Evaluation of Delays and Accidents at Intersections to Warrant Construction of a Median Lane

ROBERT B. SHAW, Pennsylvania Department of Highways, and
HAROLD L. MICHAEL, Joint Highway Research Project, Purdue University

The objective of this study was to evaluate the conditions under which the construction, maintenance, and interest costs for a median lane would be warranted at suburban and rural approaches to an intersection. Delay times and accident rates to through vehicles caused by left-turning vehicles were analyzed in depth at three right-angle intersections which had median lanes, and at eight right-angle intersections which did not.

Seconds of delay per hour to through vehicles caused by left-turning vehicles were determined for the major approaches to the eleven intersections during daylight-weekday hours; 6 a.m. to 6 p.m., Monday through Friday. The accidents caused by left-turning vehicles were collected for almost a 5-yr period and analyzed to determine accident rates for each major intersection approach. This study found a substantial reduction in the number of accidents attributed to left-turning vehicles and negligible delay times to through vehicles at the intersection approaches which had median lanes. The accident rates and delay times were analyzed by a multiple linear regression analysis.

Although this study is based only on daylight-weekday hours, the findings are of considerable value in planning the construction of median lanes. The reduction in accidents and delays estimated for a period of years resulting from the construction of a median lane is used to determine if the construction, maintenance, and interest costs of the median lane at an intersection approach are justified.

•THE increase in motor vehicle use during recent years throughout the United States has greatly affected highway operation. This increase has created an added demand on all components of the highway system and has resulted in increased operating costs to the motoring public. Intersections are an important component of this system and the increased travel volumes have created congestion at many approaches in the urban, suburban, and rural areas. This study investigated one possible technique for congestion relief at suburban and rural intersection approaches.

Congestion at approaches to intersections is a cause for many of the critical problems in highway traffic operations and control (8). Where the intersection is at grade, streams of turning and crossing vehicles must join and cross each other. The points within the intersectional area used in common by these intersecting streams are focal

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points of accidents and delay. Delays result when vehicles in different streams wish to pass through these focal points at or nearly at the same time. Accidents often result when drivers make mistakes in judgment of the time and place that such intersecting movements will occur.

The time and place of conflicts at approaches to intersections may be altered by traffic controls or design. Channelization of intersections at grade has been defined (6) as the separation or regulation of conflicting traffic movements into definite paths of travel by pavement markings, raised islands or other suitable means to facilitate the safe and orderly movement of both vehicles and pedestrians. Channelization is, therefore, used to control the place of conflict between intersecting traffic streams and to influence the time element by separating the conflict points and controlling the speeds at which these conflicts occur.

The median lane is one form of channelization used to separate the conflict points between left-turning vehicles and through vehicles. It provides a temporary, protected storage location for vehicles waiting to make a left-turn movement. This is a report on the results of a research project concerned with warrants for such median lanes, performed by the Joint Highway Research Project of Purdue University.

The objective was to evaluate the conditions for which the construction, maintenance, and interest costs of a median lane would be warranted at suburban and rural approaches to an interesection. Delay times and accident rates to through vehicles caused by left-turning vehicles were analyzed in depth at three right-angle intersections which had median lanes and at eight right-angle intersections which did not. By evaluating the benefits from the reductions in delay times and accident rates realized from the presence of a median lane, a method was developed which can be used to determine when construction of a median lane is economically justified.

STUDY LOCATIONS

The eleven intersections are located within a 60-mile radius of Lafayette-West Lafayette, Ind. (Fig. 1). These intersections are located on highways near Lafayette-West Lafayette, Kokomo, and Indianapolis. The approximate 1965 populations of these urban areas were 65,000, 50,000 and 500,000, respectively. Each intersection had the following characteristics: (a) signal or stop control, (b) four approaches, (c) intersection at right-angle, (d) restricted parking, and (e) suburban or rural location.

A large percentage of the traffic using these intersections was through traffic destined for Chicago, Indianapolis, Fort Wayne, or South Bend. The 1965 major street weekday ADT's for the intersections ranged from 7,100 to 27,500. A summary of the characteristics for the study intersections is given in Tables 1 and 2.

PROCEDURE

Delay Date

The delay time incurred by a through vehicle caused by a left-turning vehicle was determined at the eleven study intersections during daylight-weekday hours; 6 a.m. to 6 p.m., Monday through Friday.

The method developed to collect the delay time data was designed to be simple, inexpensive, and easily adaptable for use by one or more observers. A typical field setup of the equipment used to study the delay time is shown in Figure 2. The equipment used in the collection of delay data consisted of traffic volume counters, 20-pen recorder, 12-volt battery, push-button box, junction box, pneumatic tubes, and electrical conducting wire.

The placement of the traffic counters A and B varied in the suburban and rural areas. Counter A was located prior to the point at which an approaching through vehicle was influenced by the presence of the intersection. Counter B was located beyond the intersection at a point where the through vehicle had resumed its initial approach speed. As the approach speed increased, therefore, the distance between counters A and B increased; this distance was designated as the "zone of influence" and varied from about 800 to 1300 ft.

