Evaluation of Delays and Accidents at Intersections for Median Lane Construction

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INTRODUCTION

The tremendous increase in motor vehicle usage during recent years in Indiana (7)* and in the United States (1) has greatly affected highway operation. This increase in motor vehicle usage has created an added demand on all components of the highway system resulting 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. 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 points of accidents and delay. Delays result when vehicles in different streams wish to pass through these focal points at the same time. Accidents result when drivers make mistakes in judgment of the time and place that 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 (5) as the separation or regulation of conflicting traffic movements into definite paths of travel by the use of 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

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* Numbers in parentheses refer to numbers in the Bibliography.

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 paper is a report on the results of a research project concerned with warrants for such median lanes.

The objective of the research was to evaluate the conditions for which the construction, maintenance, and interest costs for a median lane would be warranted at suburban and rural approaches to an intersection. To achieve this objective, delay times and accident rates to through vehicles caused by left-turning vehicles were analyzed in depth at three right-angle intersections which already possessed median lanes and at eight right-angle intersections which did not have median lanes. By evaluating the benefits from the reduction in delay times and accident rates realized by 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.

THE STUDY LOCATIONS

The eleven intersections used in this study are located within a sixty mile radius of Lafayette-West Lafayette, Indiana (Figure 1). These intersections are located on highways near the cities of Lafayette-West Lafayette, Kokomo, and Indianapolis. The approximate 1965 populations of these urban areas were 65,000, 50,000, and 500,000, respectively. These eleven intersections possessed the following characteristics:

1. Signal or stop controlled,
2. Four approaches,
3. Right-angle,
4. Parking restricted on approaches, and
5. Located in suburban or rural areas.

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 shown in Tables 1 and 2.

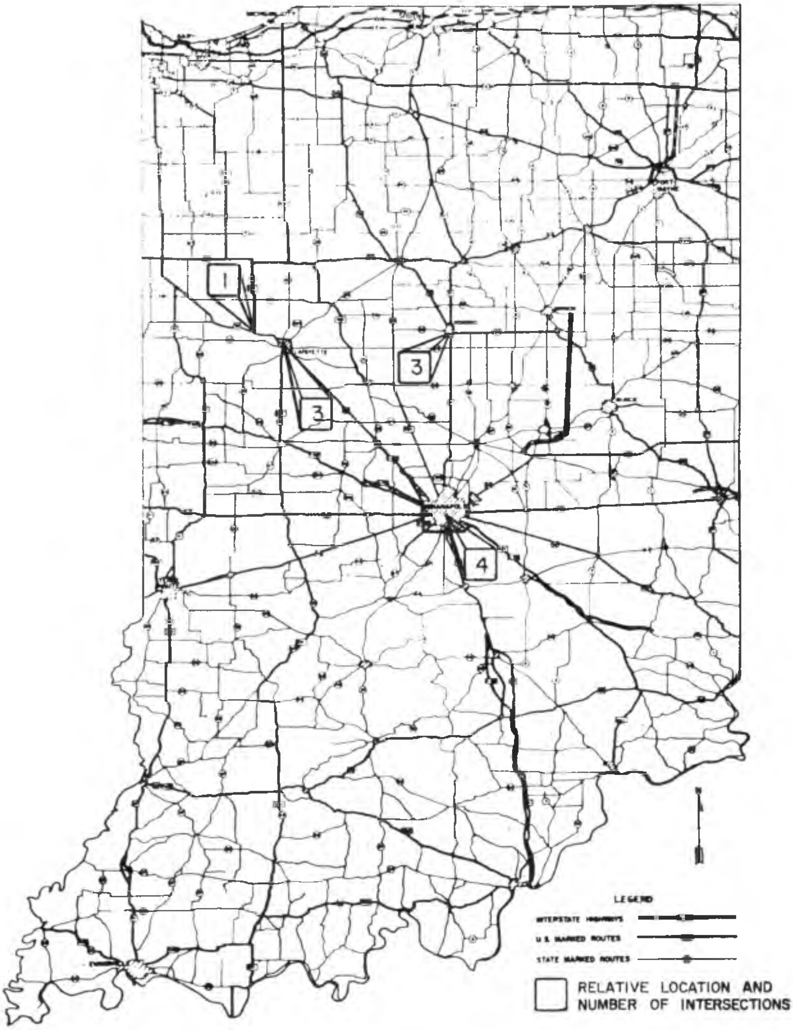

Fig. 1. Map of Indiana with relative locations of study intersections.

