Wayne State University

COLLEGE OF ENGINEERING

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ASSESSMENT OF THE BENEFITS OF TWO-WAY CENTER LEFT TURN LANES

PHASE I - Report
(Revised)

STATE-OF-THE-ART REPORT

Prepared by

Department of Civil & Environmental Engineering
Wayne State University

Sponsored by

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Transportation Building
425 West Ottawa
Post Office Box 30050
Lansing, Michigan 48909

July, 1994

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16. Abstract

This study contains a review of the state of the art related to "Assessment of the Benefits of Two-way Center Left Turn Lanes" (TWCLTL). A critical review of related published materials and reports have been made and validity of various papers based on credible analytic and empirical approaches have been made. Paramateric summaries have been prepared and included in this report so that the readers can clearly see and understand the usefulness and validity of various published materials.

An experimental plan for Phase II study, for testing the benefits of TWCLTL is included in this report. Use of statistically valid test plan is essential in this very important topics where there are many incorrect and marginally correct papers which have influenced the practice in the past.

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STATE-OF-THE-ART REVIEW

In recent years there have been steadily growing traffic volumes on urban and suburban arterials, primarily due to the growth in population and lack of capacity in the existing freeway system. The development of localized shopping centers and other strip commercial and office developments along arterial roadways have created an increased demand for mid-block access. Demand for turning in and out of these roadside strip developments often causes both operational and accident problems.

Most of these problems are associated with the turning movements to and from the arterials. The left turning maneuvers, particularly, affect the traffic flow in that, the left turning traffic has to wait to get an acceptable gap in the oncoming through traffic before making the movement, and if the driver judgment is faulty in the assessment of the length of available gaps, it may result in severe traffic conflicts and some times accidents.

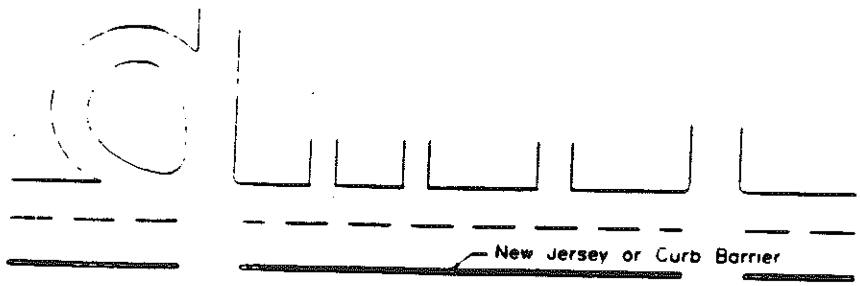
Literature on past research reveals that there have been many attempts to remedy this problem. Based on the documentation available,(15,16,25) the left turn treatments have been broadly classified into two groups.

1. Indirect Left Turn Treatments,
2. Direct Left Turn Treatments.

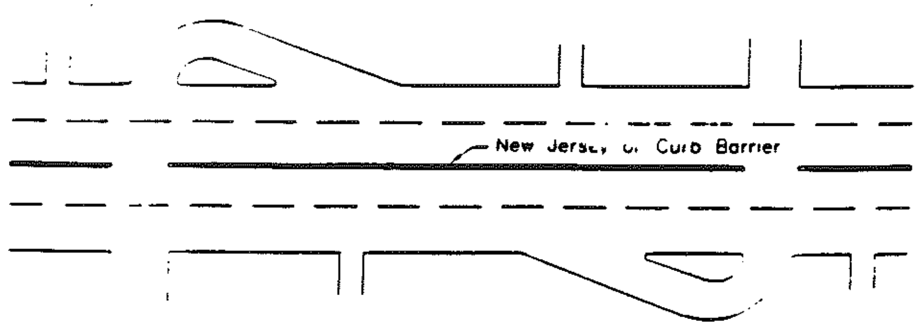
The direct left turn treatments permit left turning vehicles to make left turn maneuvers directly over the median (flush cross section), while indirect left turn treatments have a non traversable median and require the left turning vehicles to use special treatments, like a clover leaf or a jug handle ramp, to make a left turn. Treatments which allow left turns, only before and after major intersections (e.g., turn- around on boulevard type roadways), are also quite common in many states, including Michigan.

Indirect Left Turn Treatments

These treatments offer no direct left turn access. Left turn movements occur by the use of indirect left turn ramps such as the ones shown in Figure 1. The clover leaf and the jug handle are some of the most popular left turn ramps used. This type of treatment often uses the New Jersey type barrier in the median to eliminate all 'U' turns and direct left turns on the highway. This helps in reducing the number of conflicts, sideswipe and rear end accidents due to the elimination of direct left turns. The only drawback in this method is, that due to the existence of a median barrier the use of a median lane is eliminated, and an additional right of way is required to install the left turn ramps, similar to the jug handle or the clover leaf ramps. From the literature referred to previously, it was found that these types of indirect left turn treatments are used in the states of Missouri(15) and Kansas(15). The clover leaf type of treatment is quite popular in the state of New Jersey.



(a) Median Barrier with Clover Leaf Type Ramp



(b) Median Barrier with Jug Handle Type Ramp

Figure 1 Indirect Left-Turn Lane Treatments

Direct Left Turn Treatments

There are four median treatments in this category. They are as follows and as shown in Figure 2 :

1. Left Turn Storage Lane.
2. Alternating Left Turn Median Lane.
3. Continuous Left Turn Lanes.
4. Two-Way Left Turn Median Lanes.

LEFT TURN STORAGE LANE (RAISED OR FLUSH MEDIAN)

This type of left turn treatment restricts the movement of traffic over the median, either by means of a raised median, or by means of a flushed cross section with appropriate pavement markings. The crossings are limited to the openings selected by the designer. This promotes safety by discouraging left turns and U turns except at a few designated locations. The storage lanes further act to 'store' the left turning vehicles, such that through traffic is not affected to the extent possible. If, however, the left turn slot (storage lane) is insufficient in length, it may cause queue spill over to the through traffic lane. This type of treatment has been found to be used in the following states : Texas (13), Kansas (15), Indiana (24), Missouri (15), California (16), Tennessee (3), Georgia (5), Ohio (8), Washington (25) and Colorado (44). The State of Michigan also uses such treatment for its arterials. Though both the flush and the raised median are in use, the raised median with crossovers has been found to be more popular in Michigan.

Shaw and Michael (25) studied this type of left turn treatment and collected the delay and accident rate data at 11 intersections and used the multiple regression technique to develop a number of equations that would estimate the benefits derived from reductions in delay and accidents in terms of several operational variables. The authors also found that the presence of such a median lane substantially reduces accidents and eliminates delay time to through vehicles resulting from left turning vehicles. Walton and others (13) did a study to compare the left turn storage lane with the two-way left turn median lane using regression analysis, and recommended that the raised and flush one way median left turn lane was more effective at major intersections that experience high left

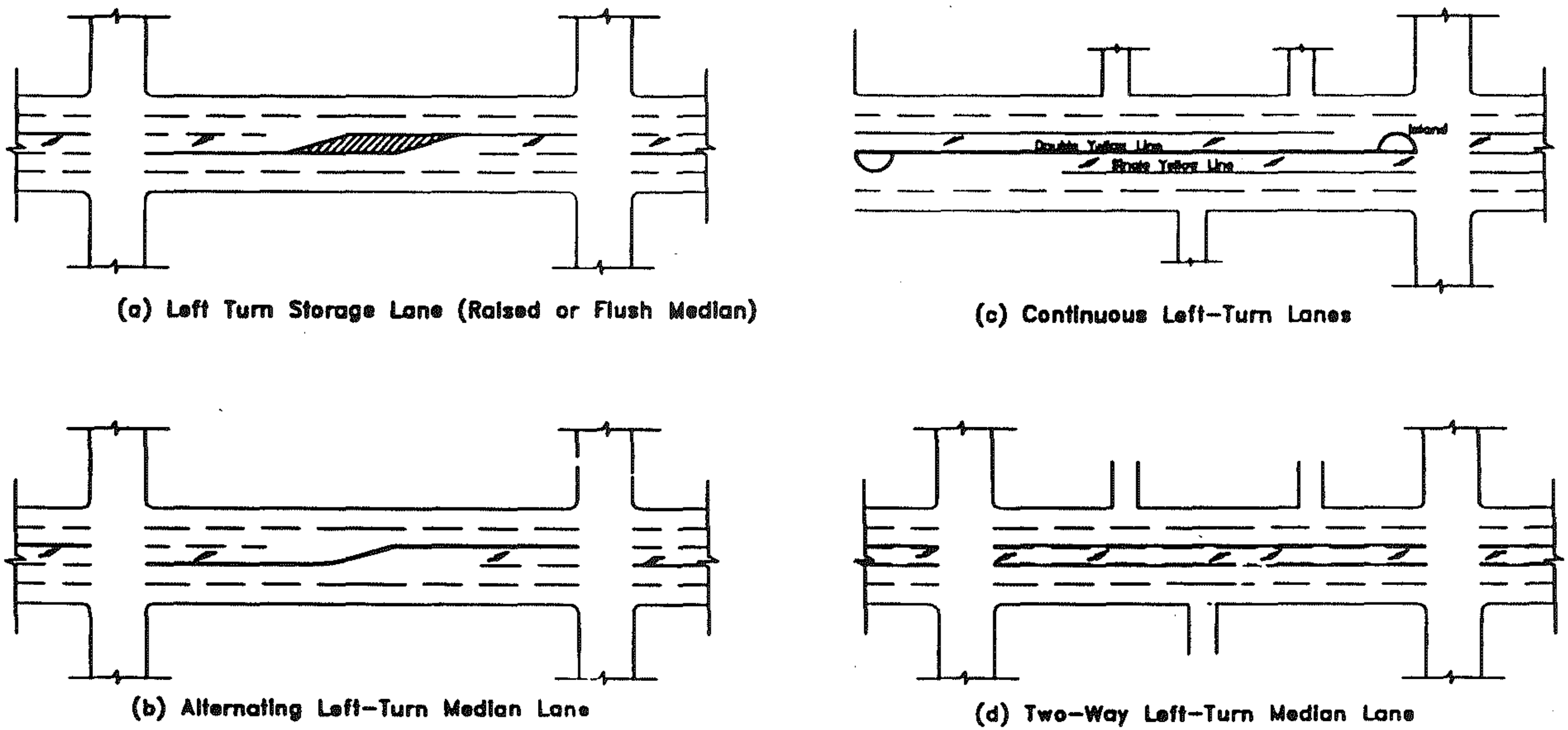


Figure 2 Direct Left-Turn Treatments

Source : Harwood and Glennon(15), Sawhill and Neuzil(25) turn demand and lesser driveway left turn demand. Most of the studies indicated that this type of treatment is desirable when there is a high through traffic volume, high speeds (greater than 45 mph), high pedestrian volumes and when access points are limited to major intersections. The installation of a raised median is the best available technique to preserve the through traffic movement function on a suburban arterial, although this is accomplished at the expense of the land access function (16). It is most suited to serve suburban highways with isolated major traffic generators, which have widely spaced high volume driveways.

Although the raised or flush median left turn lane reduces potential traffic accidents and delays, it tends to increase travel time for drivers who wish to turn left, as compared to the situation where median openings are continuous. Also operational flexibility is reduced, such as, allowing operation of emergency vehicles and work zones with lane closures, and discourages new strip development.

McCoy and Malone (4) analyzed accident experience on signalized and unsignalized intersections with and without left turn lanes. The degree to which the left turn lanes reduced accidents was computed and the statistical significance of the percentage reduction was determined using the chi-squared test. Left turn lanes at signalized intersections were found to significantly reduce rear-end, side swipe and head on left turn accidents. However, at uncontrolled approaches, the left turn lanes were found to increase substantially the right angle accidents. So a trade-off analysis has been suggested by the authors, between accident reductions and increase in right angle accidents, while considering the installation of a left turn storage lane at an uncontrolled intersection.

M. D. Harmelink (45) conducted a study on left turn storage lanes at unsignalized intersections. In this study, volume warrants were developed to determine the need of left turn storage lanes, and if needed, the length of the storage lanes required for various combinations of approach volumes, opposing volumes and left turn demand. This study was done using queuing theory. It was assumed that the arrivals of left turning vehicles follow poisson distribution and both arrival and service time distributions are negative exponential. Different parameters like critical gap, average time required for making a left turn, and average time required for a left turning vehicle to clear itself from the through lanes were derived from field studies (mentioned in the paper).

Theoretical arrival rates and observed arrival rates (as stated in the paper) agreed with each other. The results were not tested for statistical significance. Curves were developed to determine the volume warrants for left turn storage, at different operating speeds, and percentage of left turning volumes using queuing theory. No validation of results was performed in this study.

Timothy R. Neuman (46) presented warrants and guidelines for the design of left turn treatments. This report (NCHRP-279) uses the curves developed by M. D. Harmelink (45) to determine the need for left turn lane provision. Elements which determine the lengths and widths of left turn lanes were also given. This report (46) is a review of the state-of-the-art and included a survey of various road agencies. However, no real world validation was used.

ALTERNATING LEFT TURN MEDIAN LANE

This treatment is similar to the flush one way left turn median lane, the difference being that, there are openings to traffic in opposing directions at regular intervals. This allows for one traffic direction to make left turns over the median into the driveways and after a specified distance, the left turn lane is open to the opposing direction of traffic. Thus, for a limited section of highway, both directions have a unique left turn lane available for continuous left turn maneuvers. This type of left turn treatment has been in use in the states of Kansas and Missouri (15).

Harwood and Glennon (15) stated that by implementing this alternating left turn median lane design, a reduction in frequency and severity of accidents will result. Accident frequency and delays are reduced by removing the stopped or slow moving vehicle queues from the through lanes, and accident severity is reduced by allowing through vehicles additional perception time to avoid left turn crossing conflicts.

Since only one lane is used in the median for left-turn movements, the width of the median should be as wide as the turning lane itself. Hence, this treatment requires only a 12 foot median. The other treatments require 14 to 24 foot medians for left turn movements (15). This design may be implemented on narrow median arterials, where pavement widening, or right of way acquisition, is difficult.

CONTINUOUS LEFT TURN LANES

This is a treatment which provides one continuous turning lane in each direction. The Figure 2(c) shows the continuous turning lanes . Each of the left turn lanes are continuous, except that at one end a channelizing island is placed to prevent through movements at signalized intersections. Accident frequency is reduced by eliminating stopped or slow moving vehicles from the through lanes, since the left turning vehicles can be stored in the continuous left turn lanes, until an acceptable gap in the opposing traffic appears. This also improves the operational characteristics by reducing delay. Literature indicates that this type of left turn treatment is used in the states of Colorado (44), and Missouri (15).

Continuous left turn lanes require a 24 foot wide median, which will accommodate two 12 foot turning lanes (15). This is one of the main disadvantages of this treatment, since it requires an additional lane, and also additional right-of-way. Since the turning lanes are continuous, this treatment is best suited when applied over sections at least 0.25 miles in length.

TWO-WAY CENTER LEFT-TURN LANE

The Two-Way Center Left-Turn Lane (TWCLTL) has a continuous median lane dedicated to left turn movements by both directions of traffic. This offers an area for deceleration and stopping before making a left turn. The secondary functions of the TWCLTL are separation of opposing traffic flows, an acceleration lane for vehicles turning left onto the arterial, a pedestrian refuge, and an emergency lane for breakdowns or for use by emergency vehicles[1] . The use of the TWCLTL has been reported in most of the states in the country, and the MUTCD describes the standard delineation methods for the same. The papers reviewed, as a part of this study, indicate the use of this treatment in at least the following states: Georgia (5), Tennessee (2), Texas (13), Kansas (15), Indiana (24), Washington (25), Ohio (14), Illinois (8), Missouri (15) and Nebraska

[1] Shaw and Micheal (24)

(6). Some illustrations in the papers indicate that the pavement markings, and other delineation methods used in different states, are some times different. Michigan also uses the TWCLTL and this is mentioned in the NCHRP report 282 (16). It is also observed that the delineation methods used by Michigan is similar to that of most of the states, except Indiana and Washington.

Warrants for use of a TWCLTL presented by Harwood and Glennon (15) include an average daily traffic of 10,000 to 20,000 on roadways with four through lanes, 5,000 to 12,000 on roadways with two through lanes, through traffic speeds of 30 to 50 mph, width of TWCLTL of 10 to 15 feet , driveway density more than 60 per mile (commercial land use) and left turn maneuvers totalling at least 20 percent of the through lane traffic volume (15). These warrants presented by Harwood and Glennon (15) have not been substantiated by any sort of validation. Their report refers to some previous studies that might have led to these warrants. Hence, it is felt that, though the warrants present a logical scenario, it cannot be accepted without ascertaining how they were derived or validating them with an empirical study.

Neuman (46) had also given some warrants using average daily traffic, turning volumes and minimum length. The critical variables that indicate the need for TWCLTL are mid block accident history involving left turning vehicles, closely spaced driveways and strip commercial or multiple unit residential landuse along the corridor. The lane widths needed for TWCLTL, depending on prevailing speed and lane use/vehicle type, are developed.

Operational Analysis on TWCLTL

Sawhill and Neuzil (25) made an operational study in 1963, in terms of :

a) Travel distance within a TWCLTL prior to a left turn maneuver during rush and non-rush hours.

b) General observations and commentary on the users' behavior.

c) Use of vehicle turn indicators prior to left turn maneuvers.

The findings include:

1. Drivers decelerate or stop within a TWCLTL before a left turn maneuver, both at rush and non-rush hours.
2. 17% of out-of-town motorists made their left turns from the through lane,
3. Average travel distance on the TWCLTL, for a local driver was 200 feet and for an out-of-town driver was 140 feet, the distance being longer during rush hours.
4. Automobiles entering the TWCLTL made little use of it as an acceleration lane.
5. Approximately 80% of the drivers use their left turn indicator signal when entering the driveway,and 40% when getting onto the roadway from the driveway.
6. Few drivers used the TWCLTL as a passing lane[2] .

This study being one of the premier efforts in the area of operational characteristics, brings out several important aspects of TWCLTL.