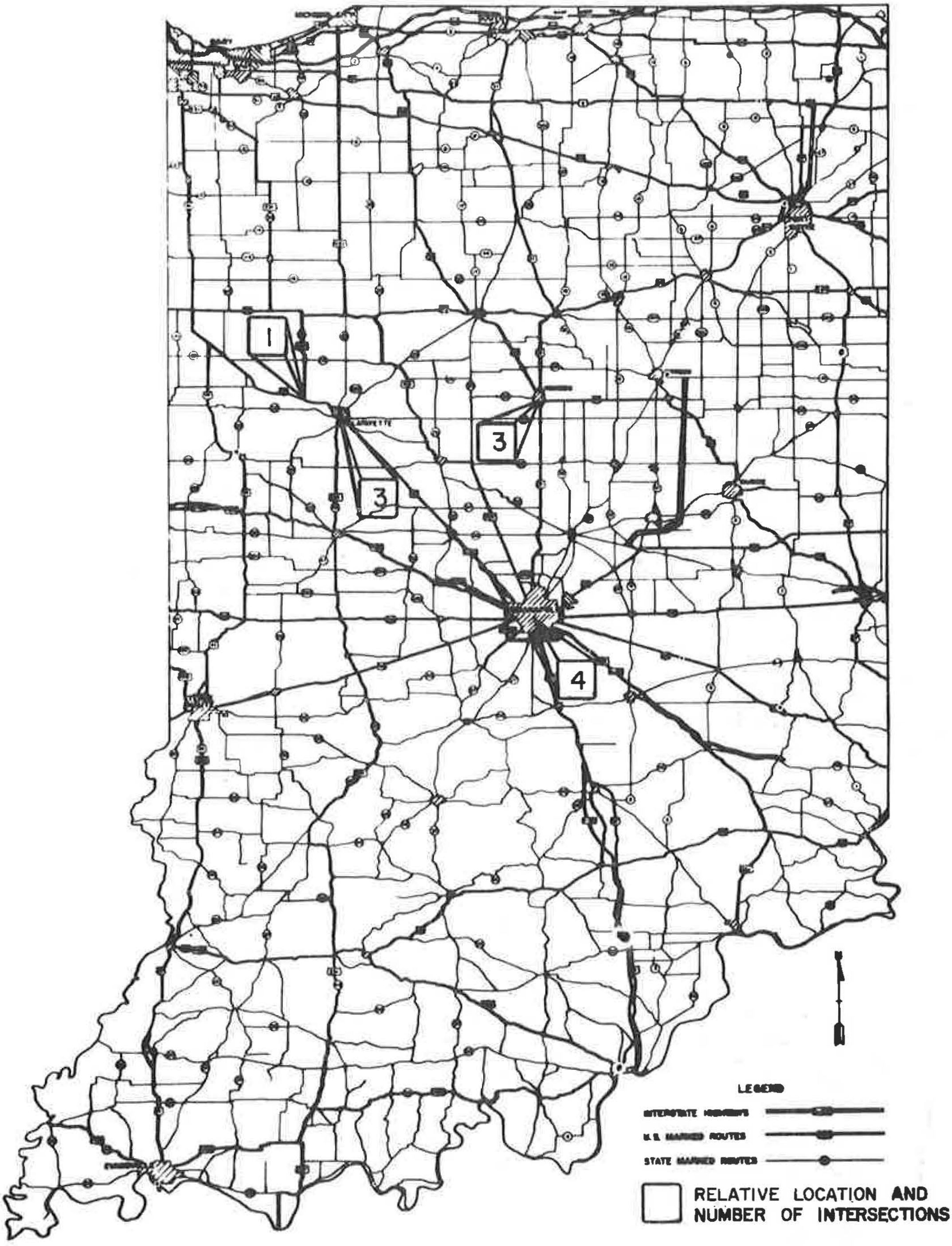

Figure 1. Relative locations of study intersections.

TABLE 1

SUMMARY CHARACTERISTICS OF STUDY INTERSECTIONS WITHOUT MEDIAN LANES

Intersection	Location	Type of Area	Type of Signalization	Weekday Approach[a] ADT Plus Weekday Opposing ADT
US 52 Bypass and Union St.	Lafayette	Suburban	Fixed time	17, 500
US 52 Bypass and SR 26	Lafayette	Suburban	Fixed time	18, 000
US 52 Bypass and Salisbury St.	Lafayette	Suburban	Semitraffic actuated	15, 800
US 52 and US 231	Lafayette	Rural	Stop sign controlled (flasher)	7, 100
SR 100 and 56th St.	Indianapolis	Rural	Fully traffic actuated	10, 500
SR 100 and Fall Creek Rd.	Indianapolis	Rural	Stop sign controlled (flasher)	7, 600
SR 100 and US 31	Indianapolis	Suburban	Fully traffic actuated	12, 900
US 35 (SR 22) and US 31 Bypass	Kokomo	Suburban	Fully traffic actuated	9, 500

[a]Weekday ADT's based on 1965 volume data.

TABLE 2

SUMMARY CHARACTERISTICS OF STUDY INTERSECTIONS WITH MEDIAN LANES

Intersection	Location	Type of Area	Type of Signalization	Weekday Approach[a] ADT Plus Weekday Opposing ADT
US 31 and US 35	Kokomo	Suburban	Fully traffic actuated	22, 000
US 31 and SR 26	Kokomo	Rural	Fully traffic actuated	15, 100
SR 100 and 30th St.	Indianapolis	Suburban	Fully traffic actuated	27, 500

[a]Weekday ADT's based on 1965 volume data.

Approach speed was the determining factor in indicating whether the intersection approach was considered to be located in a suburban or a rural area. Intersection approaches were classified as suburban when the approach speed was greater than 30 but less than 45 mph. Rural intersections were those locations where the approach