STUDY PROCEDURE

Delay Data

The delay time incurred to 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

Table 1. Summary characteristics of study Intersections without median lanes

Intersection	Location	Area Type	Type of Signalization	Weekday Approach * ADT Plus Weekday Opposing ADT
U. S. 52 By-Pass & Union Street	Lafayette	Suburban	Fixed time	17,500
U. S. 52 By-Pass & S. R. 26	Lafayette	Suburban	Fixed time	18,000
U. S. 52 By-Pass & Salisbury Street	Lafayette	Suburban	Semi-traffic actuated	15,800
U. S. 52 & U. S. 23 (S. R. 53)	Lafayette	Rural	Stop-sign controlled (flasher)	7,100
S. R. 100 & 56th Street	Indianapolis	Rural	Fully-traffic actuated	10,500
S. R. 100 & Fall Creek Road	Indianapolis	Rural	Stop-sign controlled (flasher)	7,600
S. R. 100 & U. S. 31	Indianapolis	Suburban	Fully-traffic actuated	12,900
U. S. 35 (S. R. 22) & U. S. 31 By-Pass	Kokomo	Suburban	Fully-traffic actuated	9,500

* Weekday ADT's based on 1965 volume data.

Table 2. Summary characteristics of study intersections with median lanes

Intersection	Location	Area Type	Type of Signalization	Weekday Approach * ADT Plus Weekday Opposing ADT
U. S. 31 & U. S. 35 (S. R. 22)	Kokomo	Suburban	Fully-traffic actuated	22,000
U. S. 31 & S. R. 36	Kokomo	Rural	Fully-traffic actuated	15,100
S. R. 100 & 30th Street	Indianapolis	Suburban	Fully-traffic actuated	27,500

* Weekday ADT's based on 1965 volume data.

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.

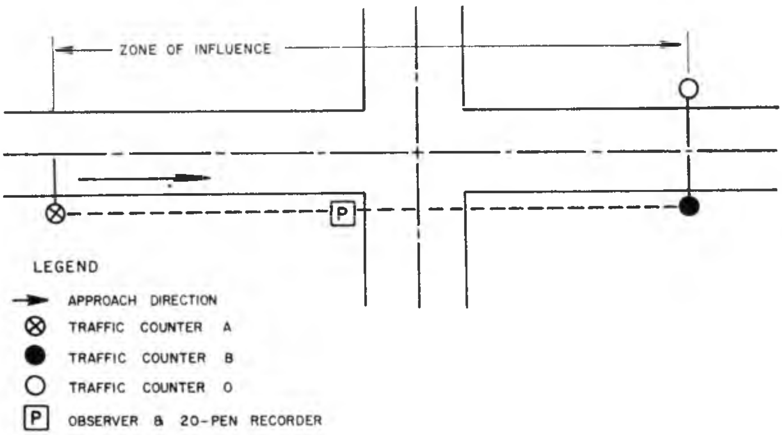

Fig. 2. Typical field setup of equipment to study delay time at an intersection.

The placement of the traffic counters A and B varied in the suburban and rural areas. Traffic counter A was located prior to the point at which an approaching through vehicle was influenced by the presence of the intersection. Traffic 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 between counters A and B was designated as the "zone of influence" and varied from about 800 to 1300 feet.

Approach speed was the determining factor to indicate whether the intersection approach was considered to be located in a suburban or a rural area. Intersection approaches were classified as surburban when the approach speed was greater than 30 miles per hour but less than 45 miles per hour. Rural intersections were those locations where the approach speed was greater than 45 miles per hour. Much greater development of the adjacent land, of course, also existed at the suburban intersections.

It was concluded very early from the field data that the delay time experienced by through vehicles was negligible at the three locations which had median lanes on their approaches. 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 five-year study period was chosen in order that an adequate sample of accidents could be obtained. Accident data were collected for the daylight-weekday hours at the 11 study intersections for the period January 1, 1961 through August 31, 1965.