Nemeth (14) conducted before and after studies on three TWCLTL sections in Ohio. The major operational variable investigated in this study was travel time. The sites included one arterial that was converted from a four lane roadway to a three lane roadway with TWCLTL, and one that was converted from a four lane to a five lane highway. The field tests conducted in this study included:

- Characteristics of the site: Length, width, volume, speeds and landuse.
- Reconstruction: The improvements effected with the inclusion of the center lane.
- Effect on flow: Running speeds and directional volumes with respect to, before installation, after installation, and six months after installation.
- Effect on safety: Number of braking and weaving conflicts, before installation, after installation, and six months after installation.

In two of the sites it was observed that there was no significant improvement in travel time, but in the third case there was substantial improvement in the travel time. Also there was an increase in volume, decrease in number of brakings, and reduction in delay. Nemeth (14) concluded that there was a measurable improvement in traffic flow and

[2] Sawhill and Neuzil (25)

safety by introduction of the TWCLTL. He also presented an implementation guide for use of the center lane for left turning. These guide lines give a step-by-step approach, but elude various characteristics that must be considered in establishing a center lane for left turning. It also does not give any reduction factors for operational characteristics.

McCoy and others (6,7,9,10) used computer simulation models using the General Purpose Simulation System (GPSS/H) language to simulate traffic flows for their studies. Given the volume, average speed of traffic, and the percentage of left turn traffic, the model simulates the traffic flow with and without TWCLTLs. The flow was determined using a probability based model. The outputs were the number of vehicles entering and exiting the segment, the number of left turns attempted and completed, the number of stops, travel time in segment, and stopped time delay. Comparisons of the outputs, with and without TWCLTL, revealed that installation of TWCLTL improves efficiency of traffic operations over a wide range of traffic volumes, left turn volumes and driveway densities, for two lane and four lane highways.

Walton et. al., (13) performed an operational study with commonly found different operational situations like short blocks, offset driveways etc. The study was done for twenty sites in Texas and the methodology adopted was comparison and individual case studies. The data collected for the study was, driveway spacing, maneuvering distance, lateral placement, traffic volume, and conflicts. This study used the analysis of variance technique to ascertain the significant effect of different lane widths and delineation systems . The operational analysis yielded the optimum measure for different parameters like lane width and driveway spacing. The authors concluded that TWCLTLs are an effective and efficient means of providing an enhanced level of service on many urban arterials.

Nemeth et. al., (10) made an operational study on TWCLTLs to evaluate potential fuel savings generated by TWCLTL through reduced stops and delays. The simulation model developed by McCoy, et. al.(6), was used to determine the reduction in stops and delays and these were converted to fuel savings . The study indicated that the annual reduction in fuel consumption was significant with the introduction of TWCLTL.

Accident Analyses on TWCLTLs

Walton and others (13) developed accident rates on TWCLTL in terms of variables like population, number of driveways per mile and number of signals per mile. Analysis was done by using standard regression technique to provide insight into the characteristics of sites, and to describe existing field applications of various left turn lane types. Equations were developed for the rate of accidents as dependent variables, for which the following procedure was adopted. Sections were formed combining the mid block and intersection data in a manner that provided as much homogeneity as possible for lane markings, parking, lane widths etc. at each site. Sections were analyzed both with and without, intersection accidents. Since raised median sections were too few for an adequate regression analysis, the analysis was done for the TWCLTL sections. Forty six equations were developed and checks for regression assumptions were made through examination of plots of residual versus independent and dependent variables, to identify inadequacies of the models and to provide clues for possible variable transformations that might improve the equations. The dependent variables were total number of accidents and total number of accidents per million vehicles. Further, the left turn accidents were observed as dependent variables. Among the independent variables the most important ones considered were weekday ADT, number of signals, number of driveways, city size; and the remaining variables considered were vehicle miles of travel, percentage of commercial land use and curbside parking.

The equation for predicting accident rate is:

Number of	=	- 43.5 + 0,00203(ADT) + 0.000175 (city population)
Accidents per		+ 0.491 (number of driveways per mile)
Mile		+ 9.20 (number of signals per mile)

The standard error for residuals is approximately 3.3 accidents/mile, the $F_{reg} = 34$ and R^2 was approximately 0.75.

The accident analyses indicated that the raised median sites have a greater proportion of accidents than the TWCLTL sites and that the best dependent variable for estimation purposes was, accidents per mile. Their analysis does not incorporate speed, which in most cases is a very important variable to be considered.

Thakkar (8) studied the effects of TWCLTL on traffic accidents. A two year before and after comparison was performed and statistical tests were used to determine significance of difference in the accident rates and their severity. Statistically significant reductions were observed in accident rates and severity on two lane and four lane urban roadways, along which commercial development had taken place during the after condition.

The evaluation procedure included a selection of sites based on a set of criteria viz., minimum change in traffic volume and traffic control, no major reconstruction during the study period, and a minimum of 0.25 mile length of study section. Thirty one sections were studied, fifteen being five lane and sixteen being three lane (selected from a total of one hundred and two five and three lane streets). Data collected was basically accident and traffic volume data (presented in the form of tables for different periods). Total accidents, by severity and the affected accident rates, as well as total severity rates and affected severity rates, were tabulated. For purposes of this study the different severity rates were calculated by the following expressions:

Accident Rate = (Number of accidents x 10^8) / [(ADT x Length) x 365]

Accident Severity Frequency = Personal injury accidents + Fatal accidents

Severity Rate = [(Fatal + injury accidents) x 10^8] / [(ADT x Length) x 365]

The measures of effectiveness (MOE) used for the study were :

1. Total accidents
2. Total accident rates
3. Frequency of injury and fatal accidents
4. Severity rates
5. Total affected accidents (left turn, rear end, and side swipe)
6. Total affected accidents
7. Total affected fatal and injury accidents
8. Total affected severity rates

The expected result was a reduction in the MOE variables.

The statistical tests used were : the Wilcoxon matched pair signed-rank test (based on work by Seigel) and the paired t-test (based on work by Haber and Runyon) were used to determine the significance of change in MOEs. In addition, the unaffected accidents were also tested. All tests were one tailed with a confidence interval of 95%.

The conclusions of the study include significant reduction in total accidents, total accident rates and accident severity for five lane and three lane sections after the installation of the TWCLTL. The TWCLTL was also found to be cost effective and recommended for implementation at two and four lane urban roads from safety and economic points of view. The following table presented the reduction in accidents.

	Five Lanes				Three Lanes			
Type	Before	After	Percent Reduction	t	Before	After	Percent Reduction	t
Left turn	275	185	32.7	1.77 (Left turn and Rear-end)	55	53	3.6	1.28 (Left turn and Rear-end)
Rear-end	352	227	35.5		133	59	55.6	
Sideswipe (same direction)	181	134	26.0	1.95	15	9	40.0	0.91
Sideswipe (opposite direction)	16	12	25.0	0.77	18	9	50.0	1.73

Note: Some of the rear-end accidents might have occurred as a result of left-turn movement by some vehicles. Therefore, the left-turn and rear-end accidents should be considered together. Thus the reduction in left-turn and rear-end accidents (combined) was 34.3 percent for five-lane and 40.4 percent for three-lane sections.

Source: Table 5; J. Thakkar (8).

Table 1 Accident Reduction by Type

Sawhill and Neuzil (25) studied accidents four years before and four years after the installation of TWCLTL on an arterial roadway. The major purpose of this was to study and compare the number, types and severity of accidents occurring on sections of arterial streets before and after installation of TWCLTL.

The site selection criteria were

1. Minimum change in traffic volume, traffic control, or adjacent land use in the past.
2. Accident data available for the past several years.

3. The TWCLTL should be of sufficient length.

Based on the above criteria, two sites for detailed accident analysis and a third site for a study involving TWCLTL related accidents only were selected. They presented the accident rates in terms of tables and graphs which reflected a modest increase in the accident rate in the first year after installation of a TWCLTL, and then a sharp drop in the accident rate for the next three years. They also reported that head on collisions within the TWCLTL were almost nil.

The conclusion of the study was that installation of TWCLTL was responsible for about 75% of the reduction in accidents after the one year after installation period. Estimates of cost of property damage accidents on a roadway without TWCLTL were 30% higher than those with TWCLTL.

Nemeth (14) conducted a study to investigate the effect of TWCLTL on accident characteristics. The study incorporated the number of braking and weaving conflicts, before and after installation of TWCLTL, as a surrogate for accidents. Six months before and six months after installation was the study period. The results show that at two of the sites, the decrease in the number of brakings and weavings was not statistically significant, but in the case of the last site, there was significant reduction in the number of brakings and weavings. The following table presents the results of the study:

	Site 2 OH-264		Site 3 US-42	
Period	Number brakings	Number weaving	Number brakings	Number weaving
Before Installation	575	589	1327	245
After Installation	685	530	567	22
6 months after installation	485	565	833	48

Source : Nemeth (14)

Table 2 Braking and Weaving Conflicts

Greiwe (42) reported results of a before and after study related to providing left turn storage lanes. This study concluded that split phasing techniques and storage lanes indicated a 78% reduction in left turn accidents at signalized intersections. He also concluded that the addition of left turn lanes at intersections showed a 67% reduction in total accidents. Craus and Mahalel (43) developed a simulation model to study safety and operational characteristics of providing left turn lanes at intersections.

Thomas (44) performed a study some three decades ago in Colorado to test the effectiveness of providing a left turn lane at intersections.

Comparison of TWCLTL and Left Turn Storage Lanes

Venigalla and others (3) did operational evaluations of TWCLTL and left turn storage lanes (non traversable median). One half mile of an arterial roadway was studied using the TRAF-NETSIM package for a number of scenarios with varying driveway densities and traffic volumes on the arterial. The TRAF-NETSIM is a stochastic simulation modeling package which can replicate traffic operations for roadway segment or network. The outputs were measured for the TWCLTLs and non-traversable medians. The dependent variables were total delay, delay to left turning traffic and delay to through traffic. They found that the average delay for the non traversable median design was higher than those on the TWCLTLs at all levels of driveway densities and traffic volumes. The difference was not very significant at lower levels of driveway densities and through traffic, but at higher levels, the difference was found to be significant.

Driveway Density (Driveways/mile)	Volume vph	Difference in delay	Difference in fuel consumption
Low (32 Driveways/mile)	600	N. S.	0.7848
	900	0.0375	0.5768
	1200	0.1275	0.9116
Medium (64 Driveways/mile)	600	0.0300	1.7615
	900	0.1300	1.7035
	1200	0.2675	2.4538

Note : These reductions would be attained if a TWCLTL is used instead of a raised median.
Source : Table 4 & 5; Venigalla, et. al., (3).

Table 3 Estimated Reduction in Total Delay and Fuel Consumption for TWCLTL over Raised Median Type Treatment.

Squires and Parsonson (5) performed a comparison of the accidents on raised median and TWCLTL. Accident data for three years was collected and regression equations were developed. Accidents on raised median and TWCLTL sections were compared. The comparison was done for sites that were similar with respect to traffic volume, access and number of lanes. Accidents per million vehicle miles and accidents per mile per year were computed for comparisons. The study revealed that the raised medians were safer than the TWCLTLs for most conditions. This may be due to the higher range of ADTs used. With higher volumes of opposing traffic, left turn movements seem to be safer at concentrated points, such as those provided by raised medians. They concluded that four lane and six lane highways with raised medians were safer than TWCLTLs, except where the driveway density is high (75 per mile), low number of signals per mile (two or fewer) and low number of approaches per mile (5 to 6). A summary of accident data presented has been reproduced here:

	Total Accidents			Midblock Accidents		
	TWCLTL	RM	% Diff	TWCLTL	RM	% Diff.
Accidents/ MVM						
4 Lane Sections	8.99	7.67	-14.7%	3.5	1.34	-61.7%
6 Lane Sections	10.82	8.15	-24.7%	4.19	1.92	-54.2%
Accidents/ Mi. /Yr.						
4 Lane Sections	99.45	70.91	-28.7%	38.78	12.39	-68.1%
6 Lane Sections	130.26	94.07	-27.8%	50.46	22.13	-56.1%

RM = Raised Median

All Values for maximum ADT of 50,000 ; and maximum drives/Mi. of 140;

Source : Table 2 and 3; Squires and Parsonson (5)

Table 4 Summary of Accident Data

Walton and others (13) presented a comparison and compilation of trade-offs between raised left turn storage lanes, flush left turn storage lanes and TWCLTL. An accident study and an operational study was done on the above sections. Regression analysis was used for accident analysis. Comparison and individual case studies for operational characteristics were used in this study. The independent variables selected for the regression analysis were weekday ADT, number of signals, number of driveways, city size and land use. The dependent variables were number of accidents per mile and number of accidents per million vehicle miles of travel. Operational analysis was done using the five most commonly used operational characteristics. The data requirements here were entrance distance, maneuvering distance, lateral placement, traffic volume and conflicts. The accident analysis results show that the raised storage left turn lane had more intersection and intersection related accidents than TWCLTL, while the TWCLTL had a higher percentage of non-intersection and driveway related accidents. The conclusions derived from the analyses were that TWCLTL's are effective means of providing an enhanced level of service whereas raised and flush left turn storage lanes are more effective at major intersections. In addition, TWCLTL is claimed to have better flexibility.

The NCHRP report by Harwood (16) lists the advantages and disadvantages of the two left turn treatments. The advantages of the raised or flush median left turn treatments are that, it reduces rear end and angle accidents associated with left turn maneuvers, provides physical separation between opposing traffic directions, discourages strip development, preserves the traffic movement function of the roadway, and provides a median refuge area for pedestrians. The disadvantages include, pavement and right of way requirements, increased delay to left turning vehicles, indirect routing required for trucks (U turns are not as easy as those for passenger cars), and lack of operational flexibility due to fixed median. The advantages of the TWCLTL are reduction in delay to through vehicles, reduction in frequency of rear end and angle accidents, operational flexibility due to separation between opposing lanes. Two other related problems are the inappropriate use of the TWCLTL by drivers and potential conflicts, between turning vehicles, which may occur at driveways located close to a major intersection. The report also states that the TWCLTL alternative has the lowest traffic conflict rate of all other median left turn lane treatments considered.

Mukherjee et. al. (1), conducted a questionnaire survey in order to find out the decision making process of highway Design Engineers of various State Departments of Transportations in selecting medians and TWCLTLs. The questionnaire had fourteen states responses and three case studies. The case studies' data was fed into different models and the results were derived. After going through the results of the survey and the results of the models, the authors reported that the different models gave conflicting results. The Highway Engineers differ in the criteria of use of TWCLTLs and medians, and the choice between a median treatment and a TWCLTL involves trade offs among safety, delay and land development considerations. The authors also stated that in each individual case, these trade offs should be identified clearly before a choice is made.

Harwood and Glennon (15), presented a selection guide for determining the operational median treatments for arterial roadways and for performing a benefit cost analysis on five different median treatment techniques. They are TWCLTLs, Continuous Left-turn lanes, Alternate Left-turn lanes, Raised Medians, and Median Barriers. The benefits considered were accident reduction and delay reduction. The costs were the cost of construction of the treatments. Three construction options were studied and they are:

Option 1: The existing roadway is wide enough to permit the installation of the median treatment without additional widening.

Option 2: Pavement widening is necessary but no additional right of way is required.

Option 3: Both pavement widening and right of way acquisition are necessary.

The estimated construction costs for each treatment and construction options were as follows:

	Per mile cost for		
Types of Median Treatments	Option 1	Option 2	Option 3
Two Way Center Left Turn Lane	$ 8,200	$ 280,200	$ 501,000
Continuous Left Turn Lane	$ 12,800	$ 403,200	$ 783,600
Alternating Left Turn Lane	$ 10,200	$ 282,200	$ 503,000
Raised Median Divider	$ 97,600	$ 369,600	$ 590,400
Median Barrier	$ 185,000	$ 304,000	$ 398,800

Table 5 Estimated Construction Costs for Different Treatments
Source: D. W. Harwood and J. C. Glennon (15)

The Benefit Cost Ratios for different left turn treatments and the selection guide for median treatment are also presented in this report.

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

Table 6 Benefit Cost Ratios for Median Treatments

Source: D. W. Harwood and J. C. Glennon (15)

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

Table 7 Selection Guide for Median Treatments

Source: D. W. Harwood and J. C. Glennon (15)

Based on the results of the studies available, the authors (15) reported that the TWCLTL can reduce 35% of total accidents. The TWCLTL and raised median perform equally well in reducing accidents when compared with the other three techniques.

TWCLTL is the most cost effective technique, based on 1975 cost data. The benefit cost analysis shows that the TWCLTL is the best choice for all conditions.

Margiotta and Chatterjee (2) conducted a field survey to investigate the relationship of geometric features, median and TWCLTL, with accidents. They selected twenty five highway segments with four through lanes located in the state of Tennessee for both median and TWCLTL cross-sections. Accidents were categorized based on accident location as:

1. All accidents along a segment
2. Mid-block/ non-intersection accidents only
3. Non-signalized intersection accidents only
4. Signalized intersection accidents only

Equations were developed to predict accidents/mile/year for all the categories, except for signalized intersection accidents. The authors reported that:

1. For highways in commercial suburban areas with four through lanes and with ADTs less than or equal to 32,500 vpd, medians are safer than TWCLTLs.
2. Mid-block/non-intersection accidents are most influenced by median design.
3. When other characteristics are similar, the highway with median will experience fewer accidents/mile/year than the one with TWCLTL.
4. The average overall accident rates show that median cross-sections have a more favorable accident experience than TWCLTLs.

Nemeth (14) presented implementation guidelines for the TWCLTLs. A review of the existing conditions in the field is suggested first. This is to establish that a conflict between mid-block left turns and through lane traffic exists, and that installation of the TWCLTL is feasible. Physical conditions to be reviewed are:

1. Driveway spacing : Closely spaced driveways indicate potential for TWCLTL.

2. Type and intensity of land use : TWCLTL are to be used where encouragement to commercial/strip development is deemed necessary.