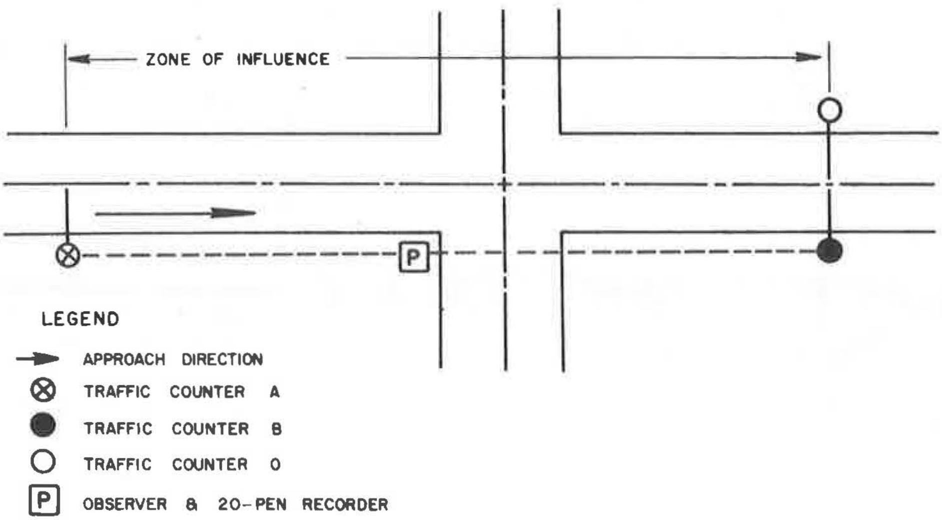

Figure 2. Typical field setup of equipment.

speed was greater than 45 mph. Much greater development of the adjacent land, of course, existed at the suburban intersections.

Traffic counters A and B were equipped with relay devices which actuated the 20-pen recorder whenever a vehicle axle crossed the pneumatic tubes connected to these two counters. Each axle actuation caused a pip on the recorder chart. An opposing traffic volume counter was located opposite counter B. Each observer had a push-button box which actuated six different pens of the 20-pen recorder, as follows:

Pen Number	Description
1	Cancel
2	Stopped time
3	Left-turn vehicular delay
4	Identification of study vehicle
5	Tube A
6	Tube B

Once the equipment was set up at the intersection, an observer selected the first approaching vehicle as a study vehicle. Each study vehicle was identified by pressing the identification button as the vehicle crossed tube A. If the study vehicle turned left or right before crossing tube B, the cancel button was pressed; if the vehicle was delayed by a left-turning vehicle at the intersection, the button signifying a left-turning vehicular delay was pressed; if the vehicle was stopped due to a traffic signal, the stopped time button was pressed both when the vehicle stopped and again when the vehicle started in motion; and finally, when the vehicle crossed tube B, the identification button was again pressed. When a study vehicle had been canceled or had passed through the zone of influence, the next succeeding vehicle to approach the intersection was selected as a study vehicle. This procedure was repeated for a 3-hr period on each approach studied at an intersection.

Additional notations were made on the recorder chart to indicate the classification of each study vehicle, and the number of stopped left-turning vehicles present in a queue. This number of stopped left-turning vehicles was later used to study adequate storage length for a possible median lane.

A study was conducted to verify whether or not the delay times incurred to through vehicles during the 3-hr study period were unique to that intersection approach for the particular time and day. The three suburban intersections in the Lafayette-West Lafayette area were selected for this purpose. Delay times for specific time periods and days of the week were measured on three successive weeks at the three intersections. It was found that the delay times for any particular time and day at a specified intersection approach were not significantly different at the 5 percent level of significance. As a result, it was concluded that adequate samples of delay time at an intersection approach could be obtained during any three consecutive hours for weekday-daylight hours.

The 20-pen recorder was operated at a rate of 6 in./min during the time each approach was studied. The elapsed time in seconds for a study vehicle to pass through the zone of influence was scaled from the recorder charts and recorded in one of the four following categories:

1. No delay;
2. Signal delay: (a) total time, (b) stopped time, (c) total time minus stopped time;
3. Left-turn vehicular delay; and
4. Left-turn vehicular delay and signal delay: (a) total time, (b) stopped time, (c) total time minus stopped time.

These data were used to determine averages of the hourly totals for each of the four categories and percentages of the vehicles delayed by a left-turning vehicle and of the vehicles delayed by a left-turning vehicle and a signal. Time differences were then determined for categories 1 and 3, and 2 and 4. The seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour in the approach direction were calculated as follows:

$$Y_D = (V)(P_L)(T_L) + (V)(P_{LS})(T_{LS}) \tag{1}$$

where

Y_D = seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour in the approach direction;
V = approach volume per hour of through traffic;
P_L = percent of through vehicles delayed by a left-turning vehicle;
T_L = difference, in sec, for the average hourly times of categories 1 and 3;
P_{LS} = percent of through vehicles delayed by a left-turning vehicle and a signal; and
T_{LS} = difference, in sec, for the average hourly times of categories 2 and 4.

An early conclusion from the field data was that the delay time experienced by a through vehicle was negligible at the three locations which had median lanes on the approaches to the intersection. Further analysis, therefore, was limited to the delay time experienced by a through vehicle at the approaches to the eight intersections which did not have median lanes.

Accident Data

An almost 5-yr study period was chosen in order that an adequate sample of accidents could be obtained. Accidents were collected for the daylight-weekday hours at the eleven study intersections for the period Jan. 1, 1961 through Aug. 31, 1965, and accident rates were calculated (Tables 3 and 4).

Data on accidents for the three intersections with median lanes clearly indicated the almost total absence of accidents caused by left-turning vehicles. As a result, it was concluded that a median lane substantially reduces accidents involving left-turning vehicles.

The accident analysis was limited to those accidents caused by left-turning vehicles which could have been prevented with the installation of a median lane. The types of accidents considered preventable were the following:

1. Accidents involving a left-turning vehicle with opposing traffic,
2. Sideswipe overtaking accidents involving a left-turning vehicle, and
3. Rear-end accidents that probably resulted from a left-turn movement.

The accident data were collected from the Accident Records Division of the Indiana State Police and local police records. Indiana state law requires that all accidents involving a personal injury, death or property damage of $50 or more be reported to the police.