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 will substantially reduce 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 for this study were the following:

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

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 without median lanes. No accidents involving a fatal injury were included in this analysis because of the rarity of such accidents and the difficulty of establishing an economic benefit.

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). In this study 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 during the hours of study. 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 as indicated in the following paragraph.

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 Highway Commission, and from charts depicting the yearly, monthly, daily, and hourly variations in traffic volume during average conditions in Indiana (11). Therefore, by knowing the location, year, month, day, and hour of an accident, the hourly volume at the time an accident occurred were estimated by applying the appropriate factors to the volume counts taken at each intersection approach.

Capacity

The practical capacity of each intersection was calculated by the method described in the 1965 *Highway Capacity Manual* (4).

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. In order to determine the effectiveness of the paved shoulders in increasing the practical capacities of these six intersections, reference was made to a study (8) 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 a 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 (2). Although 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 total 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" (9).

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 of these tests was to develop simplified equations which would usually and adequately predict delay times and accident rates for both suburban and rural intersections by using a small 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 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 presented in Tables 4 and 6 as the simplified predictions equations for delay time and accident rates, respectively.

Delay Time

The variables listed in Table 3 represent the independent variables that were used in the final analysis to develop separate prediction equations for the suburban and rural areas. The coefficients of the variables used in these multiple linear regression equations are shown in Table 4. These two tables should be used for reference in the following discussion.

Table 3. Independent Variables Used in the Final Multiple Linear Regression Analysis of Delay Time Data for Suburban and Rural Area

Number	Variable Description
8	Green Time to Cycle Length Ratio of Through Approach
10	Grade of Approach, Percent
11	Number of Approach Lanes
12	Width of the Approach Roadway at the Intersection, Feet
13	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second
15	Approach Volume Per Hour, Vehicles Per Hour
16	Opposing Volume Per Hour, Vehicle Per Hour
17	Number of Left-Turning Vehicles in Approach Direction Per Hour
19	Number of Commercial Vehicles in Approach Direction Per Hour
22	Ratio of Approach Volume Per Hour to Capacity of Approach Direction
23	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
26	Total Volume Per Hour in Approach and Opposing Directions, Vehicles Per Hour

Suburban Area

The prediction equation explaining the greatest amount of variability in suburban delay time (Y_{DS}) and developed from the variable coefficients in Table 4 is shown in the following equation:

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

The multiple correlation coefficient equals 0.828. The variables in this equation 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 variable that was the most significant in the multiple linear regression equation for suburban delay time is underlined in Table 4. This variable is the total volume per hour in the approach and opposing

Table 4. Coefficients for Multiple Linear Regression Equations—Delay Time

	Suburban		Rural	
Dependent Variable	Y_{DS}*	Y_{DS}	Y_{DR}*	Y_{DR}
Constant	—620.838	483.788	—242.880	—44.469
X_8		—726.881		
X_{10}		—33.292		50.673
X_{11}		—338.278		
X_{12}				—13.514
X_{13}		—4.157		
X_{15}				1.003
X_{17}	3.505	4.347		5.017
X_{19}		—3.635	—9.119	—2.735
X_{22}		—1027.246		547.598
X_{26}	<u>0.886</u>**	<u>1.984</u>	<u>1.669</u>	<u>0.731</u>
R	0.791	0.828	0.958	0.986

* This equation represents the simplified prediction equation.

** The coefficient underlined represents the variable that is most significant in the regression equation.

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 non-delayed 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:

$$Y_{DS} = -620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

The multiple correlation coefficient equals 0.791. The variables in this simplified equation 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 in this simplified prediction equation 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}) and developed from the variable coefficients in Table 4 is shown in the following equation:

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

The multiple correlation coefficient equals 0.986. The variables in this equation 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 in the multiple linear regression equation 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 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 rural delay time is as follows:

$$Y_{DR} = -242.880 - 9.119\ X_{19} + 1.669\ X_{26}$$

The multiple correlation coefficient equals 0.958. The variables in this simplified equation 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 in this simplified prediction equation 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}).