3. Ease of alternate access : the existing alternative access methods have to be studied.

4. Distance between intersections : Intersections normally require channelized left turn storage lanes. Hence, for very small blocks TWCLTL may not be ideal.

5. Section length : Longer lengths serve better.

6. Number of lanes : Three and Five lane applications are common, Seven lane installations have also been satisfactory.

7. Pavement width : lanes wider than Sixteen feet might encourage TWCLTLs, lesser lane widths may demand widening of the existing roadway.

8. Right of way limits.

9. Curb parking : may have to be eliminated.

10. Sight distance : May have a role to play in high volume roads.

11. Speed limit.

The existing traffic conditions to be investigated are:

1. Traffic volumes : Existing through volumes and the capacity of major intersections should be investigated.

2. Traffic flow characteristics : Distribution of through and turning volume during the day may be an important consideration.

3. Accident history : TWCLTLs are effective in reducing rearend and left turn accidents.

Finally, future developments should be considered before implementing the TWCLTL. If the future land use goals of the community is strip development, TWCLTL will be the best choice. TWCLTL also has some potential for increasing the carrying capacity of arterials.

Nemeth (14) has listed an exhaustive list of guidelines for the installation of the TWCLTL. These results were based on the opinions expressed by Transportation Engineers, a state-of-the-art review, and a before and after study. The questionnaire survey had seventy responses that represented thirty six states in the country. The author lists "perceptions" of effectiveness of the different types of median treatments based on this survey. Many of the author's guidelines are based on these "perceptions" and it is felt that this may be questionable since there is no validation by proper statistics or experimental data. Further, the rest of the guidelines developed were based on the before and after studies done. Only three sites were evaluated in this study and a number of conclusions were drawn from the same. Here again it is felt that the author uses a far less number of sites than required for deriving some reliable conclusions. The list of guidelines is valid from a general point of view, and it is suggested that the guidelines be accepted as "guidelines" and not as "warrants" for the installation of TWCLTL.

REVIEW OF MDOT CURRENT PRACTICE

As a part of this study a review of MDOT current practice related to this study was performed, which involved the following:

1. A review of MDOT's nomographs for determining the need of exclusive left turn lanes at unsignalized intersections on two lane highways.
2. MDOT's recommended practice of estimating accident reduction percentages for center left turn lanes.
3. MDOT's accident reduction benefit measures used in Time of Return (TOR) analysis.
4. Verbal discussion with MDOT permit section engineers in Lansing and the Metro district.

The background information, which formed some of the basis for the above noted documents, was also reviewed. The following are the salient points of this review:

Review of Left turn lane installation criteria at unsignalized intersections (two lane road)

- The source of data for these documents has been reviewed and the method of development of these nomographs is outlined in Appendix I.
- The nature of the family of curves based on the percent of left turn, opposing traffic and approach traffic seems reasonable.

- It is expected that the criteria should be based on delay, gap availability and accident experience.
- Several capacity analyses using the latest version of HCS package were performed using the threshold values of the nomographs, all of which indicated that the level of service for left turning traffic for specified levels of approach volumes and opposing traffic will operate at the Level of service 'A' even when the center lane for left turning is not provided.

Review of MDOT's recommended practice of center left turn lanes document

- Accident reduction

This table of accident reduction factors is based on some external and some internal (possibly) documents.

- Craus and Mahalel (43) (MDOT Ref. 1) did not perform any statistical test to conclude the rear end accident reduction percentages. It was someone else's work that they happen to quote it in their paper.
- Greiwe's (42) (MDOT Ref. 2) performed a before and after study with the Poisson test of significance for eight intersections with and without the left turn lane and the accident reduction was found to be statistically significant. Greiwe's work strictly pertains to intersections and this study proved that the provision of left turn lane produces significant reduction in all types and total accidents.
- I.T.E. Technical Committee (5B-4) report (MDOT Ref. 3)

  This data probably represents aggregating various past works. Use of percent reduction in accidents from this document is probably acceptable as a starting point, but one ought to remember that research by a committee always is devoid of control and as such needs to be validated.

Variables Considered in the State of the Art Review by various researches

A review of the state-of-the-art revealed the existence of important information as described in the earlier section. In order to identify quickly which paper has used which variables in their studies, tabular summaries of reference papers, and the associated variables are presented below :

Independent variables selected by various studies were :

Independent variables	Reference Paper Numbers
1. Driveway Density	2,3,6,7,10,13,15,16,19,26,28,29,30,36.
2. Traffic volume	1,2,3,4,5,6,7,9,10,11,12,13,16,18,19,22,23, 24,25,26,28,29,30,31,36,42,43,44,45,46.
3. Speed	1,3,4,9,10,11,13,16,26,28,36,45,46.
4. Alternate Designs	1,3,15,18,42.
5. Location	5.
6. Left turn percentage	6,7,9,11,12,16,19,23,26,28,31,36,43,44,45.
7. Number of lanes	1,8,22,24,31,37,46.
8. Length of section	8,11,25.
9. Urban Development (land use)	8,13,14,16,20,22.
10. Arrival Patterns	9,11.
11. Driveway Locations	11.
12. Number of Signals	1,13,15,29,30,37.
13. Type of Delineation	13.
14. Access conditions	14.
15. Spacing of Intersections	14.
16. City size	13,29.

The various **dependent variables** used by different studies were:

Dependent variables	Reference Paper Numbers
1. Accident Rate	1,2,4,5,8,13,15,16,18,24,28,29,37,42,43.

2. Total Delay	3,6,7,15,43.
3. Delay to Left-turning vehicles	1,3,6,9,10,11,19,24.
4. Fuel Consumption	3,10.
5. Delay to through vehicles	1,3,9,10,11,15,24.
6. Travel Time	9,11,19,36.
7. Severity	8,16,30,44.
8. Accident types	4,8,15,16,22,31,37,44.
9. Stops	6,7,9,10,11,12,19.
10. Accidents per Mile	5,13,26.
11. Total Accidents	8,12,13,15,18,22,23,24,30,31,36,42,43.
12. Speed	14.
13. Lane Change Maneuvers	19.
14. User's Behavior	25.
15. Level of Development	10.
16. Traffic Volume	14.

The various **classification variables** selected by different studies were:

Classification variables	Reference Paper Numbers
1. Driveway Density	2,3,5,6,10,11,13,15,19,25.
2. Volume	1,2,3,5,7,10,11,14,18,24,25, 42,43.
3. Number of Lanes	5,24.
4. Openings/Mile	5.
5. Delays	6,7,10,15.
6. Signals/Mile	5,13.
7. Type of Accident	7.
8. Measures of Effectiveness	7.

9. Left Turn Volumes	11,19,25,43.
10. Population	13.
11. Flow	19.
12. Distance Traveled In TWCLTL	25.
13. Speed	14.
14. % of Accidents	25.

Study methods used by various researchers are as follows:

Model/Experiment	Reference Paper Numbers
1. Simulation	3,6,9,10,11,12,16,19,43.
2. Before - After	8,14,22,25,36,42,44.
3. Comparative Parallel	3,5,7,9,11.
4. Questionnaire Survey	1,2,10,18,20,21,45.
5. Regression Analysis	2,5,6,13,24,26,28,29,.
6. Individual Case Study (Data Analysis)	4,5,10,13,23,30,31,37,45.

WHAT IS KNOWN

A review of the state-of-the-art has led to the following:

1. The center lane for left turning at midblock situations is desirable under certain geometric, landuse, traffic and public policy combinations.
2. Providing the center lane for left turning at intersections is desirable both from the point of view of safety and operational characteristics. This has been objectively shown in previous studies.
3. Various independent variables have been conclusively identified to be used in the assessment of impacts of continuous center lane for left turning.
4. Most road agencies are using the CLTL concept without concrete effectiveness data. In most instances they have used CLTL as a policy without objective cost

benefit data. For example, the standards being followed by MDOT for two lane roads does not show any sign of delay, congestion, etc. at all threshold levels. This is due to inclusion of the so called warrants in NCHRP 279 without any evidence of field verification data and lack of definition of warrants. That is, what level of delay and/or other operational and safety ills may constitute a condition of intolerable limit that may require treatment.

Left turn storage lane at intersections

When combined with appropriate signal timing and phasing, it:

- Reduces left turn accidents
- Reduces total accidents
- Increases capacity of through lanes
- Improves level of service for left turning traffic as well as through traffic

Center Lane for Left Turning(mid block)

- Simulation studies indicate significant traffic operational benefits. However, their model calibration is generally non existent in the papers.
- Professionals use this as a policy rather than objective benefit criteria. For example, use of warrants as reported in NCHRP 279 (46) at many levels of demand will not result in any benefit relative to delay or level of service.
- The following are critical variables to be considered:
    1. Left turn demand
    2. Opposing traffic
    3. Gap Characteristics
    4. Driveway density
    5. Community policy regarding encouraging or discouraging driveway access
    6. Fuel consumption
    7. Head on left turn accidents

8. Rearend accidents
9. Total accidents
10. Side swipe accidents
11. Level of service

WHAT IS NOT KNOWN

1. At what driveway density and traffic demand combinations mid block CLTL is cost beneficial?
2. What are the warrants for use in determining requirements of CLTL for :

    two lane to three lane

    four lane to five lane

    six lane to seven lane, etc.

It is, therefore, recommended that the center lane for left turn study will be limited to non-intersection locations (mid block) only. It is proposed to use the following as classification variables:

1. ADT
2. Driveway density
3. Urban - Suburban
4. Operating speed

The independent variables to be investigated are :

1. Opposing traffic volume
2. Left turn demand

The dependent variables to be investigated are :

A. Operational Characteristics -

    Level of Service

    Travel Time and delay

Traffic Conflict

B. Accident Characteristics -

Head on left turn accidents

Rear end accidents

Side swipe accidents

Total accidents

The purpose of selecting some key independent variables like ADT, Driveway density, Urban-suburban location and Operating speed as classification variables, is to increase the chances of developing better models with only a few independent variables. It is a common practice in research to sometimes treat some independent variables as classification variables. For the purpose of the Phase II study the above noted variables will be considered.

Tabulation of key references

In order to assist a reader to identify limitations and successes of various key papers and research reports, a summary in tabular form of the state-of-the-art is presented in Table No. 8. as shown in the following pages of this report. The Table shows only some key attributes of the papers which were considered important to the proposed study.

Tabulation of % change in accidents

A summary of % change in accidents from the state-of-the-art is presented in tabular form in Table No. 9. to assist a reader to identify the effects of TWCLTL installation. The table shows the % change in accidents attributable to TWCLTL as reported by various authors. The reduction factors shown in the table are for midblock situations of TWCLTL's only. Table No. 10 shows the % change in accidents due to installation of left turn pocket lanes at intersections.

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stud-ied	Comments/Critique
D.Mukherjee, R. Margiotta et. al.(1) *	ITE Journal 1993.	Signal operation, Before and after studies, Volume, Capacity, Median width, U-turns, Speeds, Accident rates, Delay to left-turning vehicles. (Factors considered)		Questionnaire survey & 3 Case studies, 31 responses.	None performed.	Two& Four lane	TWLTL is best to manage driveways and landuse, Engineers differ in it's assessment. Comparison of <u>TWLTL</u> and Raised median performed. Safety and Operational effects are determined. Only midblock considered.
R. Margiotta and A. Ch-atterjee (2) *	University of Tennessee Report, May 1992.	Accident rate.	Traffic volume.	Case study, 25 locations.	Analysis of Co-variance, To find coeff. of regression.	Four	Only four lane sections were considered. Comparison of <u>TWLTL</u> and Non-Traversable median performed. Safety effects determined. Only midblock considered.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stud-ied	Comments/Critique
M. M. Ve-nigalla, R. Margiotta, et. al.(3) *	Prepublicat-ion paper, for TRB 1992.	Total delay, delay to left turning vehicles and through vehicles, fuel consumption.	Driveway density, tra-ffic volume, speed, turn demand & distn., medi-an spacing, length of study section.	Simulation, 48 different computer runs.	t-test significant at 0.05 LOC.	Four	Speed, traffic patterns , land-use have not been included in the simulation model. Comparison of <u>TWLTL</u> and Raised median performed. Safety effects are determined. O -nly midblock considered.
P. T. Mc Coy, M. S. Malone (4)	TRR 1239, 1989.	Right-angle, Rearend, Sideswipe, Left-turn, headon accidents and rates.	Approach category, Speed, AADT.	Data analysis, 46 locations.	Chi-Squared test. signific-ant at 0.05 LOC.	Four	Only intersections on four lane roadways were considered. Signalized & unsignalized intersections considered. Safety effects are determined.
C. Squires & P. Pars-onson (5) *	TRR 1239, 1989.	Accident rate, Accident per mile.	Signals per mile, driveway density, approaches per mile, Traffic volume.	Data analysis, Regression, 39 locations.	One tail Student t-test, significant.	Four and six	Concluded that raised medians were always safer. Comparison of <u>TWLTL</u> and Raised median performed. Safety effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes studied	Comments/Critique
J .L. Ballard, P. T. McCoy (6) *	TRR 1195, 1988.	Total delay, delay to left turning vehicles, percentage of stops.	Traffic volume, left turn percentages, driveway densities.	Computer Simulation, Regression, 3 locations.	Paired t-test, Significant at 0.05 LOC.	Four	The model is capable of dealing with many types, but only four lanes were analyzed.Calibration unclear. Study was on **TWLTL** only. Operational effects are determined. Only midblock considered.
P.T. McCoy and et. al. (7) *	TRR 1195, 1988.	Total stops and total delay .	Traffic volume, left turn percentages, driveway densities.	Cost-Effectiveness analysis.	Chi-Squared test, significant at 0.05 LOC.	Four	Guidelines presented are all pertaining to Nebraska not presented in general. Study was on **TWLTL** only. Safety & Operational effects are determined. Only mid-block considered.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu- died	Comments/Critique
J. S. Thak- kar (8) *	TRR 960, 1984.	Total accidents, rearend, leftturn, sideswipe acc- idents and rates, sever- ity rate.	# of lanes, length of section , traffic volume.	Before-after with MOE, 31 sections.	Wilcoxon matched pair, Significant @ 0.05 LOC.	Two and four	Safety effectiveness and Cost effectiveness ana- lyses were also done. Study was on TWLTL only. Safety effects are determined. Only mid- block considered.
J. L. Bal- lard, P. T. McCoy (9) *	TRR 923, 1983.	Travel time(delays), stops.	Traffic Volume, % left turns, arrival pattern, average speed.	Simulation study, 20' sections.	No test Performed.	Two	The simulation model considers most of the critical variables. Calibr- ation unclear.Study was on TWLTL only. Operati- onal effects are determined.
Z. A. Nemeth, P. T. McCoy, Ballard (10) *	TRR 901, 1983.	Delay for left turn volume , fuel consum- ption, stops, level of development.	Driveway density, speed, traffic volume.	simulation, & comparison with earlier work.	No tests.	Two and four	Data used is from very small sample sizes, simul- ation model has inherent problems. Calibration un- clear.Study was on TWLTL only. Opera- tional effects (fuel Consumption) considered.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes studied	Comments/Critique
P. T. McCoy and et. al.(11). *	TRR 869, 1982.	Stops, delays, travel time.	Traffic Volume, % left turns, arrival pattern, average speed, driveway density.	Simulation , 150, 20' sections.	t - test, significant at 0.05 LOC.	Two	TWLTL improves the efficiency of traffic operations, authors recommend further research. Study was on **TWLTL** only. Operational effects are determined.
J. Lee and T. Nulinazzi (12).	TRR 757, 1980.	Total accidents, severity, stops, delays.	Traffic Volume, % turns, % trucks, approach width.	Simulation , 2 locations.	t - test, significant at 0.05 LOC.	Two & more	The model results are stated to have an acceptable accuracy. Intersections are considered. Design guidelines are given.
C. Micheal Walton & et. al.(13) *	TRR 737, 1979.	Accidents, accidents per mile, accident rate, entrance & manuevering distances, lateral palcement.	Traffic Volume, signals per mile, driveway density, city size.	Data analysis, Regression, 20 locations.	No tests	Two, four & six	Wide range of guidelines for highway designs and traffic engineers were suggested.Study was on **TWLTL** only. Safety and Operational effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
Z. A. Nemeth (14) *	TRR 681, 1978.	Traffic volume, speed, brake applications, weavings.	Adjacent land use, access conditions, spacing of intersections.	Before & after study, 3 locations.	No tests.	Two and four	Suggested implementation guidelines for installation of left turn lanes.Study was on TWLTL only. Safety and Operational effects are determined.
D. W. Harwood, J C. Glennon (15) *	TRR 681, 1978.	Accident Rate, Total Delay, types of acci-dents, total accidents.	ADT, Driveway dens-ity, Alternate Designs, # of signals.	Benefit cost analysis, State of the art review.	No tests.	Not Specif -ied.	This is a state of art review so the results are not site specific. Assump-tions were made depend-ing on different studies. Different median treatm-ents are considered, with emphasis on TWLTL. Safety and Operational effects are considered. One reference from which values are taken has no adequate data.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
D. W. Harwood (16) *	NCHRP Report 282, March 1986.	Accident rate, accident severity, accident types.	Traffic volume, % truc-ks, land use, % left tur-ns, lane width, shoulder width, speed, driveway density, unsignalized intersections per mile.	Simulation and Data Analysis.	Analysis of Covariance, significant & 0.05 LOC.	Three, four & five.	Information on Multilane design alternatives for a suburban setting was giv-en which may be used in decision making process. Roadways with different median treatments are considered, with emphasis on **TWLTL** . Safety and Operational effects are considered.
ITE Comm. 5B-4 (18) *	ITE Journal, March 1985.	Accident Rate, total accidents, traffic volumes, speeds, delays, number of lanes, roadway width, cost, alternate designs. (Factors discussed)		Questionnaire survey, 71 responses.	No tests	Four, Six and Two.	Comparison of MALs and TWLTLs was not done effectively due to lack of data. Study was on **TWLTL** and MAL only. Safety and Operational effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu- died	Comments/Critique
A.S. Heikal & Z. A. Nemeth (19). *	ITE Journal, June 1985.	Travel time, no. of stops, delay time, no. of lane change maneuvers.	Traffic volume, turning volume, driveway density.	Simulation by ARTSIM.	No tests	Four	Assumptions like, turning volumes not been expl- ained. Calibration uncl- ear.Study was on <u>TWLTL</u> only. Operational effects are determined.
ITE Comm. 4A-2(20) *	ITE Journal, February 1981.	Policy information, signs & markings, accident experience, lane width, effect on strip develop- ment, applications. (Factors discussed)		Questionnaire survey, 106 responses.	No tests	Not Specif ied	This was a survey that included professionals from 29 states.Study was on <u>TWLTL</u> only. Design and use explained.
ITE Comm. 5-S (21)	ITE Journal, February 1981.	Storage lane width, storage length, bay taper, median width, approach taper, departure taper. (Factors discussed)		Questionnaire survey, 50 responses.	No tests	Not Specif ied	Survey of professionals from 14 states, 5 countries and 31 cities. Intersections considered. Recomme- nded guidelines for left turn channelization.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
M. R. Hoffman (22) *	Traffic Engineering, Aug.1974.	Total accidents, rearend, head on, right angled, side swipe, other accidents.	Traffic volume, cross section, roadside development.	Before and after, 4 sections.	No tests	Four	Just one year accident data was used for the analysis which may not be adequate. Study was on **TWLTL** only. Safety effects are determined.
James C. Ray (23). *	TE March, 1961.	Total accidents.	Traffic volume, turning volume.	Case study, one.	No tests	Four	TWLTL performed well. No adequate data. Study was on **TWLTL** only. Description of the process and effect of installation of TWLTL given.
R. B. Shaw & H. L. Michael (24)	HRR 257, 1968.	Accident Rate, Delay to left turning vehicles, Delay to through vehicles, signal delay, total accidents.	Traffic volume, # of lanes.	Case study, 11 locations. (Intersections)	Multiple Linear Reg., with R^2 values 0.609 to 0.986.	Two and four	The paper deals with inter-sections, but supports the separate left turn concept. Cost analysis done for del-ay. Intersections are cons-idered. Safety and Operational effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
R. B. Saw-hill & D. R. Neuzil (25). *	HRR 31, 1963.	Use of left turn indica-tors, travel distance in LTL, user's behavior, accident types.	Traffic volume, length of section, traffic configuration.	Before and after, 4 locations.	No tests	Two and four	One of the oldest works on LTLs.Study was on TWLTL only. Safety and Operational effects are determined. Intersectioins and midblock considered.
M. R. Parker (26) *	Report to Virginia Highway & Transportat-ion Council, 1983	Accidents per mile, delay.	Traffic volume, turning volume, speeds, driveway density.	Regression analysis.	Not specified.	Four	If stopping site distance is less than AASHTO stand-ards and if access is requi-red on only one side TWLTL should not be us-ed. Different median trea-tments are considered, wi-th emphasis on TWLTL . Safety effects and design guidelines are given.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
P. T. McCoy & J. L. Ballard (28) *	Report to University of Nebraska, Lincoln, Aug. 1986.	Accident rate, delay.	ADT, left-turn %, driveway density, speeds.	Regression anaysis.	Chi-square test , Signifi-cant at 0.05% LOC.	Four.	Cost-effectiveness meth-odology was presented to determine the cost-effect-iveness of TWLTL media-ns. Study was on TWLTL only. Safety & Opera-tional effects are deter-mined. Only mid-block considered.
M. R. Parker Jr. (29) *	Virginia Hi-ghway and Tranpsporta-ion Research Council, 1981.	Accidents rate, left turn delay.	Signals/mile, ADT, driveways/mile, Population.	Data analysis, Regression analysis.	Not specified.	Not specifi -ed.	RMs are not safer than TWLTL in most cases. Study was on TWLTL and RM comparison. Safety & Operational effects are determined.
Parsonson, Peter S. (30) *	Final report for Georgia county, Feb. 1990.	Accidents, Severity.	ADT, Driveways/Mile, Signals/mile.	Data Analysis.	Analysis of Covariance.	Four & Six.	Raised medians are safer than TWLTL when used with four and six lanes.Study was on TWLTL and RM only. Safety effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
K. R. Agent (31)	Research report 526, Kentucky DOT. July 1979.	Left-turning accidents, total accidents.	ADT, Left-turning volumes, No of lanes.	Data Analysis.	Not Specified.	Four.	Intersections with left turn lanes had low accident rates. Intersections are considered. Safety effects are determined.
Z. A. Nemeth (36) *	Report to Ohio State University, 1976.	Traffic volume/lane, Driveway density, Left-turning volume, Delay, Accidents, traffic conflicts, travel time, speeds. (Topics discussed)		Questionnaire survey & Before-after studies for 2 sites.	No tests	Four.	After extensive review of litrature and nation wide survey the author gave guidelines for TWLTL usage.Study was on <u>**TWLTL**</u> only. Safety effects are determined. Only midblock considered.
T. J. Foody & W. C. Richardson (37).	Report submitted to Ohio Dept. of Transp., Nov. 1973.	Left turn accident rate, Accident Rate.	Signalization, No of lanes, Intersection type.	Data Analysis, 363 locations.	t-test, significant @ 0.05 LOC.	Gener-al.	Out of the 363 intersect-ions studied, intersections with left turn lanes had low accident rates. Signalized and unsign-alized intersections consi-dered. Safety effects are determined.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu-died	Comments/Critique
R. W. Griewe (42).	ITE Journal, June 1986.	Left turn accidents, Accident Rate, total accidents.	Traffic volume, Alternate designs.	Before and after, 8 locations.	Poisson test at 95% LOC.	Not specifi -ed.	The paper deals with intersections, but supports the separate continuous left turn lane concept without testing. Safety effects are determined
J. Craus & D. Mahalel (43).	ITE Journal, July 1986.	Total delay, % of stopped vehicles,total accidents, accident rate.	Traffic volume, Left turn percentage.	Simulation.	No tests	Not specifi -ed.	The paper deals with intersections, but supports the separate left turn concept without testing. Model calibration unclear. Intersections are consid-ered. Safety effects are determined.
R. C. Thomas (44) *	Traffic engineering, December 1966.	Left turn, Rearend, pedestrian accidents, Injury accidents.	Traffic volume, signali-zed and non-signalized left turns, non-interse-ction left turns.	Before and after, 37 locations.	None Performed.	Four	The paper deals with intersections and non-intersection sections in a segment. Study was on <u>TWLTL</u> only. Safety & Operational effects are determined. Intersections and midblock considered.