In most instances the collision diagram and description of the accident from the investigating officer report form provided the necessary information to distinguish a preventable accident from a nonpreventable accident. It was concluded, however, that additional accidents probably were attributed to left-turning vehicles. A study was conducted, therefore, to determine additional rear-end collisions caused by left-turning vehicles which were not recorded as such on the investigating officer report forms. Accident rates for the other rear-end collisions were calculated for the eight intersections without median lanes and for the three intersections with median lanes (Tables 3 and 4). The difference in the averages of these two accident rates was then used as a basis to randomly assign additional rear-end accidents which could be considered preventable with the installation of a median lane.

TABLE 3

ACCIDENT RATES AT STUDY INTERSECTIONS WITHOUT MEDIAN LANES[a]

Intersection	Cause and Type of Accident[b]			
	Left-Turn		Other	
	Rear-End	Right-of-Way	Rear-End	Right-of-Way
US 52 Bypass and Union St.	0.151	0.490	0.151	0.075
US 52 Bypass and SR 26	0.183	0.366	0.440	0.073
US 52 Bypass and Salisbury St.		0.167	0.417	
US 52 and US 231 (SR 53)	0.186	0.279		0.466
SR 100 and 56th St.		0.126	0.315	0.126
SR 100 and Fall Creek Rd.	0.437	0.262		0.699
SR 100 and US 31	0.360	0.514		0.051
US 35 and US 31 Bypass	0.075	1.196	0.149	0.299
Average	0.278	0.604	0.361	0.405

[a]Accident rates are expressed as the number of accidents per million vehicles for the period Jan. 1, 1961 through Aug. 31, 1965.

[b]Accidents are classified according to cause: left-turn vehicle or other; and according to type: rear-end or right-of-way.

The accident data were analyzed on a yearly basis at each intersection approach to determine an accident rate, number of accidents per million vehicles caused by left-turning vehicles, at each of the eight intersections. No accidents involving a fatal injury were included because of the rarity of such accidents and the difficulty of establishing an economic loss.

Volume

In delay and accident studies, volume has correlated well with delay times and accident rates. This volume can be represented as an hourly volume or as the annual average weekday traffic (ADT). Both the hourly volumes and the weekday ADT were used in the analysis.

The traffic volume counters, used as part of the equipment to measure delay time, were employed simultaneously to obtain the approach and opposing volumes per hour for a given direction of travel. An observer was used to record the number of left-turning and right-turning vehicles, as well as the classification of vehicles entering the intersection approach. It was, therefore, possible to analyze volumes, turning movements, and commercial vehicles for the same period of time the delay data were collected.

The approach and opposing hourly volumes at the time the accident occurred and the weekday ADT's were correlated with the accident rate. Because volume counts were not available for the entire study period, these hourly volumes were estimated.

The traffic volumes obtained at the time the delay data were collected were supplemented by volume data from the Division of Planning, Indiana State Highway Commission. Factors were determined from the volume data collected, from records of the Commission, and from charts depicting the yearly, monthly, daily, and hourly variations in traffic volume during average conditions (12). Therefore, by knowing the location, year, month, day, and hour of an accident, the hourly volumes at the time an accident occurred were estimated by applying the appropriate factors to the volume counts taken at each intersection approach.

TABLE 4

ACCIDENT RATES AT STUDY INTERSECTIONS WITH MEDIAN LANES

Intersection	Type of Accident	
	Rear-End	Right-of-Way
US 31 and US 35	0.301	0.422
US 31 and SR 26	0.220	0.396
SR 100 and 30th St.	0.177	0.133
Average	0.240	0.354

Capacity

The practical capacity of each intersection was calculated by the method described in the Highway Capacity Manual (7).

Six of the signalized intersections had paved shoulders on the right side which allowed through vehicles to maneuver around a left-turning vehicle. These paved shoulders also acted as turning lanes but were not designated for this specific movement. To determine the effectiveness of the paved shoulders in increasing the practical capacities of these six intersections, reference was made to a study (9) which indicated that each paved shoulder carried approximately one-third the capacity of a properly constructed and signed turning lane.

The practical capacity was calculated for an extra turning lane if more than one lane existed for a direction of travel. This lane was assumed to be a left-turn only lane if the predominant turning movement at that approach was left, and assumed to be a right-turn only lane if the predominant turning movement at that approach was right. If the additional lane was only a paved shoulder not constructed, signed, or used exclusively as turning lane, only one-third of the turning lane capacity was added to the through lane capacity.

The two stop-controlled intersections were also protected with flashers. Although no precise method was available to evaluate the practical capacity of these two unsignalized intersections, it was assumed that the crossroad traffic interference caused a wave-like behavior to the through traffic which approached the behavior of traffic under signal control (1). As the crossroad traffic interference did not result in interrupted flow, the practical capacities of these intersections were computed as if the intersections had been operated under traffic control signals with a green time to cycle length ratio of one.

ANALYSIS OF DATA

Multiple Linear Regression

Many variables possibly affecting the delay and accident data were analyzed by multiple linear regression. This method provided expressions for predicting the seconds of delay per hour caused by left-turning vehicles to the volume of through vehicles per hour, and the number of accidents per million vehicles caused by left-turning vehicles at approaches to intersections in both the rural and suburban areas. The computer program used in this study for the multiple linear regression analysis was the BIMD-2R, Stepwise Regression (10).

Tests were conducted on the resulting delay time and accident rate prediction equations to determine whether each independent variable in each equation was significant. The purpose was to develop simplified equations which would in most instances adequately predict delay times and accident rates for both suburban and rural intersections by using a fewer number of independent variables. An option in the BIMD-2R program provided for a summary table listing the order each independent variable entered the multiple linear regression equation and the corresponding increase in the multiple coefficient of determination (R^2) associated with each new variable. The F-test (3) was used to determine the first independent variable which did not add significantly to the increase in the multiple R^2, given the other independent variable or variables already in the regression equation. For example, tests were conducted at a 5 percent level of significance to determine whether a significant increase resulted from the addition of a second independent variable given the first independent variable, or from the addition of a third independent variable given the first two independent variables already in the regression equation. The results of these tests are the basis for the formulation of simplified predictions equations for delay time and accident rates.