Accident Rate

The variables listed in Table 5 represent the independent variables that were used in the final analysis to develop separate prediction equations for the suburban and rural areas. The coefficients of the variables used in these multiple linear regression equations are shown in Table 6. These two tables should be used for reference in the following discussion.

Table 5. Independent Variables Used in the Final Multiple Linear Regression Analysis of Accident Rate Data for Suburban and Rural Areas

Number	Variable Description
7	Number of Approach Lanes
8	Width of Approach Roadway at the Intersection, Feet
10	Approach Volume Per Hour at Time the Accident Occurred, Vehicles Per Hour
11	Opposing Volume Per Hour at Time the Accident Occurred, Vehicles Per Hour
12	Weekday Approach ADT, Vehicles Per Day
13	Weekday Approach ADT Plus Weekday Opposing ADT, Vehicles Per Day
14	Total Intersection Weekday ADT, Vehicles Per Day
15	Ratio of Approach Volume Per Hour to Capacity of Appjroach Direction
16	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
17	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second

Table 6. Coefficients for Multiple Linear Regression Equations—Accident Rate

	Suburban		Rural	
Dependent Variable	Y_{AS}*	Y_{AS}	Y_{AR}*	Y_{AR}
Constant	3.6203	1.2411	1.1333	0.6411
X_7	—1.1407	—1.0882		—0.2848
X_8				—0.0110
X_{10}		0.0029	0.0015	0.0045
X_{11}				—0.0077
X_{12}	1.2446	1.3094		
X_{13}	—0.7723**	—0.08496		0.8690
X_{14}	0.0371	0.0824	—0.0497	—0.6018
X_{15}				—2.9019
X_{16}		—1.6262		6.0704
X_{17}		0.0443		
R	0.743	0.781	0.609	0.825

* This equation represents the simplified prediction equation.
** The coefficient underlined represents the variable that is most significant in the regression equation.

Suburban Area

The prediction equation explaining the greatest amount of variability in the suburban accident rate (Y_{AS}) and developed from the variable coefficients in Table 6 is shown in the following equation:

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

The multiple correlation coefficient equals 0.781. The variables in this equation 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 variable that was the most significant in the multiple linear regression equation for suburban accident rate is underlined in Table 6. This variable 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 non-delayed through vehicle (X_{17}).

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

$$Y_{AS} = 3.6203 - 1.1407 X_7 + 1.2446 X_{12} - 0.7723 X_{13} + 0.0371 X_{14}$$

The multiple correlation coefficient equals 0.743. The variables in this simplified equation 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}) and developed from the variable coefficients in Table 6, is shown in the following equation:

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

The multiple correlation coefficient equals 0.825. The variables in this equation 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 in the multiple linear regression equation 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:

$$Y_{AR} = 1.1333 + 0.0015\ X_{10} - 0.0497\ X_{14}$$

The multiple correlation coefficient equals 0.609. The variables in this simplified equation 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 in this simplified prediction equation 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 due to 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 at rural and suburban intersections which is due to the absence of a median lane permits the evaluation of benefits to be expected from construction of such a lane. The application of these equations to such evaluation is a simple process which is outlined in the two examples which follow.

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 construction of such a lane is equal to or less than the economic benefits derived from such construction. Benefits are reduced delays to through vehicles and number of accidents attributed to left-turning vehicles. Use is made of the simplified prediction equations developed in this study to determine such reduction in delay and in accident rates.

The first example considers the case where adequate right-of-way exists on both approaches of a two-lane highway in a suburban area to a signalized intersection. 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 may be constructed and new through lanes designated.

The second example considers the case where a median strip at least 16 feet in width is located between the major approaches to be 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 through 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 in order to obtain the representative 1965 costs presented in each example.

Actual cost of delay was determined for the southbound approach to the intersection of U.S. 52 By-Pass and S.R. 26 in Lafayette, Indiana. 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.

Average costs for an accident caused by left-turning vehicles were determined from the accident report forms collected for the period January 1, 1961 through August 31, 1965. The average cost of each injury in 1965 was set at $1900 (10). 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 six percent interest rate was used to obtain the annual costs for construction and maintenance of the median lane based on 1965 unit costs.