Table No. 8 Tabulation of Summaries of Papers Referred

Authors	Journal/ date	Dependent Variables	Independent Variables	Model/# of locations	Statistical Test/ Significance?	Lanes stu- died	Comments/Critique
M. D. Harmelink (45)	HRR - 211, 1967.	Gap, Delay to left turning vehicles.	Opposing traffic volume, Advancing traffic volume, % left turning, operating speed.	Queuing Analysis / 5 locations. Questionaire survey, 80 responses.	None Performed.	Four & Two	The graphs developed are capable to determine left turn storage needed for di- fferent volume combinati- ons. Analytical model not compared with field data. Unsignalized Intersections are considered.
Timothy R. Neuman (46) *	NCHRP 279, Nov. 1985	Delay to through vehicles and Left turning vehicles.	ADT, Speed, Traffic composition, # of lanes.	State of the art review.	None Performed.	Four & Two	Recommends warrants and design for different left turn lane treatments. Used volume warrants without any verification. Study includes TWLTL also. Operational effects are determined.

*** indicates that the study dealt with TWLTL**

Numbers in parenthesis found in 'Authors' column represent the reference paper numbers in the list of references.

ITE:	Institute of Transportation Engineers	TRB:	Transportation Research Board	TRR:	Transportation Research Recor
LOC:	Level of Confidence	MOE:	Measures of Effectiveness	HRR:	Highway Research Record
LTL:	Left Turn Lane	#:	Number	MALs:	Median Acceleration lanes
TWLTLs:	Two Way Left-Turn Lanes	LTLs:	Left-Turn Lanes	ARTSIM:	Arterial Simulation Model.

Table No. 8 Tabulation of Summaries of Papers Referred

Number	Source	No. of road segments	Length of road segments (km)	No. of Lanes		No. of Years		% Change in Acc. between Before & After						Type of Statistical test	Remarks
				Before	After	Before data	After data	Total Acc.	Left turn Acc.	Rear end Acc.	Right angle Acc.	Side swipe Acc.	Other Acc.		
1	Janak S. Thakkar, TRR 960(8)	15	11.29 (miles)	4	5	2	2	-32	-32 (Affected accidents: Left turn, Rear end, Side swipe accidents)					Wilcoxon matched pair test	Study done by the author
2	Janak S. Thakkar, TRR 960 (8)	16	7.36 (miles)	2	3	2	2	-41	-46 (Affected accidents: Left turn, Rear end, Side swipe accidents)					Wilcoxon matched pair test	Study done by the author
3	C. Michael Walton & et al. TRR 737 (13)	1	2.7	4	5	1	1	-38	-90 (Left turn & Rear end accidents combined)		Above types of accidents were not considered in the study			No statistical tests	Author gave the accident reduction factors from study done by C.B. Busbee which is published in ITE, Dec. 1975.
4	Douglas W. Harwood & John C. Glennon, TRB 681(15).	1	1.6	Author did not specify: a) no. of lanes of the roadway b) time period considered before and after installation of TWLTL				-35	Types of accidents were not considered in the development of accident reduction factors. The reduction factor of 35% quoted is based on other studies.					No statistical tests	Author developed the accident reduction factor based on results from different studies for a typical arterial roadway with similar characteristics as those considered in referred studies. Seems more intuitive than objective.
5	5 B-4, ITE, March 1985 (18)	30	Authors did not specify: a) length of the roadway b) no. of lanes of the roadway c) time period considered before and after installation of TWLTL					-28	-36	Above types of accidents were not considered in the study				No statistical tests	The technical committee of ITE deveoloped the accident reduction factors depending on data received through questionaires and literature review
6	Max R. Hoffman, Traffic Engineering 1974 (22).	4	6.58 (miles)	4	5	1	1	-33	-45	-62	+14	-7	+6	No statistical tests	Too small a sample size used in the study. The same is published as a report by B.A.Conradson and N. Al-Ashari for Michigan Department of State Highways in 1972.
7	R.B.Sawhill & D.R. Newzil HRR 31(25)	1	1.66	4	5	4	4	-26	+140	-28	Above types of accidents were not considered		-30	No statistical tests	Too small a sample size used in the study
8	R.B.Sawhill & D.R. Newzil HRR 31(25)	1	2.4	6	7	3	1	-6	-29	-19	Above types of accidents were not considered		+16	No statistical tests	Too small a sample size used in the study

Note: + sign means increase and - sign means decrease

Table No. 9: Percent change in types of accidents after using Center Lane for Left Turns (Includes only those papers which give accident reduction factors)

No.	Source	No. of Intersections		No. of lanes		No. of Years		% Change in Acc. between Before & After						Type of Statistical test	Remarks
		Signal-ized	Unsignal-ized	Before	After	Before data	After data	Total Acc.	Left turn Acc.	Rear end Acc.	Right angle Acc.	Side swipe Acc.	Other Acc.		
1	P.T. McCoy, M.S. Malone, TRR 1239, 1989 (4)	10 (LTL) 11 (No LTL)	12 (LTL) 13 (No LTL)	Not used	4 & 5	Not used	3	Not analyz-ed in the study	-86(u) -66(s)	-88(u) -59(s)	+68 (u) -37(s)	-52(u) -73(s)	Not consi-dered in the study	Chi-Squared test was performed	Comparative Parallel Study performed by the author
2	P.T. McCoy, M.S. Malone, TRR 1239, 1989 (4)	Author did not spec-ify no. of signalized and unsignalized int-ersections consider-ed in the study		4	5	Author did not specify no. of years consid-ered in the study		-48(u) -17(s)	-37(u) -54(s)	-85(u) 15(s)	+153 (u)	Above types of accidents were not considered in the study		Statistical tests perfor-med but not specified as what type	Author gave accident reduc-tion factors from a study done by C.G. Hammer publi-shed in HRR 286, 1969
3	K.R. Agent, Research report 526, Kentucky DOT, July 1979 (31)	Author did not spec-ify no. of signalized and unsignalized int-ersections consider-ed in the study		Not used	4 & 5	Not used	5	Did not in-clude in the study	-77(u) -54(s)	Above types of accidents were not used in the study				Statistical tests perfor-med but not specified as what type	Comparative Parallel Study performed by the author
4	T.J.Foody & W.C. Richardson, Ohio DOT, Nov. 1973 (37)	61 (LTL) 135 (No LTL)	33 (LTL) 134 (No LTL)	Not used	4 & 5	Not used	2	-32(u) -9(s)	-27(u) -39(s)	Above types of accidents were not used in the study				Statistical tests perfor-med but not specified.	Comparative Parallel Study performed by the author
5	R.W. Greiwe, ITE June 1986. (42)	8	Author did not include in the study	Author did not specify no. of lanes at the inters-ections cons-idered in the study		2	1	-58	-62	-46	-54	Not analy-zed in the study	-68	Poisson test for signific-ance is performed	Too small sample size used in the study
6	Joseph Craus and David Mahelal, ITE July 1986. (43)	25	Not included in the study	Author did not specify no. of lanes at the inters-ections cons-idered in the study		Acc/year compared		-40	Types of accidents were not used in the study					Significant at 1% LOC but type of test not specified.	Author gave accident reduc-tion factors from a study done by Ben-Yakov and Craus J. in Israel, 1980
7	R.S. Thomas, Traffic Engineering, Dec. 1966 (44)	10	27	4	5	1	1	-28	33(s) -68(u)	-52	Author did not include in the study			No Statis-tical tests performed	Study done by the author

Note: + sign means increase and - sign means decrease
s - Signalized intersections
u - Unsignalized intersections

Table No. 10: Percent change in types of accidents after using Left Turn Lanes at Intersections (Includes only those papers which give accident reduction factors)

EXPERIMENTAL PLAN FOR PHASE II

I. Determination of Variables:

The purpose of using some key independent variables as classification variables is to obtain some homogeneity amongst the sample sites in each group. Thus, the effect of only a few variables will be tested on the selected dependent variables.

Based on the state-of-the-art review, the following independent variables will be used as classification variables.

- ADT (Average Daily Traffic) expressed as Vehicles per Hour
  - Low
  - Medium
  - High
- Driveway Density expressed as Driveways per Mile
  - < 20
  - 20 - 40
  - > 40
- Number of Lanes
  - 2 - 3 lanes
  - 4 - 5 lanes
  - 6 - 7 lanes
- Operating Speed expressed as Miles per Hour
  - Low (< 30 mph)
  - Medium (30 - 45 mph)
  - High (45 - 55 mph)

A flow chart which shows the different classification variables is presented in Figure 3.

The Independent Variables proposed for the study are:

- Opposing traffic volume

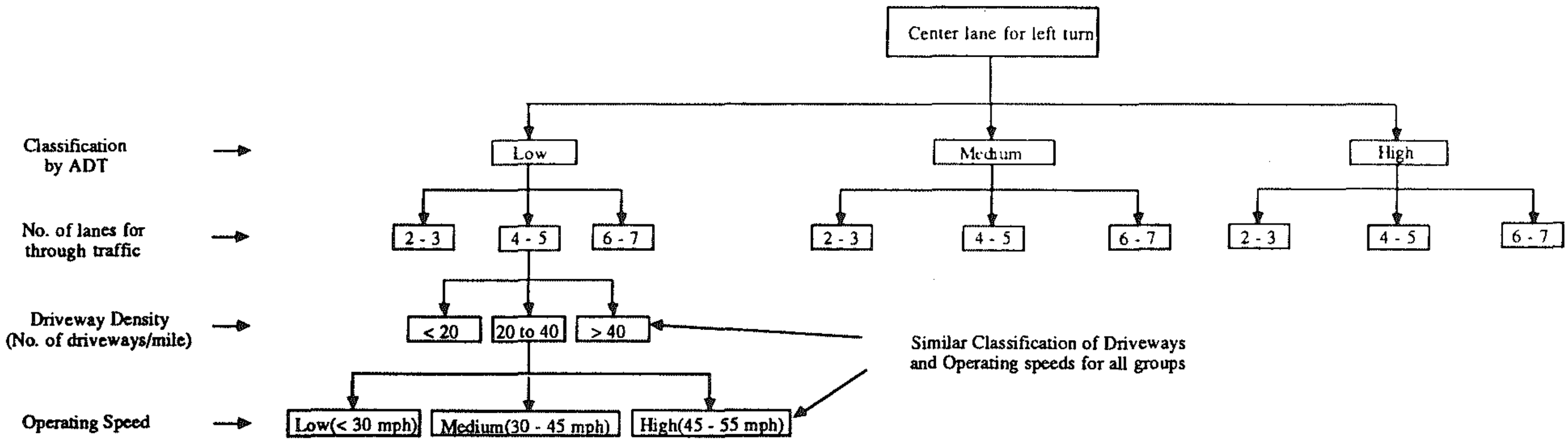


Figure 3. Typical Classification Scheme

- Left turn demand

The dependent variables proposed for the Phase II study i.e., which are going to be measured as an effect of the left turn treatment are,

A. Traffic Operations related:

1. Delay
2. Travel time
3. Traffic conflict
4. Level of service

B. Safety Related:

1. Total accidents
2. Left turn head-on accidents
3. Angle Accidents
4. Side swipe accidents
5. Rear end accidents

II. Statistical Testing and procedures

Measures of effectiveness (MOE) will be determined to compare means of two groups for different dependent variables. Measures of Effectiveness for different relationships between the dependent variables and independent variables identified from the state-of-the-art review will be developed.

The MOE data comparison worksheet, as the one shown in Table 11 (47), will be used for all the dependent variables.

In the Phase II study it will be difficult to find "Before" data for the sample sites. So, evaluations of the treatment is proposed to be done using a Comparative parallel Study.