Delay Time

The variables in Table 5 represent the independent variables which were considered in the initial analysis for predicting the variability in delay times for both suburban and rural areas. The results from this initial regression analysis were examined for significance and duplication, and certain variables deleted. The final delay time prediction equations were based on the remaining independent variables.

TABLE 5

INDEPENDENT VARIABLES—SUBURBAN AND RURAL DELAY TIMES

Number	Variable
3	Type of area—suburban or rural
4	Flasher (stop) controlled
5	Fixed-time controlled signalization
6	Semitraffic-actuated controlled signalization
7	Fully traffic-actuated controlled signalization
8	Green time to cycle length ratio of through approach
9	Green time to cycle length ratio of left-turn phase
10	Grade of approach, %
11	Number of approach lanes
12	Width of approach roadway at the intersection, ft
13	Average speed through intersection for a nondelayed through vehicle, ft/sec
14	Ratio of width of access points to zone of influence length
15	Approach volume per hour, vph
16	Opposing volume per hour, vph
17	Number of left-turning vehicles in approach direction per hour
18	Number of right-turning vehicles in approach direction per hour
19	Number of commercial vehicles in approach direction per hour
20	Number of approaching through vehicles per hour delayed by a left-turning vehicle only
21	Number of approaching through vehicles per hour delayed by a left-turning vehicle and a signal
22	Ratio of approach volume per hour to capacity of approach direction
23	Ratio of opposing volume per hour to capacity of opposing direction
24	Average number of stopped left-turning vehicles in an approach queue per hour
25	Total volume per hour in approach and opposing directions, vph

Suburban Area—The prediction equation explaining the greatest amount of variability in suburban delay time (Y_{DS}) is the following:

$$Y_{DS} = 483.788 - 726.881 X_8 - 33.292 X_{10} - 338.278 X_{11} - 4.157 X_{13} + 4.347 X_{17} - 3.635 X_{19} - 1027.246 X_{22} + 1.984 X_{26} \quad (2)$$

The multiple correlation coefficient is 0.828. The variables explain approximately 69 percent (R^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a suburban intersection approach.

The most significant variable for suburban delay time is the total volume per hour in the approach and opposing direction (X_{26}). Other important variables are the green time to cycle length ratio for the through approach (X_8), the percent grade of the approach (X_{10}), the number of approach lanes (X_{11}), the average speed through the intersection for a nondelayed through vehicle (X_{13}), the number of left-turning vehicles per hour in the approach direction (X_{17}), the number of commercial vehicles per hour in the approach direction (X_{19}), and the ratio of the approach volume per hour to the capacity of the intersection approach (X_{22}).

The simplified prediction equation for suburban delay time is as follows:

$$Y_{DS} = -620.838 + 3.505 X_{17} + 0.886 X_{26} \quad (3)$$

The multiple correlation coefficient is 0.791. The variables explain approximately 63 percent (R^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a suburban intersection approach.

The most significant variable is the total volume per hour in the approach and opposing directions (X_{26}). The other independent variable is the number of left-turning vehicles per hour in the approach direction (X_{17}).

Rural Area—The prediction equation explaining the greatest amount of variability in rural delay time (Y_{DR}) is the following:

$$Y_{DR} = -44.469 + 50.673\,X_{10} - 13.514\,X_{12} + 1.003\,X_{15} + 5.017\,X_{17} - 2.735\,X_{19} + 547.598\,X_{22} + 0.731\,X_{26} \quad (4)$$

The multiple correlation coefficient equals 0.986. The variables explain approximately 97 percent (R^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a rural intersection approach.

The most significant variable for rural delay time is the total volume per hour in the approach and opposing directions (X_{26}). Other important variables are the percent grade of the approach (X_{10}), the width of the approach roadway at the intersection (X_{12}), the approach volume per hour (X_{15}), the number of left-turning vehicles per hour in the approach direction (X_{17}), the number of commerical vehicles per hour in the approach direction (X_{19}), and the ratio of the approach volume per hour to the capacity of the intersection approach (X_{22}).

The simplified prediction equation for rural delay time is as follows:

$$Y_{DR} = -242.880 - 9.119\,X_{19} + 1.669\,X_{26} \quad (5)$$

The multiple correlation coefficient is 0.958. The variables explain approximately 92 percent (R^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a rural intersection approach.

The most significant variable is the total volume per hour in the approach and opposing directions (X_{26}). The other independent variable is the number of commercial vehicles per hour in the approach direction (X_{19}).

During the collection of delay data, notations were made on the recorder chart indicating the number of stopped left-turning vehicles in each queue. It was possible, therefore, to determine an average number of stopped left-turning vehicles in a queue per hour. This average number could then be used to determine the adequate storage length for a proposed median lane.

The required length of the proposed median lane will vary at each intersection approach. The following factors, however, should be considered when determining the length of the proposed storage lane: (a) approach volume, (b) percent left-turning vehicles, (c) average approach speed, and (d) average number of stopped left-turn vehicles in a queue per hour.

Accident Rate

The variables in Table 6 represent the independent variables which were considered in the initial analysis for predicting the variability in accident rates for both suburban and rural areas. The results from this initial regression analysis were examined for significance and duplication, and certain variables deleted. The final accident rate prediction equations were based on the remaining independent variables.