The prediction equations 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 following two examples, annual cost estimates for delay times and accident rates are presented 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, 6 p.m. to 6 a.m., 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 following two examples may not be the best possible solution to the chosen intersection approaches, but are only illustrative examples for the application of the simplified prediction equations developed in this study.

Example—One

This example attempts to justify the construction of median lanes on both approaches to the intersection of U.S. 52 By-Pass and S.R. 26 in Lafayette, Indiana. The U.S. 52 By-Pass is a two-lane highway in a suburban area with adequate right-of-way for median lane construction existing on both approaches to the intersection. The conditions before and after construction of the median lanes are shown in Figure 3.

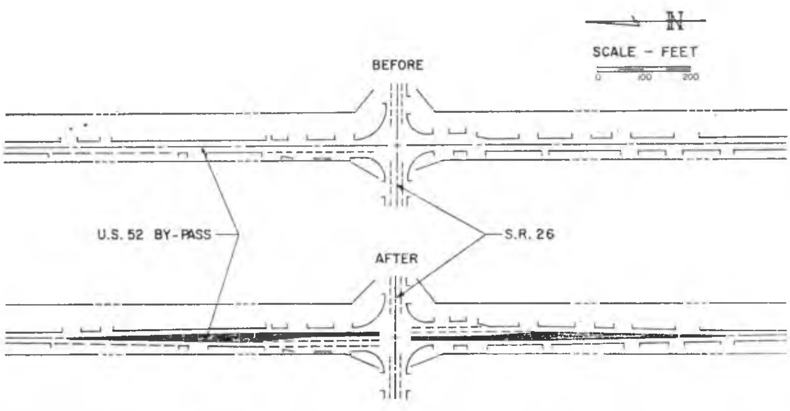

Fig. 3. Conditions before and after construction of median lanes at U.S. 52 By-pass and S.R. 26.

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 based on the simplified prediction equation developed for suburban areas. The equation is stated below with the following 1965 values for the variables:

$$Y_{DS} = -620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

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

An annual increase in traffic of three percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding five and ten year periods.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined based on the simplified prediction equation developed for suburban areas. This equation is stated below with the following 1965 values for the variables:

$$Y_{AS} = 3.6203 - 1.1407\ X_7 + 1.2446\ X_{12} - 0.7723\ X_{13} + 0.0371\ X_{14}$$

	Northbound	Southbound
X_7	1	1
X_{12}	8.80	9.20
X_{13}	18.0	18.0
X_{14}	26.3	26.3

An annual increase in traffic of three percent was also assumed to evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding five and ten year 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 presented in Table 7. The results indicate that the construction, maintenance, and interest costs for median lanes on both approaches to the intersection of U.S. 52 By-Pass and S.R. 26 can be justified over a five-year period using 365 days per year.

Table 7. Summary Cost Estimates for Example—One (U.S. 52 By-Pass and S.R. 26)

	Costs	Annual Cost in Dollars			
		1965-1969		1965-1974	
		260 Days/Yr	365 Days/Yr	260 Days/Yr	365 Days/Yr
I. Median Lanes					
A. Preparation	$ 1,462				
B. Construction	20,822				
C. Finishing	100				
D. Signs and Maintaining Traffic	3,000				
Total Cost	$25,984				
E. Maintenance and Misc. (15.0%)	3,898				
Total Cost	$29,882				
F. Annual Cost @ 6.0% Interest Rate (C + M + I)		6,078	6,078	4,061	4,061
II. Cost Reduction Estimates					
A. Delay Time (C_{DS})		2,450	3,439	2,838	3,984
B. 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*	+ 567**	+ 671	+ 2,582

* 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.

** 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.

Example—Two

This example attempts to justify the construction of a median lane on the northbound approach to the intersection of U.S. 31 By-Pass and Lincoln Road in Kokomo, Indiana. The U.S. 31 By-Pass is a four-lane divided highway in a suburban area with an existing median 40 feet in width. The southbound approach to the intersection already possesses a left-turn lane. The conditions before and after construction of the median lane are shown in Figure 4.