OBJECTIVE AND MOE LISTING

S.no	Evaluation Objective	Measures of Effectiveness (MOE)
	Determine the effect of the treatment on:	Percent change in:
	Safety Related:	
1.	Total Accidents	
2.	Left turn Head-on Accidents	
3.	Angle Accidents	
4.	Sideswipe Accidents	
5.	Rear end Accidents	
	Traffic Operational Related:	
1.	Delay	
2.	Travel Time	
3.	Traffic Conflict	
4.	Level of Service	

Table 11. Objectives and MOE listing

Sample sites will be selected for individual groups, as shown in Figure 3, which are similar in characteristic both for sites with and without center lane for left turning. This would make it possible for testing of significance without any "Before" data. A typical scheme of a comparative parallel study is shown in Figure 4 (47). The MOE comparison worksheet that will be used for the comparative parallel study plan is shown in Table 12 (47). In this method, we need to find sites for each group (as presented in the classification scheme). For example, a low ADT condition sites will be selected as follows:

<u>Control group</u> - Roadway segments with:

Low ADT (say)

2 Lanes

< 20 driveways / mile

30 - 45 mph Operating speed

<u>Treatment group</u> - Roadway segments with:

Low ADT (say)

3 lanes (with CLTL)

< 20 driveways / mile

30 - 45 mph Operating speed

Please note that between these two groups, the only difference in critical characteristics is that the treatment group has three lanes, whereas, the control group has two lanes. Now, if we observe the statistical difference in one or all dependent variables; then the difference will be attributable to the treatment, in this case the third lane.

A. Determination of sample size

In order that reliable data and results are to be attained in statistical testing, the sample size must be carefully selected. Proper determination of the sample size requires an estimate of the variance of the dependent variables.

For example, for safety related dependent variables, left turn head-on accidents may be selected as a critical variable in the determination of sample size criteria.

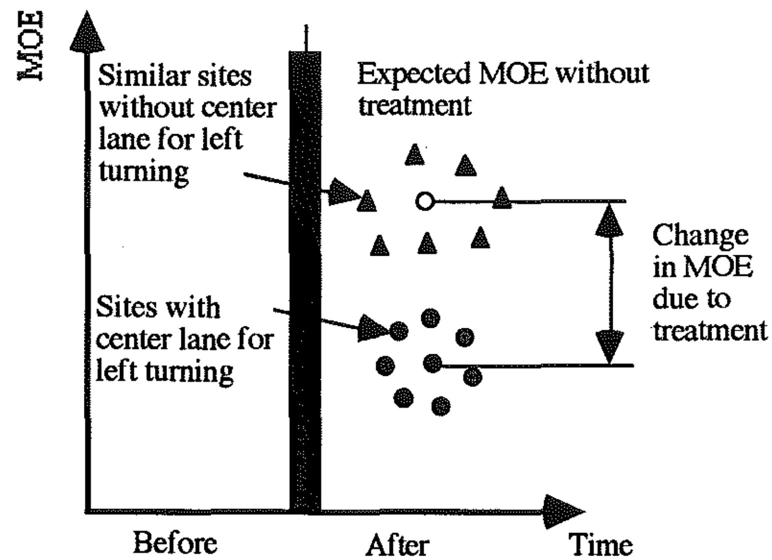


Figure 4. Comparative Parallel Study

MOE DATA COMPARISON SHEET

MOE Data Summary	Control After (A_{CF})	Project After (A_{PF})	Expected After	Percent Reduction (%)
Dependent Variables Listing				

Table 12. Illustration of MOE data Comparison Worksheet for Comparative Parallel Study Plan

For Traffic operational related variables, delay to left turning vehicles (major street) may be selected as the critical variable.

To develop an estimate of variance for the critical variables, a few sites will be selected and the data will be collected for the critical variables. The selection of sites for the initial measurement of critical variables will depend on the classification scheme. The acceptable level of error for the study would be decided based on the limit on the sample size and the accuracy desired in the results. Different values of error would be selected and different ranges of sample sizes would be calculated using the estimated variances of the critical dependent variables. Depending on the resources and time constraints, the sample size would be selected using the minimum error.

The sample size requirements will be developed, for the groups which were shown in the flow chart in Figure 3, for a 95% level of confidence.

A sensible goal while selecting a sample size should be to make precise estimates of population parameters. This results in the reduction of errors in the sample parameters. The question then becomes, "How do we select this sample of locations and how large a sample is needed ?"[3]

According to the classification scheme shown in Figure 3, the sample size will be determined for each group. For example, the sample size will be determined for the group of sites with low ADT, four lanes, driveway density between 20 - 40 and an operating speed of 30 - 40 mph, and also for five lanes with the rest of the characteristics the same. The effect of the left turn lane treatment will be determined for all the groups. It is important to recognize that some of these classifications can be combined or eliminated based on data availability.

As the population of each group will be limited in number, the sample size for each group will be determined using the estimates of population size of that particular group. The control group sample size for each group will be assumed to be the same because the control group will have the same characteristics of the treatment group.

---

[3] Sampling and Statistics Handbook for Research, Chester Mc Call (48)

The formula which will be used to determine the sample size is as follows (48):

$$n = (\hat{\sigma} * Z / \varepsilon)^2$$

where:

n is the estimated sample size necessary for the desired precision and level of confidence.

$\hat{\sigma}$ is the preliminary estimate of the population standard deviation of the critical dependent variables.

Z is the two-tailed value of the standardized normal deviate associated with the desired level of confidence.

ε is the acceptable error, or half of the maximum acceptable confidence interval.

Here the values of $\hat{\sigma}$, Z, and ε are to be decided in advance. This formula works well when it is known that the population size is large.

The formula presented below is proposed to be used to determine the size of a random sample needed to estimate a population mean where the size of the population is finite and known (48):

$$n = \hat{\sigma}^2 / [(\varepsilon / Z)^2 + (\hat{\sigma}^2 / N)]$$

where:

n is the estimated sample size necessary for the desired precision and level of confidence.

$\hat{\sigma}$ is the preliminary estimate of the population standard deviation.

Z is the two-tailed value of the standardized normal deviate associated with the desired level of confidence.

ε is the acceptable error, or half of the maximum acceptable confidence interval.

N is the population size.

An alternative formula derived from the above formula, indicating the effect of population size (48), is given as,

$$n^{-1} = N^{-1} + (\varepsilon / \hat{\sigma} Z)^2$$

As we are evaluating the treatments using a comparative parallel study, the characteristics of the control group and the treatment group will be assumed to be same except only the treatment (i.e., center lane for left turn).

We are testing the means of independent samples; i.e., the treatment group and the control group. This needs statistical testing of the two means and variances. The two tests and the procedures which will be used are explained here.

A flow chart describing the steps in developing the sample size and testing the significance is shown in Figure 5.

B. Types of statistical tests and procedures:

The statistical testing will be done for individual groups in the classification scheme. The means and variances of the dependent variables of each group will be tested for significance using tests for means and variances. Critical independent variables, such as the left turn demand and opposing volume will be controlled. Typical tests for comparison of means and variances are outlined below.

Student's t-test (48):

This test will be appropriate for testing the effect of the center lane for left turn, when we compare two means from independent samples. The null hypothesis will be decided as "there is no significant difference between the means at 95% level of confidence".

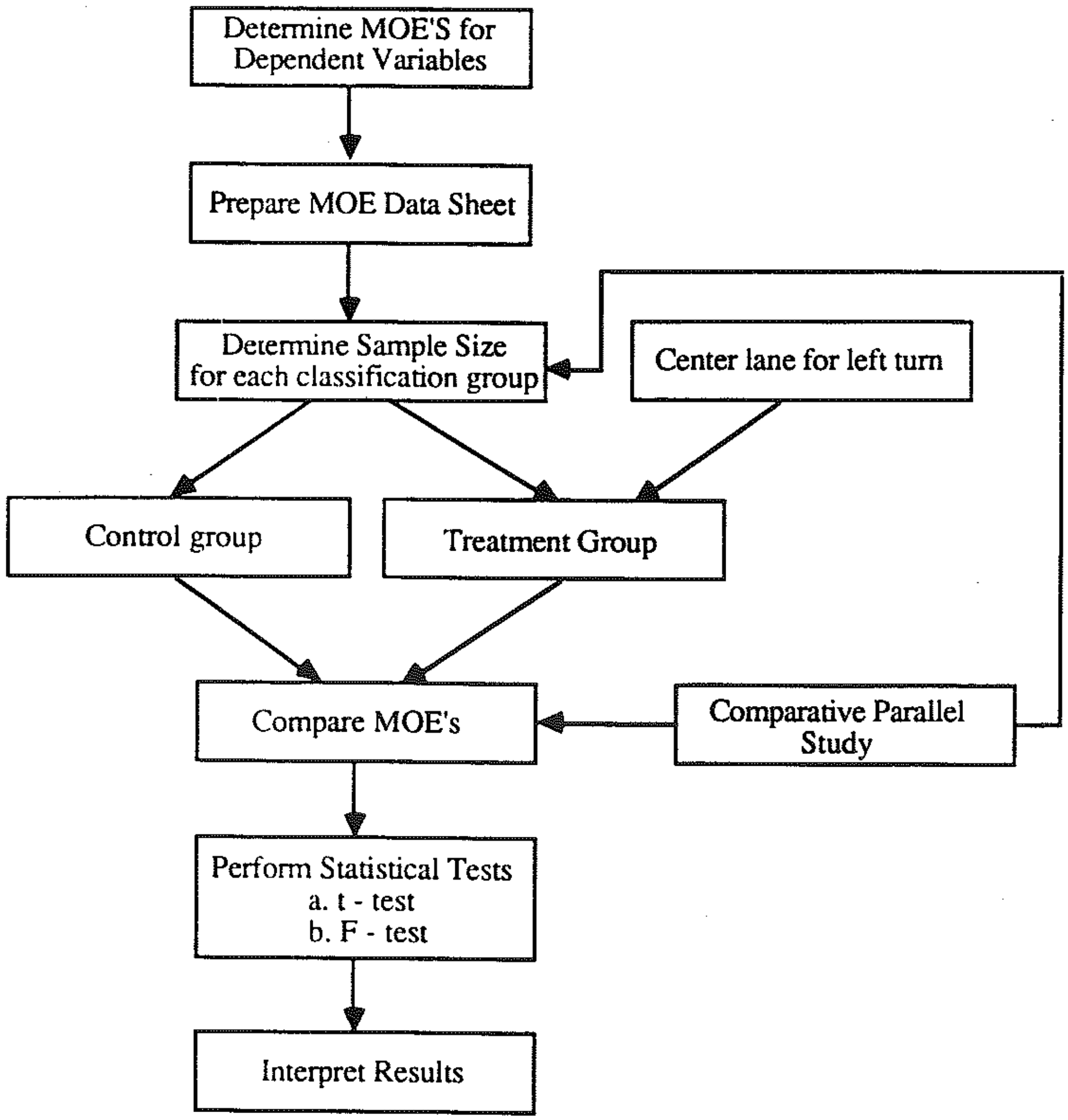


Figure 5. Typical Flow Chart Showing Steps for Statistical Testing

i.e., symbolically,

$$H_o : \mu_1 = \mu_2$$

The standard error of the means will be calculated using the formula:

$$S_{\bar{x}_1 - \bar{x}_2} = S_{po}\sqrt{n_1^{-1} + n_2^{-1}}$$

where:

$$S_{po} = \sqrt{[(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2]/(n_1 + n_2 - 2)}$$

If the samples are of the same size, then the above formula becomes:

$$S_{po} = \sqrt{(S_1^2 + S_2^2)/2}$$

where:

n_1 is the sample size for the treatment group.

n_2 is the sample size for the control group.

S_1 is the standard deviation for the treatment group.

S_2 is the standard deviation for the control group.

S_{po} is the pooled estimate for the standard deviation.

The test statistic for testing the hypothesis that two population means are not different is:

$$t_c = (\overline{X}_1 - \overline{X}_2)/S_{\overline{X}_1 - \overline{X}_2}$$

with associated $(n_1 + n_2 - 2)$ degrees of freedom.

Now, it is to be decided whether to do a two-tailed or one-tailed t-test.

It will be appropriate to use a two-tailed t-test to be more conservative in determining significance. By using the two tail test, we will determine whether the treatment has a significant effect on the dependent variables which will be attributable to the CWLTL. The test will not determine whether the effect is an increase or decrease in the dependent variable.

Then, the alternate hypothesis would be symbolically:

$$H_1 = \mu_1 \neq \mu_2$$

Null hypothesis would be rejected if the calculated value is more than the critical value from the table at a 95% level of confidence. If the null hypothesis is rejected, it represents that the CLTL has a significant effect on the dependent variable tested. This test will be performed for all the dependent variables selected earlier.

F - test (48):

The previous test indicates that a test on two sample standard deviations is necessary before running a test on two sample means to ascertain whether it was likely that the population standard deviations were the same.

Null Hypothesis: There is no significant difference between the two sample variances at a 95% level of confidence.

i.e., symbolically,

$$H_0 : \sigma_1^2 = \sigma_2^2$$

The appropriate test statistic is:

$$F_c = S_1^2 / S_2^2$$

where:

$$S_1^2 > S_2^2$$

where:

S_1^2 and S_2^2 represent the variances of the control group and experimental group, and

$(n_1 - 1)$ and $(n_2 - 1)$ are the degrees of freedom for the numerator and denominator respectively.

To accept the hypothesis the calculated F value should be less than the critical value at a 95% level of confidence.

The number of groups that can be rigorously tested in the Phase II study is a function of sample size requirements. In the most comprehensive version of the study, we will require eighty-one groups of control sites and eighty-one groups of treatment sites. Assuming (say) ten sites per group, we will need 1620 total sites. Collecting accident data and existing volume data for these sites will be a monumental task. The number of sites will further increase if the preliminary variance data of the critical variables indicate, that we need say twenty or thirty sites per group.

From the sampling formula discussed earlier it is evident the larger the standard deviation, the larger the size of the sample will be. In this regard, it is important to note that the standard deviation will be greater for operational variables like delay per vehicle or traffic conflict counts. Whereas, the standard deviation for critical accident variables is expected to be less in magnitude. In order to minimize the sample size requirements we may use accident rates i.e., accidents per million or 100 million vehicle miles of travel, rather than accident frequency.

For example, if we take four lane segments (say 1/2 mile) to be representative of population, say, with the following characteristics:

Mean ADT	30,000 veh.
Mean Left turn head-on accidents	10 acc./year
Mean Rear end accidents	8 acc./year
Mean Side swipe accidents	5 acc./year
Mean Right angle accidents	10 acc./year
Mean Total accidents	8 acc./year

And, say, left turn head-on and right angle accidents are critical variables. It is assumed that population size i.e., number of 1/2 mile segments, is unknown.

Now, converting these into accident rates, the following can be calculated for the two critical variables:

$$\text{Mean left turn head-on accident rate} = \frac{10 \text{ X } 10^6}{0.5 \text{ X } 30{,}000 \text{ X } 365}$$

$$= 1.83 \text{ acc./ MVMT}$$

$$\text{Mean right angle accident rate} = 1.83 \text{ acc./ MVMT}$$

Using left turn head-on accidents as the critical variable we can calculate the estimate of the sample size. Since we are using Student's t-test to test significance, we will have to use the t_{cr} value to calculate the sample size.

Let us assume that the standard deviation for the two groups i.e., the control and the treatment group, are the same. As calculated before, the mean of the left turn head-on accidents is 1.83 acc./ MVMT. Let us assume that 95% of the values of the left turn head-on accidents for the samples should be within ±10% of their mean value.

i.e., 1.83 X 0.1 = 0.183 acc./ MVMT.

It is known that for a normal distribution, the area of the distribution is covered by six standard deviations of the distribution.

Then, the estimate of the standard deviation of the left turn head-on accident rate will be,

$$\sigma_1' = \sigma_2' = \left(\frac{0.183 + 0.183}{6}\right) = 0.061 \text{ acc./ MVMT}$$

If we assume allowable error as 2.5% i.e., half the confidence interval, then the estimate of the sample size using normal distribution is,

$$n_1' = n_2' = 2 \times \left(\frac{1.96 \times 0.061}{0.025}\right)^2 = 45.74 \cong 46 \text{ sites/ group.}$$

To calculate the actual estimate of the sample size, we have to determine the value of t_{cr}. The degrees of freedom are,

$$n_1 + n_2 - 2 = 46 + 46 - 2 = 90$$

Then,

$$n_1 = n_2 = 2\times\left(\frac{1.98\times0.061}{0.025}\right)^2 = 46.68 \cong 47 \text{ sites/ group.}$$

If we want a smaller sample size, the error allowed can be changed to 5% that is L.O.C of significance testing will be 90% (assuming). Then, the the estimate of the sample size using normal distribution is,

$$n'_1 = n'_2 = 2\times\left(\frac{1.645\times0.061}{0.05}\right)^2 = 8.06 \cong 8 \text{ sites/ group.}$$

To calculate the actual estimate of the sample size, we have to determine the value of t_{cr}. The degrees of freedom are,

$$n_1 + n_2 - 2 = 8 + 8 - 2 = 14$$

Then,

$$n_1 = n_2 = 2\times\left(\frac{1.761\times0.061}{0.05}\right)^2 = 9.23 \cong 10 \text{ sites/ group.}$$

While an acceptable error of 0.05 is not as strong as 0.025, it may be within the acceptable limits.

Let us say, we assume a plan to work with twenty-five sites as the minimum number of sample. Based on this assumption, let us investigate how much of the Phase II analysis can be covered with the available resources of say $34,000.00.

Test the differences in performance variables between four lane and five lane arterial segments.

a) For a high ADT level (say 30,000 +)

Driveway density = 20 or greater / mile

Operating speed = 30 mph or greater

Please note that the above grouping means collapsing several classifications as per Figure 3. This may introduce an increased difference between site variances, thus reducing the power of statistical tests.

In order to perform statistical tests, twenty-five sites of four lane segments of arterials will be selected. These twenty-five sites will serve as the control group, and another twenty-five sites of five lane segments with similar characteristics will be selected as the treatment group.