Suburban Area—The prediction equation explaining the greatest amount of variability in the suburban accident rate (Y_{AS}) is the following:

$$Y_{AS} = 1.2411 - 1.0882\,X_7 + 0.0029\,X_{10} + 1.3094\,X_{12} - 0.8496\,X_{13} + 0.0824\,X_{14} - 1.6262\,X_{16} + 0.0443\,X_{17} \quad (6)$$

TABLE 6

INDEPENDENT VARIABLES—SUBURBAN AND RURAL ACCIDENT RATES

Number	Variable
2	Type of area, suburban or rural
3	Flasher (stop) controlled
4	Fixed-time controlled signalization
5	Semitraffic-actuated controlled signalization
6	Fully traffic-actuated controlled signalization
7	Number of approach lanes
8	Width of approach roadway at the intersection, ft
9	Width of opposing roadway at the intersection, ft
10	Approach volume per hour at time the accident occurred, vph
11	Opposing volume per hour at time the accident occurred, vph
12	Weekday approach, ADT, vpd
13	Weekday approach ADT plus weekday opposing ADT, vpd
14	Total intersection weekday ADT, vpd
15	Ratio of approach volume per hour to capacity of approach direction
16	Ratio of opposing volume per hour to capacity of opposing direction
17	Average speed through the intersection for a nondelayed through vehicle, ft/sec

The multiple correlation coefficient is 0.781. The variables explain approximately 61 percent (R^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach.

The most significant variable for suburban accident rate is the weekday approach ADT plus the weekday opposing ADT (X_{13}). Other important variables are the number of approach lanes (X_7), the approach volume per hour at the time the accident occurred (X_{10}), the weekday approach ADT (X_{12}), the total intersection weekday ADT (X_{14}), the ratio of the opposing volume per hour to the capacity of the opposing intersection approach (X_{16}), and the average speed through the intersection for a nondelayed through vehicle (X_{17}).

The simplified prediction equation for the suburban accident rate is as follows:

$$Y_{AS} = 3.6203 - 1.1407\, X_7 + 1.2446\, X_{12} - 0.7723\, X_{13} + 0.0371\, X_{14} \quad (7)$$

The multiple correlation coefficient is 0.743. The variables explain approximately 55 percent (R^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach.

The most significant variable in this simplified prediction equation is the weekday approach ADT plus the weekday opposing ADT (X_{13}). Other independent variables are the number of approach lanes (X_7), the weekday approach ADT (X_{12}), and the total intersection ADT (X_{14}).

Rural Area—The prediction equation explaining the greatest amount of variability in the rural accident rate (Y_{AR}) is the following:

$$Y_{AR} = 0.6411 - 0.2848\, X_7 - 0.0110\, X_8 + 0.0045\, X_{10} - 0.0077\, X_{11} + 0.8690\, X_{13} - 0.6018\, X_{14} - 2.9019\, X_{15} + 6.0704\, X_{16} \quad (8)$$

The multiple correlation coefficient is 0.825. The variables explain approximately 68 percent (R^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a rural intersection approach.

The most significant variable for rural accident rate is the total intersection weekday ADT (X_{14}). Other important variables are the number of approach lanes (X_7), the width of the approach roadway at the intersection (X_8), the approach volume per hour at the time the accident occurred (X_{10}), the opposing volume per hour at the time the accident occurred (X_{11}), the weekday approach ADT plus the weekday opposing ADT (X_{13}), the ratio of the approach volume per hour to the capacity of the approach direction (X_{15}), and the ratio of the opposing volume per hour to the capacity of the opposing direction (X_{16}).

The simplified prediction equation for the rural accident rate is as follows:

$$Y_{AR} = 1.1333 + 0.0015 X_{10} - 0.0497 X_{14} \quad (9)$$

The multiple correlation coefficient is 0.609. The variables explain approximately 37 percent (R^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a rural intersection approach.

The most significant variable for rural accident rate is the total intersection weekday ADT (X_{14}). The other independent variable is the approach volume per hour at the time the accident occurred (X_{10}). This simplified equation, however, does not adequately predict the accident rate at a rural intersection approach as indicated by the low multiple correlation coefficient. As a result the full prediction equation should be used.

APPLICATION OF PREDICTION EQUATIONS

General

The development of prediction equations for estimating the delay time and accident rate due to the absence of a median lane at rural and suburban intersections permits the evaluation of benefits to be expected from construction of such a lane. Application of these equations to evaluation is a simple process.

The application is limited to two extreme conditions under which median lanes might be proposed. It is assumed that a median lane is warranted when the costs of its construction are equal to or less than the economic benefits derived. Benefits are realized by reduced delays to through vehicles and a reduction in the number of accidents attributed to left-turning vehicles. The simplified prediction equations are used to determine such reductions in delay time and accident rates.

The first example considers the case where adequate right-of-way exists on both approaches of a two-lane highway to a signalized intersection in a suburban area. The existing pavement on one or both sides of the highway must be widened for a specified distance on both approaches so that median lanes can be constructed and new through lanes designated.

The second example considers the case where a median strip at least 16 ft wide is located between the major approaches to a signalized intersection of a four-lane divided highway in a suburban area. The left-turn lanes will be constructed within the existing median and no changes to the existing lanes are required.

The basic specifications and construction costs for median lanes were obtained from the Indiana State Highway Commission, Division of Traffic. Several contracts of intersection channelization projects were examined to obtain representative 1965 costs.

The actual cost of delay time was determined for the southbound approach to the intersection of US 52 bypass and SR 26 in Lafayette. The cost of delay for the average vehicle type was calculated to be $2.25 per hour of delay. This cost estimate includes time and fuel costs for deceleration, acceleration, and idling, and a time cost for comfort and convenience. The unit costs and rates used in the determination of the hourly estimate for delay costs are given in Table 7.

Average costs for an accident caused by a left-turning vehicle were determined from the accident report forms collected for the period Jan. 1, 1961 through Aug. 31, 1965. The average cost of each injury in 1965 was set at $1900 (11). The average accident costs, which included both property damage and injury costs, were calculated to be $710 in suburban areas and $1352 in rural areas.