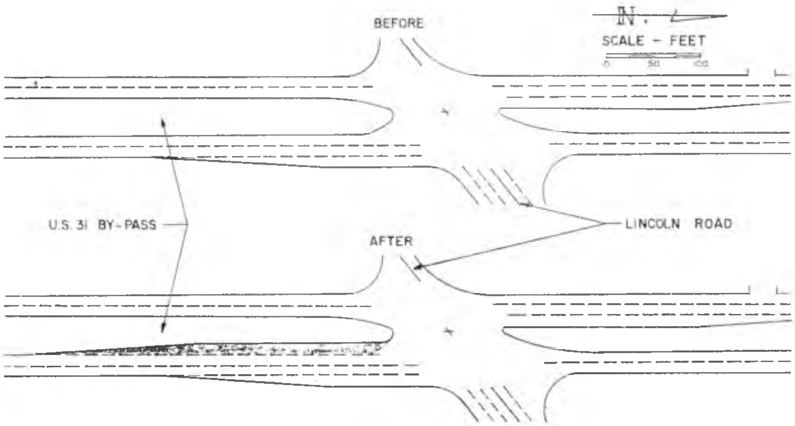

Fig. 4. Conditions before and after construction of a median lane at U.S. 31 By-pass and Lincoln Road.

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 based on the prediction equation developed for suburban areas. The simplified equation is stated below—with the following 1965 values used for the variables:

$$Y_{DS} = -620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

	Northbound
X_{17}	7
X_{26}	890

An annual increase in traffic of three percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding five and ten year periods.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined based on the simplified prediction equation developed for suburban areas. This equation is stated below with the following 1965 values used for the variables:

$$Y_{AS} = 3.6203 - 1.1407\ X_7 + 1.2446\ X_{12} - 0.7723\ X_{13} + 0.0371\ X_{14}$$

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

An annual increase in traffic of three percent was also assumed to evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding five and ten year periods.

A summary of the annual cost estimates determined for median land construction and the resulting reduction in delay time and number of

Table 8. Summary Cost Estimates for Example—Two (U.S. 31 By-Pass and Lincoln Road)

	Costs	Annual Cost in Dollars			
		1965-1969		1965-1974	
		260 Days/Yr	365 Days/Yr	260 Days/Yr	365 Days/Yr
I. Median Lane					
A. Preparation	$ 40				
B. Construction	3,521				
C. Finishing	200				
D. Signs and Maintaining Traffic	1,000				
Total Cost	$4,761				
E. Maintenance and Misc. (15.0%)	714				
Total Cost	$5,475				
F. Annual Cost @ 6.0% Interest Rate (C + M + I)		1,114	1,114	744	744
II. Cost Reduction Estimates					
A. Delay Time (C_{DS})		473	664	607	853
B. Accidents (C_{AS})		814	1,427	717	1,007
Total Reduction Cost ($C_{DS} + C_{AS}$)		1,287	2,091	1,324	1,859
Difference ($C_{DS} + C_{AS}$) —(C + M + I)		+ 173*	+ 977	+ 580	+ 1,115

* 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.

accidents is presented in Table 8. The results indicate that the construction, maintenance, and interest costs for the median lane on the northbound approach to the intersection of U.S. 31 By-Pass and Lincoln Road could be justified over both the five-year and the ten-year periods using either 260 weekdays or 365 days per year.

RESULTS AND FINDINGS

The results and findings of this study, which evaluated the conditions on which the construction of median lanes at intersection approaches in suburban and rural areas would be warranted, 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 derived from a reduction in delay and in accidents for suburban and rural areas is as follows:

$$C_{DS} + C_{AS} \geqslant C + M + I$$
$$C_{DR} + C_{AR} \geqslant C + M + I$$

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

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

$C + M + I$ is the 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, namely (Example—1) at the intersection of U.S. 52 By-Pass and S.R. 26 in Lafayette and (Example—2) at the intersection of U.S. 31 By-Pass and Lincoln Road in Kokomo. 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 sixteen feet or more and many intersections on other four and

two lane highways possess the warrants for construction of median lanes.

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