The following data will be collected for the noted fifty sites:

Driveway Characteristics - For many arterials before selecting the above noted fifty sites. MDOT will provide stretches of roadways and associated ADT's. W.S.U. will determine site characteristics.

Accident data - Two to three years worth of accident data will be collected for each of the fifty sites. MDOT will provide a computerized data base to W.S.U. In addition, hard copy accident reports may be necessary. W.S.U. will analyze all data.

Delay data - Determination of delay data will be extremely difficult to capture. By definition, delay is equal to the difference between actual travel time through the site and the expected travel time. In order to capture meaningful travel time and delay data, one must perform literally scores of travel time runs through each site. Since this is impractical, it is proposed to capture stopped time delay only. Even this data requires capturing stop time delay for all vehicles at each site for various time periods. It is proposed that video taping of all the fifty sites will be performed for various time periods. The video tapes will then be observed in the laboratory, under controlled environment, to capture the stopped time delay data. Just viewing and capturing all vehicles' stop time delay may require four to six hours for one to two hours worth of video tape. Thus this data may require 200 to 300 person hours of viewing time for fifty sites. WSU will coordinate with MDOT's district Traffic Engineers' office to set up video taping of sites.

Traffic Conflict - If this variable is used for analysis, W.S.U. researchers will have to collect field data since conflict data requires trained personnel.

It is anticipated that W.S.U.'s research team estimated time for, say, fifty sites data collection and analysis will be as follows:

Site selection	250 person hours.
Data collection	600 person hours.
Analysis	500 person hours.
Interpretation & report writing	400 person hours.
Miscellaneous	100 person hours.
Total	1850 person hours.

This is just an estimate of person hours. There will be significant cost and time associated with site visits and coordination.

Therefore, it is proposed that in Phase II study, the proposed four lane to five lane issue be studied thoroughly. This will result in reliable results in terms of benefits and disbenefits associated with CLTL associated with five lane arterials.

GLOSSARY

AASHTO: American Association of State Highway and Transportation Officials.

Accident: Any unplanned event that results in fatality, injury, property damage or loss.[4] Also referred to as **Crash.**

Accident Rate: The number of accidents occurring during a specific period of time, divided by a measure of the degree of vehicular exposure over the same period. For intersections, the unit for accident rate is number of accidents per million vehicles entering the intersection. For segments, it is the number of accidents per million vehicle miles of travel.

Analysis of Variance: A statistical technique that tests for significant differences in the dispersion characteristics between two or more data sets.

Arterial : Roadways that serve both through traffic and provide access to abutting properties (often commercial).

Alternating Left Turn Lane (ALTL): A left turn treatment, which allows one traffic direction to have opportunity to cross the median into driveways and after a specified distance the left turn lane is physically opened to opposing direction of traffic.

Before-and-After Study: An experimental plan used in evaluation of safety and/or operational characteristics, and is based on data collected before and after implementation of the projects improvement.

Capacity: The maximum rate of flow at which vehicles can be expected to traverse a point or uniform segment of a lane or roadway during a specified period, under prevailing roadway, traffic, and control conditions[5] .

Channelizing Island: An island painted or raised used to direct traffic in the required manner. The island indicates that the traffic should not cross but may proceed on either side.

Chi-Square Test: Chi square test is a 'goodness of fit test'. Used for testing hypotheses related two sets of data or distributions.

Conflict: Evasive action taken by a motorist to avoid an impending collision, also used as **Traffic Conflict.** In simple terms it is a "near miss' situation.

Continuous Left Turn Lane (CLTL): A left turn treatment, where two center lanes are provided, one for each direction of traffic. The median is traversable.

Control of Access: The condition where the right of the owners or occupants of abutting land or other persons to access, light, air, or view in connection with highway is fully or partially controlled by public authority[1].

Curb: A vertical sloping roadway element generally along and defining a roadway.

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[4] Highway Safety Improvement Program User's Manual, FHWA-Goodell Grivas Inc., Southfield, MI
[5] Highway Capacity Manual, Special Report No. 209, TRB, NRC, Washington D.C.

Curbcut: Same as **Driveway.**

Decelerating Taper: An exclusive lane that is separate from the lane of through traffic. This area provides for deceleration of vehicles or stopping to make the turning manuvers.

Delay: Additional travel time experienced by a driver, passenger, or pedestrian beyond what would reasonably be expected for a given trip.

Delineator: A light-reflecting device mounted at the side of the roadway , in series with others, to indicate the alignment of the roadway .

Driveway: Any access to residences, commercial establishments or recreational establishments from the roadway. This is often used synonymously with **Curbcuts** in this report.

Entrance Distance: Distance from the intersection to where the vehicle enters the turn lane before making a left-turn maneuver.

Experimental Plan: A method of evaluation involving alternate techniques which will allow for determination of project or improvement impacts. The experimental plan selection criteria depends on project characteristics and data availability.

Freeway: A multilane divided highway having a minimum of two lanes for exclusive use of traffic in each direction and full control of access and egress.

Gap Study: A study conducted to measure the time headway or gap between vehicles along a highway section.

Hazard: Certain conditions on highways/roadways that may contribute to probability of crashes.

ITE: Institute of Transportation Engineers.

Lane Line: Line that separates two lanes of traffic traveling in the same direction.

Lateral Placement: The lateral position of the vehicle in the lane.

Left Turn Storage Lane (LTSL): A left turn treatment provided at intersections. This uses either raised medians or flush medians, and helps in separating left turning vehicles from through traffic. The median is non-traversable. Also referred to as **Non Traversable Median (NTM), Storage lane, Channelized One Way Left Turn Median Lane (COWLTML) .**

Level of Service: A qualitative measure describing operational conditions within a traffic stream. In this report, it is described in terms of factors such as speed, volume, travel time and traffic interruptions .

Level of Significance: Refers to the outcome of specific statistical test of hypothesis.

Measures of Effectiveness (MOE): Variables, often dependent variables, describing the quality of service provided by the left turn treatment to drivers, passengers or pedestrians. Some MOEs may be speed, delay etc.

Maneuvering distance: Distance required for the left turning vehicles to fully enter the left turn lane.

Median: A separator between opposing directions of traffic in a divided highway. Median may be just a double yellow striped division , barrier, raised island or green patch on the roadway. They are normally non-traversable, except when left turn treatments are provided, such as TWCTL, CLTL, ALTL.

Midblock: The section of the roadway which lies between two major intersections.

MUTCD: Manual of Uniform Traffic Control Devices.

Operational Variables: Variables related to operational aspects. For example, delay and stops as a result of a new improvement. Usually describes level of service.

Passing Lane: In this report, it is used to describe a lane which is used to pass or overtake another vehicle. The TWLTLs have often been reported to be misused as passing lanes.

Platoon: A group of vehicles or pedestrians traveling together as a group, this may be voluntary or involuntary.

Right-of-Way: A term used to denote land, property or interest therein, usually acquired in the form of a strip to build a roadway.

Stochastic: A random process.

Surrogate: Serving in place of or standing for something else. For example, number of braking and weaving conflicts may be used as a surrogate for accidents.

T Test or the Student's T test: A statistical technique for testing the null hypothesis. This is applicable to test of hypothesis that a random sample of observations is from a normal population with mean and variance unspecified. This test should be used when sample size is less than 30.

Two Way Left Center Turning Lane (TWLCTL): Is a left turn treatment, where a center median lane is used by traffic in both directions as a storage lane for left turning. Also referred to as **Two Way Left Turn Lane (TWLTL), Continuous Two Way Left Turn Median Lane (CTWLTML).**

Weaving: A maneuver when the motorist changes lanes.

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APPENDIX I

Review of M. D. Harmelink's Paper
"Volume Warrants for Left Turn Storage Lanes At Unsignalized Grade Intersections"
Published in HRR 211, 1967

REVIEW OF HARMELINK'S STUDY (WARRANTS FOR INSTALLATION OF LEFT TURN LANES)

The nomographs currently being used by MDOT were actually developed by M. D. Harmelink (45) in a study entitled, "Volume Warrants for Left Turn Storage Lanes at Unsignalized Intersections". The analysis is based on a queuing model. It was assumed in this study that the arrivals of left turn vehicles follow a Poisson distribution and that the service time distribution is negative exponential. The study was conducted for four lane and two lane roadways.

The development of Warrants were based on the following conditions:

1. On four lane highways it is the presence of left turning vehicles extending onto the through lanes that will affect safety and capacity: the probability of this occurrence was assumed not to exceed 0.05 for divided highways, and 0.03 for undivided highways. On two lane highways the probability of occurrence of the arrival of advancing through vehicles, behind a stopped left turning vehicle, was assumed to be less than or equal to 0.02 for an operating speed of 40 mph, 0.015 for an operating speed of 50 mph, and 0.010 for an operating speed of 60 mph.
2. The arrival of left turn vehicles was assumed to follow a Poisson distribution, and service time a negative exponential distribution.
3. On four lane highways, the average time, t_1, required for making a left turn was used as 4.0 sec. On two lane highways, it was 3.0 sec. These values were determined from field studies as reported by the author.
4. The required critical headway gap, G_c, in the opposing traffic stream for a left turn maneuver was reported as 6.0 sec for four lane roadways and 5.0 sec for two lane roadways. These values were determined from field studies. However, no specific data was presented.
5. On a two lane roadway the average time, t_e, required for a left turning vehicle to clear itself, or exit from the advancing lane, was reported as 1.9 sec.

The average time that a left turning vehicle must wait for a suitable gap in the opposing traffic stream is,

$$t_w = \left[\frac{3600}{V_o e^{-V_o G_c / 3600}}\right] - \left[\frac{3600}{V_o}\right] - G_c$$

The mean service rate is given by

$$\mu = \text{Unblocked Time} / t_1$$

where,

Unblocked time is denoted as, sec / Hr.

t_1 is in sec.

The values of the unblocked time were taken from the graphs from "Traffic Engineering" by Matson, T. M., Smith, W. S., and Hurd, F. W., a text book used in 1940's and 50's.

The author developed left turn lane requirements for different values of opposing volumes by determining the amount of advancing volume.

The advancing volume was calculated by,

$$V_A^2 = \frac{2400\rho\mu}{L(1-L)(t_w + t_e)}$$

where

μ is the average service rate

ρ is the utilization factor and is equal to λ/μ

The different limits for the utilization factor is determined by the limits set on the probabilities of left turning vehicles extending into the through lane. The utilization factor was assumed not to be less than the probability limit. The warrants for a left turn provision were developed based on this concept.

For two lane highways, the probability of exceeding the capacity of the storage lane by one or more vehicles was assumed as equal to $(1 - \rho)$ and the value of P_o was determined from the probability of occurrence of the arrival of through vehicle behind a stopped left turn vehicle.

Then, $Po = (1 - \rho) \leq 0.980$ (For 40 mph operating speed)

≤ 0.985 (For 50 mph operating speed)

≤ 0.990 (For 60 mph operating speed)

Depending on this condition, the boundary values of ρ for various operating speeds on two lane highways were derived as,

For 40 mph operating speed, $\rho \geq 0.02$

For 50 mph operating speed, $\rho \geq 0.015$

For 60 mph operating speed, $\rho \geq 0.01$

Different values of advancing traffic volumes were calculated and plotted against corresponding opposing traffic to come up with warrant curves for the left turn provision on different highways. These graphs were developed for different percentages of left turning traffic and operating speeds.

A sample graph (Figure 1) was derived using the author's (45) analytic procedure and is presented here for two lane highways with a left turn percentage of 5% and operating speed limit of 40 mph.

A graph (Figure 2) has been developed between opposing traffic and the average time that a left turning vehicle must wait for a suitable gap, t_w, using Harmelink's assumptions (45), to show the assumption of negative exponential distribution for service time.

So, Harmelink's (45) study was mostly analytical with some minor field tested data, which he mentions in his paper without giving any hard data for a reader's evaluation of its validity. Neuman (46) in NCHRP 279 essentially used them verbatim; and MDOT is currently using the same. It is important to note that Harmelink's study used field data (at least that is what author claims) for only a few input parameters.

The basic reasons for installation of a center lane for left turns are to:

- reduce delay for left turn and through vehicles
- decrease travel time
- reduce traffic conflict
- minimize left turn head-on accidents
- minimize other types of accidents

Therefore, a roadway situation must reach a point when all of the above noted problems are occurring at an intolerable level to road users, or are not cost beneficial, before installation of a center lane for left turning can show any objective benefit.

Several capacity analyses were performed using the nomograph values (as per NCHRP 279) to determine level of service of the main street traffic, including the left turning traffic as shown in Appendix II. In all the cases, the level of service for major streets' traffic came out to be "A", which means that the threshold volume levels and turning percentages for installation of the center lane for left turning is far too conservative and may not yield any measurable benefit in a real life situation. Thus, chances of being a cost beneficial treatment is almost none.

It is important to note that the current HCS technique for unsignalized intersections is being revised. In fact, all indications are that the 1985 procedure is too conservative. In any case, field validation of these curves are essential if we install a center lane for left turns on the basis of such curves.

The basic problem in NCHRP 279 & Harmelink's study is that neither reports defined what is the definition of warrant. In order to verify the observation, a four lane road near a strip commercial center in Macomb County was video taped for thirty-five minutes. This tape showed following traffic data:

WB 13 Mile Rd. Advancing Volume = 342

EB 13 Mile Rd. Opposing Volume = 459

Left turn Volume = 38

Total delay for Left turning vehicles = 88.7 sec. for 38 vehicles.

Another field verification study was performed on a four lane road near a strip commercial center in the City of Roseville. The traffic was video taped for twenty-five minutes and then the volume counts were done in the transportation lab at W.S.U.. The following volume data was observed:

WB Frazho Rd. Advancing Volume = 202

EB Frazho Rd. Opposing Volume = 145

Left turn Volume = 23

Total delay for Left turning vehicles = 47.2 sec. for 23 vehicles.

These volumes at the two sites were expanded to hourly volume rates and HCS analyses were performed. This analysis shows Level of Service for west bound left turning traffic. The average delay for west bound left turning traffic, in the field, was 2.33 sec. per vehicle (88.7 sec./ 38 veh. = 2.33 sec.) for the first site and 2.05 sec. per vehicle (47.2 sec./ 23 veh. = 2.05 sec.) for the second site.

No one can dispute that a 2.33 sec./veh. and a 2.05 sec./veh. delay is not an intolerable situation and should not require any treatment from the point of view of traffic operations. However, using fig.4-12 from NCHRP it can be seen that for 787 vph and 485 vph opposing volume, even 15 vph left turn traffic will require a center lane for left turn. This clearly proves that the early 1960's study lacked real world validity of what constitutes volume warrant for a center lane for left turn; and NCHRP 279 just copied it without even validating what was included in the report. The printed reports of the HCS analyses were included in Appendix III to show the level of service for the left turning traffic at the two sites.