A 6 percent interest rate was used to obtain the annual costs for construction and maintenance of the median lane based on 1965 unit costs.

TABLE 7

1965 UNIT COSTS AND RATES USED TO CALCULATE THE HOURLY DELAY COST[a]

Item	Passenger Vehicles	Commercial Vehicles
1. Fuel, \$/gal	0.32	0.28
2. Idling, gal/min	0.007	0.011
3. Time, \$/hr	1.55	2.80
4. Comfort and convenience, \$/veh-mi	0.01	0.01

[a]These unit costs and rates are average values (3, 8, and 9).

The prediction equation used to estimate the seconds of delay per hour and the number of accidents per million vehicles to through vehicles caused by left-turning vehicles are based on weekday-daylight hours. These predicted delay times and accident rates, therefore, include only 12 hours per day for 260 days of the year. For a second calculation, it was assumed that the delay times and accident rates for the weekend-daylight hours are the same or greater than the delay times and accident rates for the weekday-daylight hours. With this assumption, computations are based on the 12 hours per day for 365 days of the year. In the two examples to follow, annual cost estimates for delay times and accident rates are based on both 260 days and 365 days per year.

It is also assumed that all delays to through vehicles from the left-turn movement and all accidents involving left-turn vehicles will be eliminated by the construction of a median lane. Although this is not completely accurate, it is substantially correct. Furthermore, the prediction equations, by not considering the night hours, give conservative values for both delay and accidents.

Cost estimates for the installation of a median lane are based on construction costs at an existing intersection approach with no additional improvements at that intersection approach. Lower costs would result when additional improvements to an existing intersection are to be made in conjunction with the median lane or when a median lane is to be installed on the intersection approach of a completely new highway.

The two examples on the following pages may not be the best possible solutions to the chosen intersection approaches, and are only illustrative examples for the application of the simplified prediction equations.

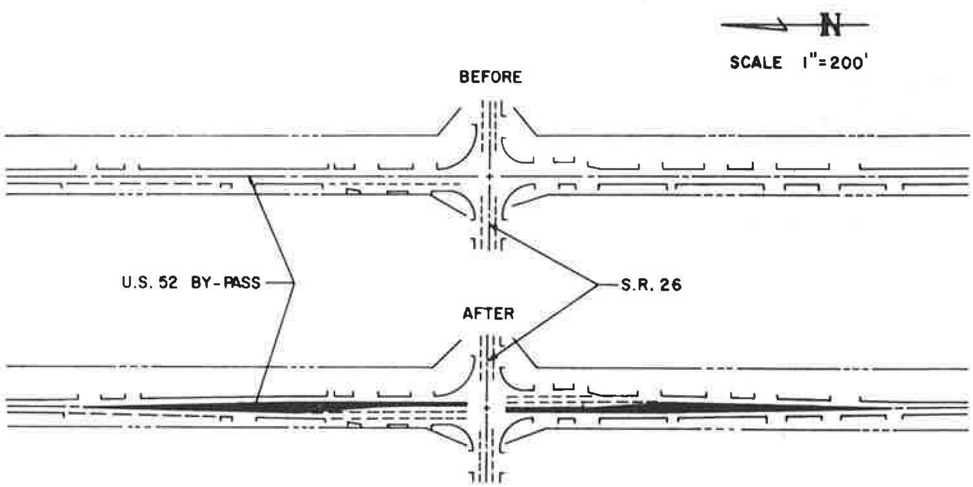

Figure 3. Conditions before and after construction of median lanes at US 52 bypass and SR 26.

Example 1

This example attempts to justify the construction of median lanes on both approaches to the intersection of US 52 bypass and SR 26. The bypass is a two-lane highway in a suburban area with adequate right-of-way for median lane construction on both approaches to the intersection. The conditions before and after construction of the median lanes are shown in Figure 3.

The annual construction, maintenance, and interest costs were determined based on 1965 unit construction costs. No attempt was made to improve the type of signalization nor to include any cost estimate for such improvement.

The number of daylight hours of delay per year attributed to left-turning vehicles was determined from Eq. 3, developed for suburban areas.

Variable	Northbound	Southbound
X_{17}	80	32
X_{26}	1107	1107

An annual increase in traffic of 3 percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding 5 and 10-yr periods.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined from Eq. 7, developed for suburban areas.

Variable	Northbound	Southbound
X_{7}	1	1
X_{12}	8.80	9.20
X_{13}	18.0	18.0
X_{14}	26.3	26.3

TABLE 8

SUMMARY COST ESTIMATES FOR EXAMPLE 1

Description	Costs	Annual Cost in Dollars			
		1965-1969		1965-1974	
		260 (days/yr)	365 (days/yr)	260 (days/yr)	365 (days/yr)
Median lanes:					
Preparation	1,462				
Construction	20,822				
Finishing	100				
Signs and maintaining traffic	3,000				
Total cost	25,984				
Maintenance and miscellaneous (15.0%)	3,898				
Total cost	29,882				
Annual cost at 6.0% interest rate (C + M + I)		6,078	6,078	4,061	4,061
Cost reduction estimates:					
Delay time (C_{DS})		2,450	3,439	2,838	3,984
Accidents (C_{AS})		2,284	3,206	1,894	2,659
Total reduction cost (C_{DS} + C_{AS})		4,734	6,645	4,732	6,643
Difference [(C_{DS} + C_{AS}) - (C + M + I)]		-1,344[a]	+ 567[b]	+ 671	+2,582

[a]A negative difference indicates that the annual cost to install median lanes cannot be justified by the annual savings in delay and accidents to through vehicles.

[b]A positive difference indicates that the annual cost to install median lanes can be justified by the annual savings in delay and accidents to through vehicles.

An annual increase in traffic of 3 percent was also assumed to evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding 5 and 10-yr periods.

