. Fifty-seven percent of the respondents to our survey suggested that the speed limit should be less than 88 km/h (55 mph) on arterials where CTWLTMLs are to be introduced. On the other hand, there are several examples of CTWLTMLs working properly even at 105 km/h (65 mph) (prior to imposition of the 88-km/h speed limit). One respondent stated that there is "no magic involved in the speed-limit sign. We have TWLTLs for miles on open rural unposted state highways. . . ." It is probable, however, that, if the frequency of midblock left turns justifies CTWLTMLs, then the lower speed limit is also justified by the intensity of roadside development.

3. The paper states that the authors believe that signing contributes marginally to driver awareness but that pavement markings, including arrows, are essential. The MUTCD (17) requires both signs and pavement markings.

Our surveys found that 96 percent of the respondents complied with the MUTCD for pavement markings and 76 percent did for signing. At least one respondent even expressed concern that the expenses involved in the required signing may keep some agencies from installing CTWLTMLs. Some agencies reported that they use signs to comply with MUTCD, but they do not really think that they are necessary. Some 50 percent of the reporting agencies use overhead signs as well as ground-mounted signs. Some interesting comments were received from them regarding their policy on overhead signs: They use overhead signs where obliteration of pavement markings by snow can be expected, where curb parking or roadside development can detract from ground-mounted signs, where frequent improper use has been observed during use of pavement markings and ground-mounted signs, and on major multilane streets that have frequent signalized intersections. They reported that overhead signs are spaced at quarter to half points between major intersections, no less than 305 m (1000 ft) apart at other locations, and no less than 46 m (150 ft) away from major intersections to ensure adequate visibility for turning vehicles. These comments indicate that many agencies have a rational approach to the decision on overhead versus side-mounted signs.

MUTCD itself has gone through several changes regarding the subject of signing CTWLTMLs. I am not at all sure that I am aware of all the relevant changes, but let me attempt to summarize briefly my understanding of the evolution of the relevant sections in MUTCD: (a) Section 2 B-17 stated that signs "shall" be used, while Section 3 B-12 stated that signs "should" be used with pavement markings (1971); (b) Change M-24 (9/27/74) eliminated the contradiction by changing "should" to "shall" in Section 3 B-12; (c) Change Sn-156 (6/29/76) stated that "The R3-9 or R3-9a sign shall be mounted overhead and over the two-way left-turn lane when there are more than three lanes"; and (d) Change: Reconsideration of Ruling Sn-156 (9/19/77): "The post-mounted R3-9b sign may be used as an alternate to or a supplement to the overhead-mounted R3-9a sign."

In conclusion, let me state again that two-way left-turn lanes provide a good solution to the problem created by midblock left turns. Starting-up problems can be expected when they are first introduced in an area. However, they provide such an obviously needed service that drivers will soon get used to them and the level of improper use will drop to a minimum, as with other forms of traffic control.

Authors' Closure

We wish to express our appreciation to those who submitted discussions. These discussions emphasize that, in general, the vast majority of current experience with CTWLTMLs indicates that accident problems are not a primary deterrent to the use of these facilities. Excessive accident rates seem to be related to improper use of CTWLTMLs; the combination of appropriate control devices and driver experience should have a positive effect on this situation.

MUTCD (17) does require that signs, as well as pavement markings, be used along CTWLTMLs. The reconsideration (9/19/77) of Change Sn-156 allows a choice between post- and overhead-mounted signs. Opinions expressed by the vast majority of those contacted during this reserach indicate that driver response to pavement markings is clearly more positive than that for post-mounted or overhead-mounted signs. As noted in the discussions, areas where markings are often obliterated by snow have definite need for effective signage.

In summary, the CTWLTML is an effective and efficient treatment for midblock turn problems. Its controlled use is recommended for a substantial variety of conditions.

Publication of this paper sponsored by Committee on Operational Effects of Geometrics.