Grade, Unsignalized Intersections

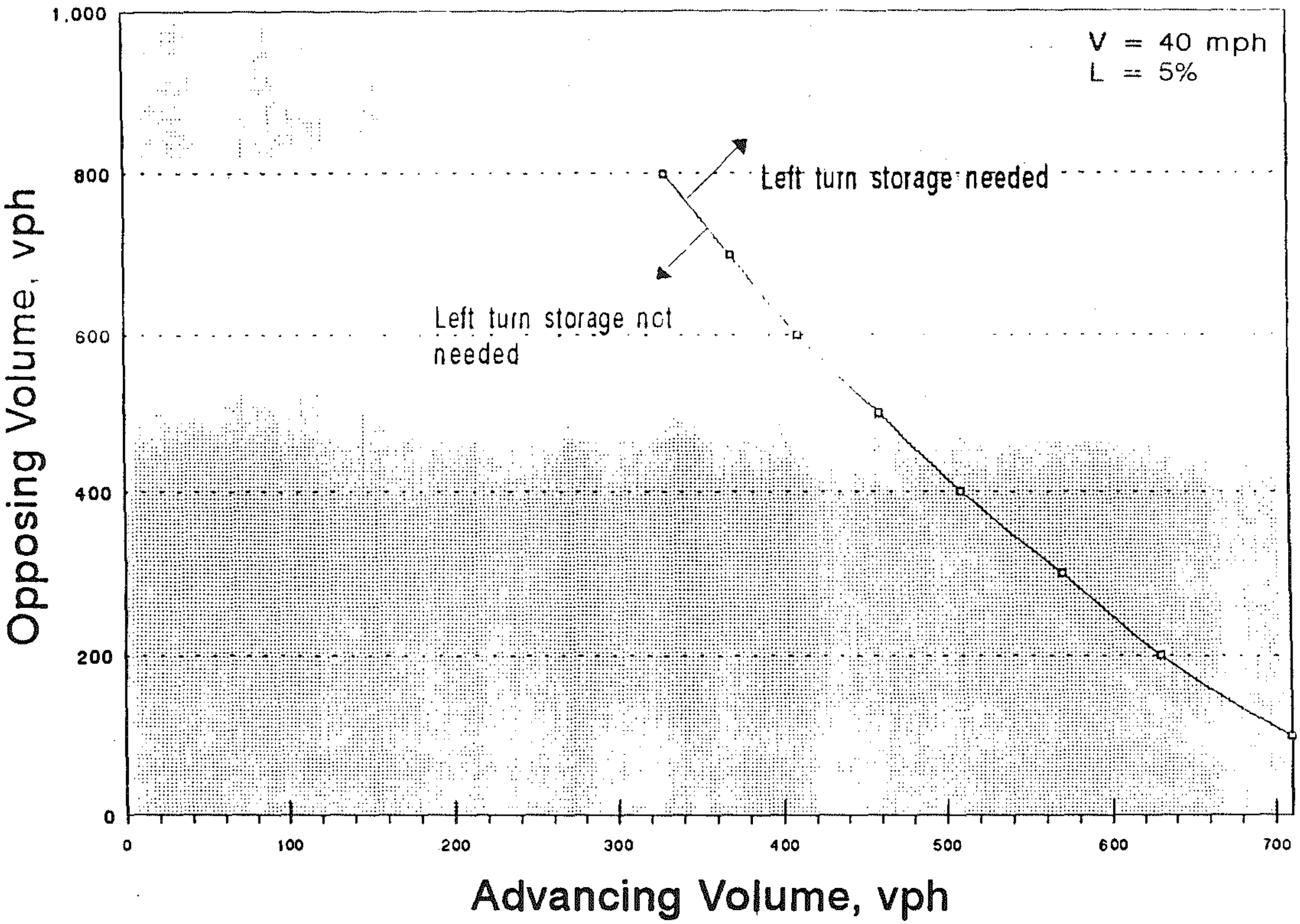
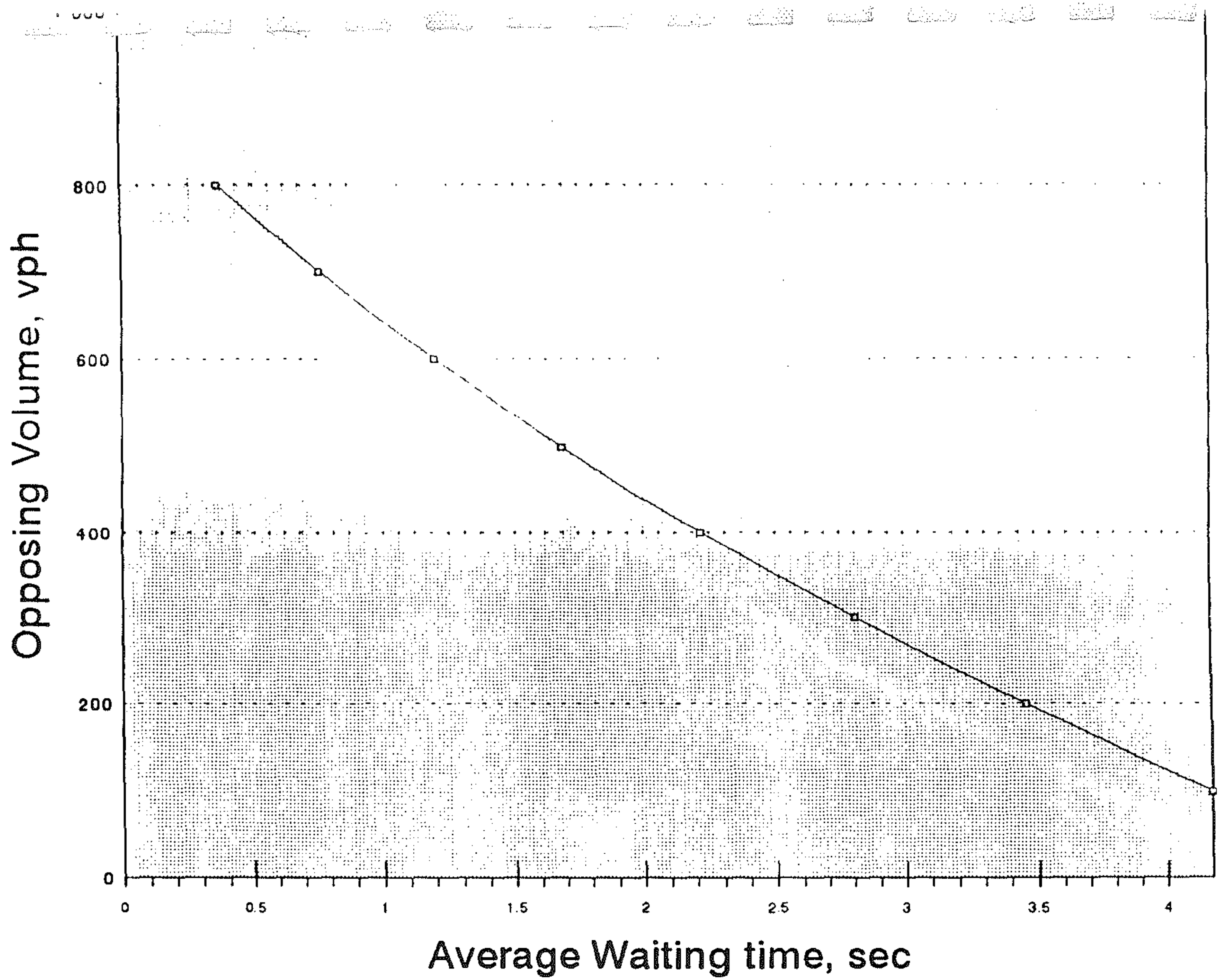
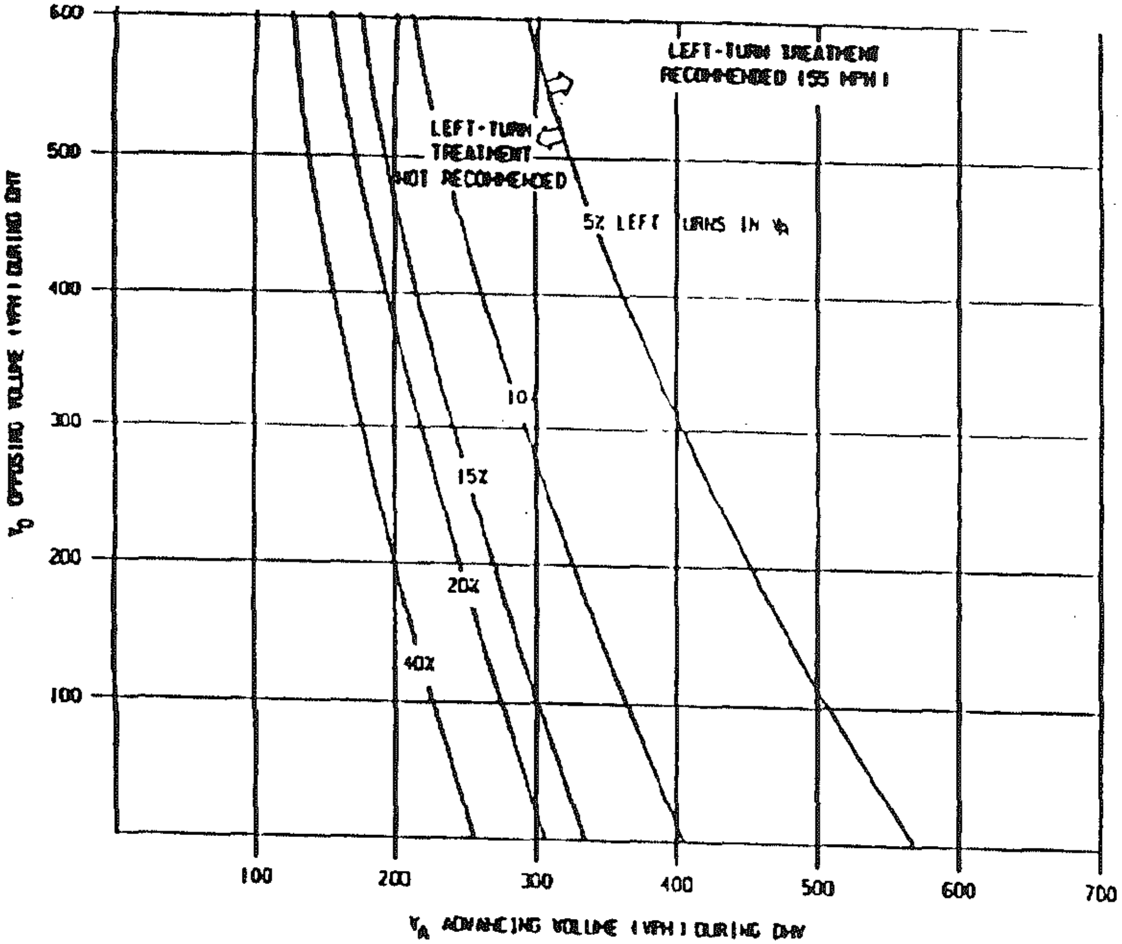


fig 1



Opposing Volume, vph
800
600
400
200
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Average Waiting time, sec

fig 2



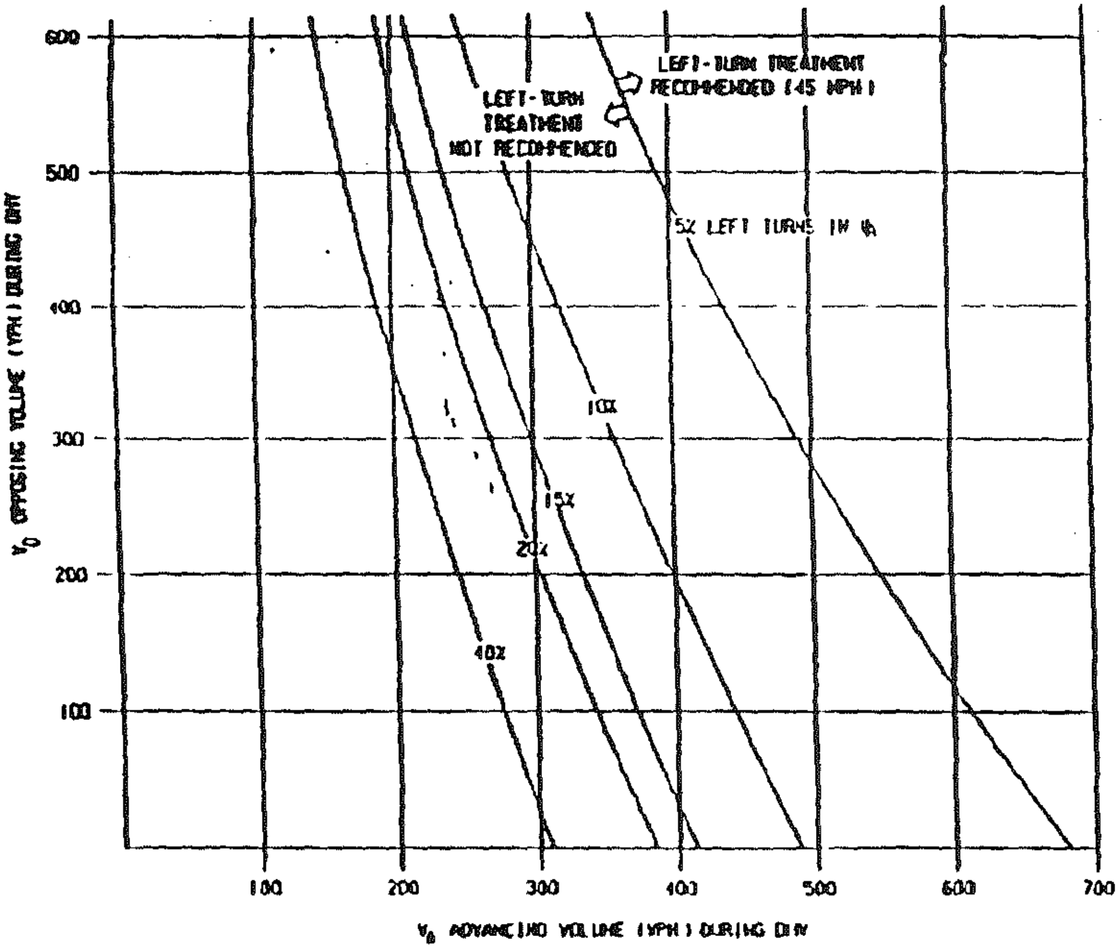
Instructions:

1. The family of curves represent the percentage of left turns in the advancing volume (V_A). The designer should locate the curve for the actual percentage of left turns. When this is not an even increment of 5, the designer should estimate where the curve lies.

2. Read V_A and V_O into the chart and locate the intersection of the two volumes.

3. Note the location of the point in #2 relative to the line in #1. If the point is to the right of the line, then a left-turn lane is recommended. If the point is to the left of the line, then a left-turn is not recommended based on traffic volumes.

TRAFFIC VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON TWO-LANE HIGHWAYS (POSTED SPEED 55 MPH)



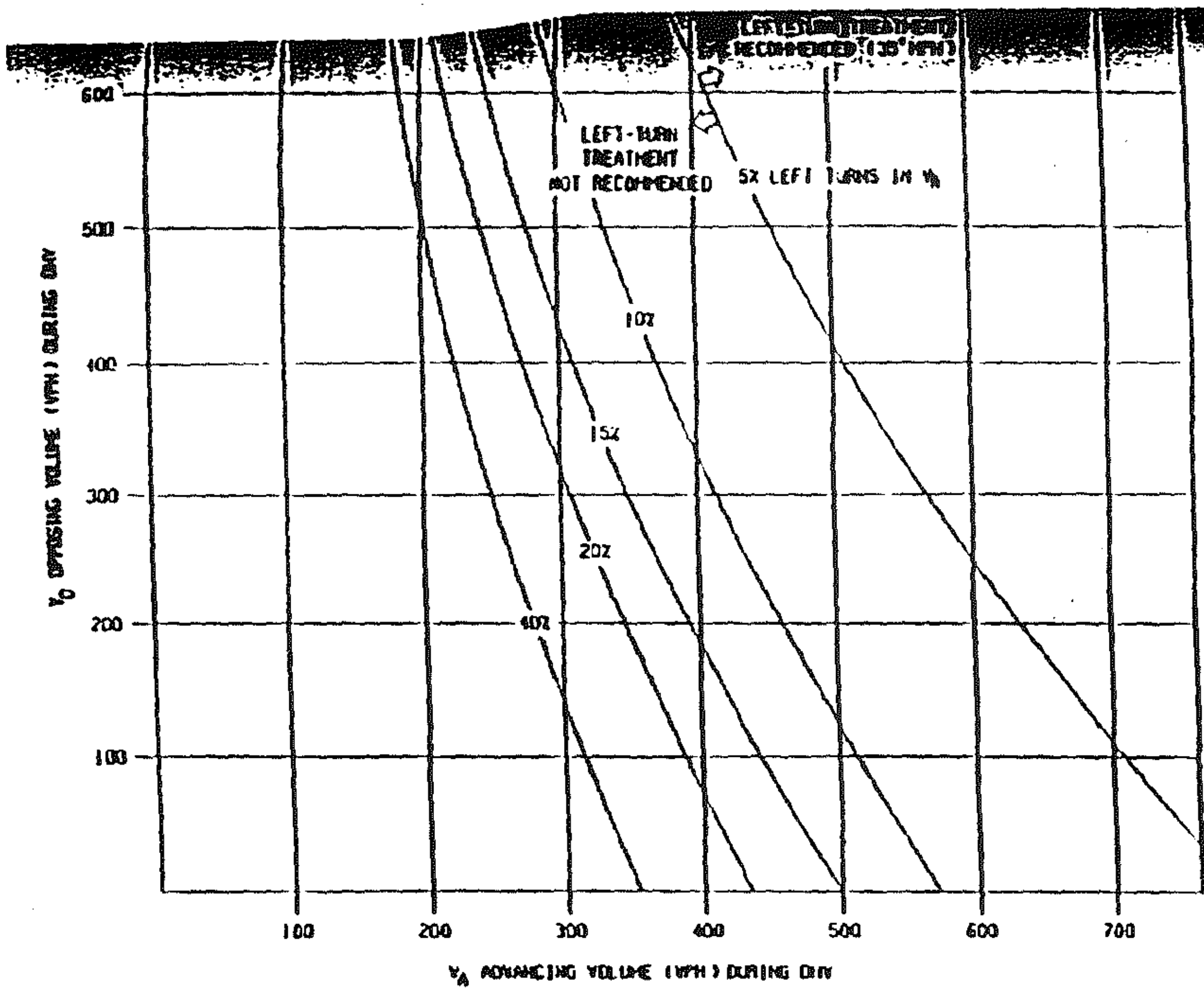
Instructions:

1. The family of curves represent the percentage of left turns in the advancing volume (V_A). The designer should locate the curve for the actual percentage of left turns. When this is not an even increment of 5, the designer should estimate where the curve lies.

2. Read V_A and V_O into the chart and locate the intersection of the two volumes.

3. Note the location of the point in #2 relative to the line in #1. If the point is to the right of the line, then a left-turn lane is recommended. If the point is to the left of the line, then a left-turn is not recommended based on traffic volumes.

TRAFFIC VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON TWO-LANE HIGHWAYS (POSTED SPEED 45 MPH)



1. The family of curves represent the percentage ... in the advancing volume (V_A). The designer ... locate the curve for the actual percentage of left turns. When this is not an even increment of 5, the designer ... should estimate where the curve lies.

2. Read V_A and V_O into the chart and locate the intersection of the two volumes.

3. Note the location of the point in #2 relative to the line in #1. If the point is to the right of the line, then a left-turn lane is recommended. If the point is to the left of the line, then a left-turn is not recommended based on traffic volumes.

__Example:__ Speed = 35mph
Advancing volume during DHV = 400vph
Opposing volume during DHV = 400vph
Percentage of left-turns in advancing volume = 7%

__Problem:__ Determine if left-turn lane is recommended.

__Solution:__ Figure indicates that the intersection of 400vph and 400vph is located to the left of the 7% curve (estimated); thus a left-turn lane is not recommended based on volumes.