A summary of the annual cost estimates determined for median lane construction and the resulting reduction in delay time and number of accidents is given in Table 8. The results indicate that the construction, maintenance, and interest costs for median lanes on both approaches to the intersection of US 52 bypass and SR 26 can be justified over a 5-yr period using 365 days per year.

Example 2

This example attempts to justify the construction of a median lane on the northbound approach to the intersection of US 31 bypass and Lincoln Road. The US 31 bypass is a four-lane divided highway in a suburban area with an existing median 40 ft wide. The southbound approach to the intersection already has a left-turn lane. The conditions before and after construction of the median lane are shown in Figure 4.

The annual construction, maintenance, and interest costs were again determined based on 1965 unit construction costs. No attempt was made to improve the type of signalization nor to include any cost estimate for such improvement.

The number of daylight hours of delay per year attributed to left-turning vehicles was determined from Eq. 3 for suburban areas.

Variable	Northbound
X_{17}	7
X_{26}	890

An annual increase in traffic of 3 percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding 5 and 10-yr periods.

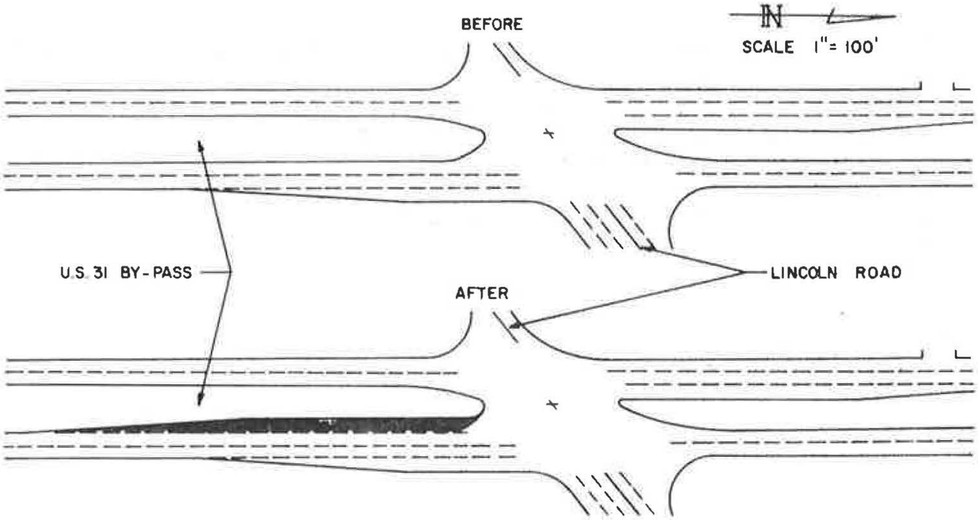

Figure 4. Conditions before and after construction of a median lane at US 31 bypass and Lincoln Road.

TABLE 9

SUMMARY COST ESTIMATES FOR EXAMPLE 2

Description	Costs	Annual Cost in Dollars			
		1965-1969		1965-1974	
		260 (days/yr)	365 (days/yr)	260 (days/yr)	365 (days/yr)
Median lane:					
Preparation	40				
Construction	3,521				
Finishing	200				
Signs and maintaining traffic	1,000				
Total cost	4,761				
Maintenance and miscellaneous (15.0%)	714				
Total cost	5,475				
Annual cost at 6.0% interest rate (C + M + I)		1,114	1,114	744	744
Cost reduction estimates:					
Delay time (C_{DS})		473	664	607	852
Accidents (C_{AS})		814	1,427	717	1,007
Total reduction cost ($C_{DS} + C_{AS}$)		1,287	2,091	1,324	1,859
Difference [($C_{DS} + C_{AS}$) - (C + M + I)]		+ 173[a]	+ 977	+ 580	+1,115

[a]A positive difference indicates that the annual cost to install a median lane can be justified by the annual savings in delay and accidents to through vehicles.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined from Eq. 7 for suburban areas.

Variable	Northbound
X_7	2
X_{12}	9.5
X_{13}	17.4
X_{14}	20.6

An annual increase in traffic of 3 percent was also assumed to evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding 5 and 10-yr periods.

A summary of the annual cost estimates determined for median lane construction and the resulting reduction in delay time and number of accidents is given in Table 9. The results indicate that the construction, maintenance, and interest costs for the median lane on the northbound approach to the intersections of US 31 bypass and Lincoln Road could be justified over both the 5 and the 10-yr periods using either 260 weekdays or 365 days per year.

RESULTS AND FINDINGS

The results and findings of this study are summarized in the following paragraphs.

1. The presence of a median lane substantially reduces the number of accidents and eliminates delay time to through vehicles resulting from left-turning vehicles.

2. A warrant for the construction of a median lane which relates the annual cost for construction and maintenance of a median lane to the total estimated benefits de-

rived from reductions in delay and in accidents for suburban and rural areas is as follows:

$$C_{DS} + C_{AS} \geq C + M + I \quad (10)$$

$$C_{DR} + C_{AR} \geq C + M + I \quad (11)$$

where

C_{DS} and C_{DR} = annual cost reduction estimates for delay time in the suburban and rural areas, respectively,

C_{AS} and C_{AR} = annual cost reduction estimates for accidents in the suburban and rural areas, respectively, and

$C + M + I$ = annual construction, maintenance, and interest costs for the median lane.

3. Equations were developed to predict delay times and accident rates for the weekday-daylight hours for through traffic at suburban and rural intersections that resulted from left-turning vehicles and the absence of median lanes.

4. Using a life of only five years, it was shown that median lanes were warranted at two example intersections. The benefits were found to be such that, when compared with the cost of a median lane, almost every intersection on a divided highway with a median of 16 ft or more and many intersections on other four and two-lane highways possess the warrants for construction of median lanes.

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