TRAFFIC VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON TWO-LANE HIGHWAYS (POSTED SPEED 35 MPH)

APPENDIX II

Results of 1985 HCS analysis performed with different volumes on two lane highways from volume warrant curves used by MDOT

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 40

PEAK HOUR FACTOR.................................. .9

AREA POPULATION................................... 10000

NAME OF THE EAST/WEST STREET...................... STREET "A"

NAME OF THE NORTH/SOUTH STREET.................... STREET "B"

NAME OF THE ANALYST............................... TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/16/93

TIME PERIOD ANALYZED.............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND: STOP SIGN

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	25	0
THRU	0	--	600	500
RIGHT	20	--	0	25

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	0	20	N
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	5.90	5.40	0.00	5.40
MAJOR LEFTS					
	NB	5.20	5.20	0.00	5.20
MINOR LEFTS					
	EB	7.10	7.10	0.00	7.10

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	129	125	125	101	D
RIGHT	24	577	577	577	553	A
MAJOR STREET						
NB LEFT	31	644	644	644	613	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 40

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/16/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	20	0
THRU	0	--	400	500
RIGHT	20	--	0	20

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	0	20	N
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	5.90	5.40	0.00	5.40
MAJOR LEFTS					
	NB	5.20	5.20	0.00	5.20
MINOR LEFTS					
	EB	7.10	7.10	0.00	7.10

CAPACITY AND LEVEL-OF-SERVICE Page-3

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	182	178	178	153	D
RIGHT	24	579	579	579	555	A
MAJOR STREET						
NB LEFT	24	648	648	648	624	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 40

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/16/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	40	0
THRU	0	--	800	500
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	0	20	N
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	5.90	5.40	0.00	5.40
MAJOR LEFTS					
	NB	5.20	5.20	0.00	5.20
MINOR LEFTS					
	EB	7.10	7.10	0.00	7.10

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	88	84	84	60	E
RIGHT	24	571	571	571	547	A
MAJOR STREET						
NB LEFT	49	630	630	630	581	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 55

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	80	0
THRU	0	--	120	200
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	6.50	5.50	0.00	5.50
MAJOR LEFTS					
	NB	5.50	5.50	0.00	5.50
MINOR LEFTS					
	EB	8.00	8.00	0.00	8.00

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	375	347	347	322	B
RIGHT	24	846	846	846	821	A
MAJOR STREET						
NB LEFT	98	823	823	823	726	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 55

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	64	0
THRU	0	--	96	400
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS	EB	6.50	5.50	0.00	5.50
MAJOR LEFTS	NB	5.50	5.50	0.00	5.50
MINOR LEFTS	EB	8.00	8.00	0.00	8.00

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	275	253	253	229	C
RIGHT	24	652	652	652	627	A
MAJOR STREET						
NB LEFT	78	636	636	636	557	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 55

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	30	0
THRU	0	--	270	300
RIGHT	20	--	0	30

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	6.50	5.50	0.00	5.50
MAJOR LEFTS					
	NB	5.50	5.50	0.00	5.50
MINOR LEFTS					
	EB	8.00	8.00	0.00	8.00

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	257	250	250	225	C
RIGHT	24	745	745	745	721	A
MAJOR STREET						
NB LEFT	37	730	730	730	693	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 45

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	80	0
THRU	0	--	120	200
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

	TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS				
EB	6.10	5.10	0.00	5.10
MAJOR LEFTS				
NB	5.30	5.30	0.00	5.30
MINOR LEFTS				
EB	7.40	7.40	0.00	7.40

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	413	382	382	358	B
RIGHT	24	943	943	943	918	A
MAJOR STREET						
NB LEFT	98	823	823	823	726	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 45

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	64	0
THRU	0	--	96	400
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS	EB	6.10	5.10	0.00	5.10
MAJOR LEFTS	NB	5.30	5.30	0.00	5.30
MINOR LEFTS	EB	7.40	7.40	0.00	7.40

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	309	285	285	260	C
RIGHT	24	740	740	740	716	A
MAJOR STREET						
NB LEFT	78	636	636	636	557	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 45

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	30	0
THRU	0	--	270	300
RIGHT	20	--	0	30

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

	TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS				
EB	6.10	5.10	0.00	5.10
MAJOR LEFTS				
NB	5.30	5.30	0.00	5.30
MINOR LEFTS				
EB	7.40	7.40	0.00	7.40

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	290	282	282	257	C
RIGHT	24	843	843	843	818	A
MAJOR STREET						
NB LEFT	37	730	730	730	693	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 35

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	80	0
THRU	0	--	120	200
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

	TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS				
EB	5.70	4.70	0.00	4.70
MAJOR LEFTS				
NB	5.10	5.10	0.00	5.10
MINOR LEFTS				
EB	6.80	6.80	0.00	6.80

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	457	427	427	403	A
RIGHT	24	998	998	998	973	A
MAJOR STREET						
NB LEFT	98	922	922	922	824	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 35

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	64	0
THRU	0	--	96	400
RIGHT	20	--	0	40

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

	TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS				
EB	5.70	4.70	0.00	4.70
MAJOR LEFTS				
NB	5.10	5.10	0.00	5.10
MINOR LEFTS				
EB	6.80	6.80	0.00	6.80

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	347	324	324	299	C
RIGHT	24	842	842	842	817	A
MAJOR STREET						
NB LEFT	78	722	722	722	643	A

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.............. 35

PEAK HOUR FACTOR................................. .9

AREA POPULATION.................................. 10000

NAME OF THE EAST/WEST STREET..................... STREET "A"

NAME OF THE NORTH/SOUTH STREET................... STREET "B"

NAME OF THE ANALYST.............................. TD

DATE OF THE ANALYSIS (mm/dd/yy).................. 12/14/93

TIME PERIOD ANALYZED............................. PEAK HOUR

OTHER INFORMATION:

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: NORTH/SOUTH

CONTROL TYPE EASTBOUND:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	20	--	30	0
THRU	0	--	270	300
RIGHT	20	--	0	30

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	--	1	1

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	Y
WESTBOUND	-----	---	---	-
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	---	---	---
NORTHBOUND	0	0	0
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	EB	5.70	4.70	0.00	4.70
MAJOR LEFTS					
	NB	5.10	5.10	0.00	5.10
MINOR LEFTS					
	EB	6.80	6.80	0.00	6.80

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
EB LEFT	24	326	318	318	293	C
RIGHT	24	948	948	948	923	A
MAJOR STREET						
NB LEFT	37	827	827	827	790	A

APPENDIX III

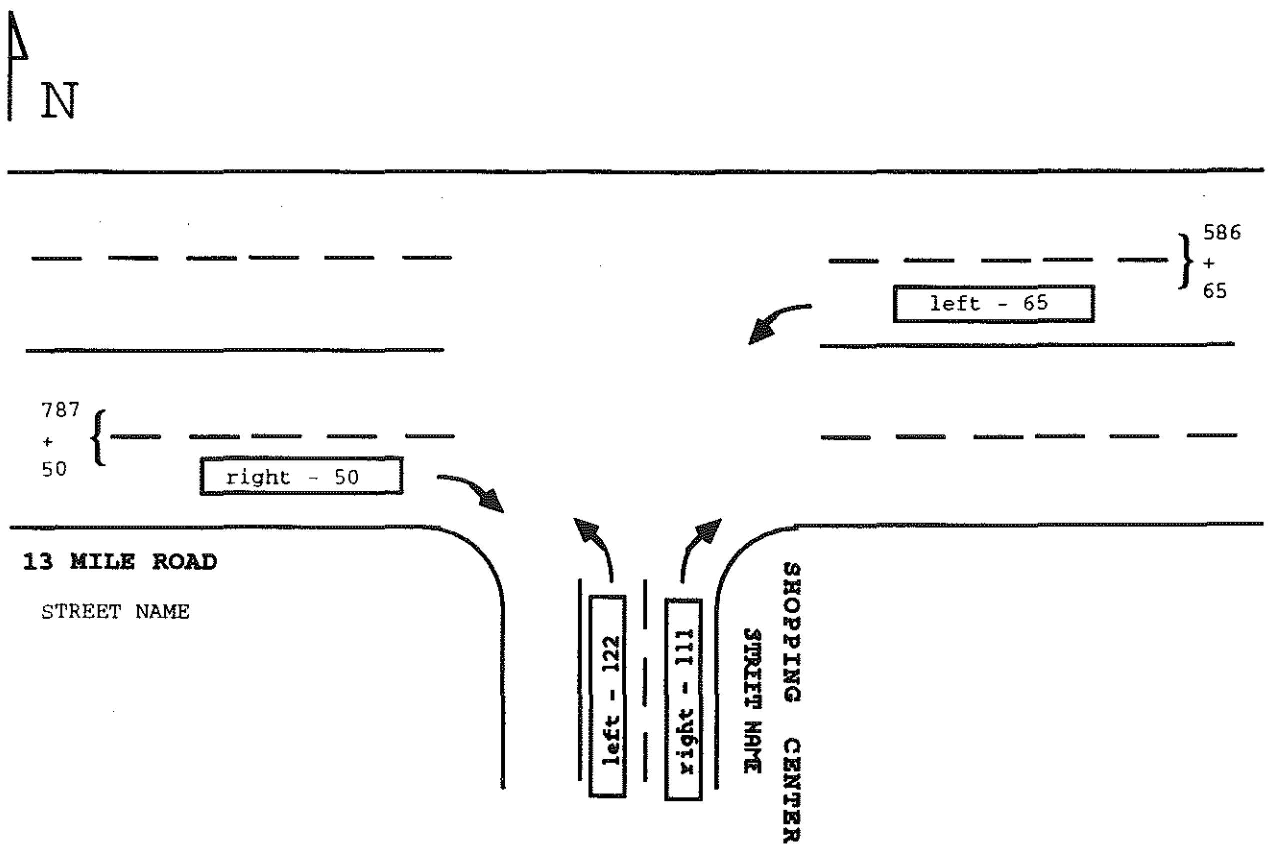
Field Studies to Test Volume Warrants in NCHRP 279

STUDY #1

LOCATION: 13 Mile Road west of Harper Avenue
St. Clair Shores, Michigan
DATE OF STUDY: February 6, 1994
TIME PERIOD OF STUDY: 2:00 P.M. to 2:35 P.M.

METHOD OF ANALYSIS

The area for analysis was video taped for 35 minutes and the volume counts were recorded upon return to the lab. The volume counts were extrapolated to hourly volume counts based on the recorded volume counts taken from the video tape. The following diagram is representative of the study area.



The following table contains the summarized results of this study.

MOVEMENT	EASTBOUND (VPH)	WESTBOUND (VPH)	NORTHBOUND (VPH)
Left	0	65	122
Thru	787	586	0
Right	50	0	111

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.. 35

PEAK HOUR FACTOR..................... .85

AREA POPULATION...................... 2500000

NAME OF THE EAST/WEST STREET......... 13 MILE RD.

NAME OF THE NORTH/SOUTH STREET....... DRIVEWAY [KROGER]

NAME OF THE ANALYST.................. TD

DATE OF THE ANALYSIS (mm/dd/yy)...... 2.7.94

TIME PERIOD ANALYZED................. OFF PEAK

OTHER INFORMATION....

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: EAST/WEST

CONTROL TYPE NORTHBOUND: STOP SIGN

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	0	65	122	--
THRU	787	586	0	--
RIGHT	50	0	111	--

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	2	2	--

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	N
WESTBOUND	0.00	90	20	N
NORTHBOUND	0.00	90	20	N
SOUTHBOUND	-----	---	---	-

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	0	0	0
NORTHBOUND	0	0	0
SOUTHBOUND	---	---	---

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	NB	5.70	5.20	0.00	5.20
MAJOR LEFTS					
	WB	5.60	5.10	0.00	5.10
MINOR LEFTS					
	NB	7.30	6.80	0.00	6.80

IDENTIFYING INFORMATION

NAME OF THE EAST/WEST STREET...... 13 MILE RD.
NAME OF THE NORTH/SOUTH STREET.... DRIVEWAY [KROGER]
DATE AND TIME OF THE ANALYSIS..... 2.7.94 ; OFF PEAK
OTHER INFORMATION....

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
NB LEFT	158	83	70	70	-88	F
RIGHT	144	685	685	685	541	A
MAJOR STREET						
WB LEFT	84	390	390	390	306	B

IDENTIFYING INFORMATION

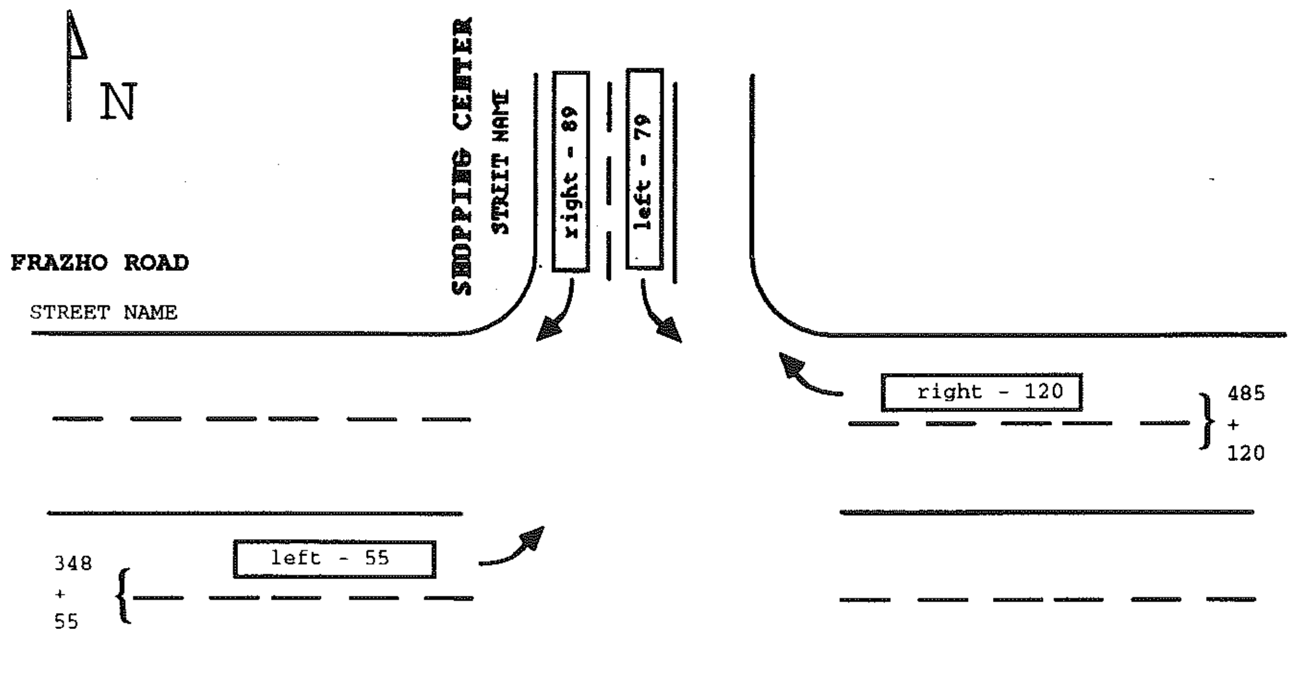
NAME OF THE EAST/WEST STREET...... 13 MILE RD.
NAME OF THE NORTH/SOUTH STREET.... DRIVEWAY [KROGER]
DATE AND TIME OF THE ANALYSIS..... 2.7.94 ; OFF PEAK
OTHER INFORMATION....

STUDY #2

LOCATION: Frazho Road east of Gratiot Avenue
Roseville, Michigan
DATE OF STUDY: February 17, 1994
TIME PERIOD OF STUDY: 11:00 A.M. to 11:25 A.M.

METHOD OF ANALYSIS

The area for analysis was video taped for 25 minutes and the volume counts were recorded upon return to the lab. The volume counts were extrapolated to hourly volume counts based on the recorded volume counts taken from the video tape. The following diagram is representative of the study area.



The following table contains the summarized results of this study.

MOVEMENT	EASTBOUND (VPH)	WESTBOUND (VPH)	SOUTHBOUND (VPH)
Left	55	0	79
Thru	348	485	0
Right	0	120	89

****

IDENTIFYING INFORMATION

AVERAGE RUNNING SPEED, MAJOR STREET.. 30

PEAK HOUR FACTOR..................... 1

AREA POPULATION...................... 150000

NAME OF THE EAST/WEST STREET......... Frazho

NAME OF THE NORTH/SOUTH STREET....... Gratiot Ave.

NAME OF THE ANALYST.................. Aimee

DATE OF THE ANALYSIS (mm/dd/yy)...... 02/17/94

TIME PERIOD ANALYZED................. non peak

OTHER INFORMATION....

INTERSECTION TYPE AND CONTROL

INTERSECTION TYPE: T-INTERSECTION

MAJOR STREET DIRECTION: EAST/WEST

CONTROL TYPE SOUTHBOUND: STOP SIGN

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	55	0	--	79
THRU	348	485	--	0
RIGHT	0	120	--	89

NUMBER OF LANES

	EB	WB	NB	SB
LANES	2	2	--	2

ADJUSTMENT FACTORS

	PERCENT GRADE	RIGHT TURN ANGLE	CURB RADIUS (ft) FOR RIGHT TURNS	ACCELERATION LANE FOR RIGHT TURNS
EASTBOUND	0.00	90	20	N
WESTBOUND	0.00	90	20	N
NORTHBOUND	-----	---	---	-
SOUTHBOUND	0.00	90	20	N

VEHICLE COMPOSITION

	% SU TRUCKS AND RV'S	% COMBINATION VEHICLES	% MOTORCYCLES
EASTBOUND	0	0	0
WESTBOUND	0	0	0
NORTHBOUND	---	---	---
SOUTHBOUND	0	0	0

CRITICAL GAPS

		TABULAR VALUES (Table 10-2)	ADJUSTED VALUE	SIGHT DIST. ADJUSTMENT	FINAL CRITICAL GAP
MINOR RIGHTS					
	SB	5.50	5.50	0.00	5.50
MAJOR LEFTS					
	EB	5.50	5.50	0.00	5.50
MINOR LEFTS					
	SB	7.00	7.00	0.00	7.00

IDENTIFYING INFORMATION

NAME OF THE EAST/WEST STREET...... Frazho
NAME OF THE NORTH/SOUTH STREET.... Gratiot Ave.
DATE AND TIME OF THE ANALYSIS..... 02/17/94 ; non peak
OTHER INFORMATION....

MOVEMENT	FLOW-RATE v(pcph)	POTEN-TIAL CAPACITY c_p (pcph)	ACTUAL MOVEMENT CAPACITY c_M (pcph)	SHARED CAPACITY c_{SH} (pcph)	RESERVE CAPACITY $c_R = c_{SH} - v$	LOS
MINOR STREET						
SB LEFT	87	210	195	195	108	D
RIGHT	98	788	788	788	690	A
MAJOR STREET						
EB LEFT	61	552	552	552	491	A

IDENTIFYING INFORMATION

NAME OF THE EAST/WEST STREET...... Frazho
NAME OF THE NORTH/SOUTH STREET.... Gratiot Ave.
DATE AND TIME OF THE ANALYSIS..... 02/17/94 ; non peak
OTHER INFORMATION....