MD–88/23

Maryland Department of Transportation

STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

STATE–OF–THE–ART STUDIES/FY87

INCREASING INTERSECTION CAPACITY WITH ADDITIONAL THROUGH LANES

AW800–007–046 (TASK 5)
FINAL REPORT

OCTOBER 1987

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. MD 88-23	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle State-of-the-Art Studies/FY 87 Task 5 - Increasing Intersection Capacity With Additional Through Lanes		5. Report Date October, 1987
		6. Performing Organization Code
7. Author(s) Melody Dai, Everett C. Carter - Paul M. Schonfeld		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Maryland, Department of Civil Engineering, College Park, MD 20742		10. Work Unit No.
		11. Contract or Grant No. AW 800-007-046 Task 5
12. Sponsoring Agency Name and Address Maryland Department of Transportation, State Highway Administration, 707 N. Calvert Street, Baltimore, MD 21202		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A review of the literature and a state-of-the-practice survey were conducted of procedures relating to the addition of through lanesat intersections. The capacity and level of service change at the intersection is of interest, since the reduction in delays and congestion are the primary reason for adding through lanes. The total length of the additional through lanes, including in advance of and beyond the intersection and associated tapers is important in the effect on utilization and hence capacity.

Definitive field studies and analyses are recommended to determine the minimum lengths for additional through lanes.

17. Key Words INTERSECTION WIDENING; INTERSECTION CAPACITY; ADDITIONAL THROUGH LANES: LENGTH OF ADDITIONAL LANES		18. Distribution Statement	
19. Security Classif. (of this report) None	20. Security Classif. (of this page) None	21. No. of Pages 34	22. Price

Form DOT F 1700.7 (8-69)

INCREASING INTERSECTION CAPACITY

with

ADDITIONAL THROUGH LANES

State of the Art

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October, 1987

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CONTENTS

I. INTRODUCTION

1.1 Problem Statement

Additional through lanes have been used as a strategy to solve the problems of intersection congestions for a long time. In general, bottlenecks often occur at intersections because intersections not only have the problems of space sharing but also have the problems of time sharing (right of way) and directional conflicts. Therefore, improving the use efficiency of intersections during green time will increase intersection capacity. However, there are some problems in using additional through lanes. These problems are as follows:

1. the ability to add additional through lanes,
2. the capacity analysis for additional through lanes,
3. the required length of additional through lanes (including taper) beyond the intersections,
4. the required length of additional through lanes (including taper) needed in advance of the intersections.

This report reviewed and discussed related studies concerning the above problems and conducted a survey to determine the current design methods in the U.S.

1.2 Organization

This report focuses on the discussion of the results of some previous studies concerning additional through lanes, the state of practice in some states, and some recommendations.

There are five sections in the report. Section II presents related literature about capacity analysis, lane use, and required lengths in advance of and beyond intersections. Section III depicts the current analysis guidelines in the U.S. Section IV discusses the information presented in Sections II and III, and hence recommends some further needed research. Section V summarizes the results and presents recommendations.

II. LITERATURE REVIEW

This chapter discusses some existing studies dealing with additional through lanes. There are two major topics in this chapter. The first one is capacity analysis of additional through lanes. This topic includes the methods of capacity analysis and the use of additional through lanes. The second one is the required length of these additional lanes as well as beyond intersections. In general, the longer an additional through lane, the better the operation, but also the more expensive it is. Therefore, the minimum required length which can provide a satisfactory operation is an important factor for the design of additional through lanes.

2-1 Capacity Analysis

The Australian Road Capacity Guide (1) suggests that an additional through lane would be treated in the same way as a through curb lane blocked by parked vehicles on the approach and exit sides of the intersection.

The Highway Capacity Manual (2) presents lane-utilization factors for the capacity analysis of signalized intersections. These lane utilization factors are based on the critical movement analysis procedure in the Transportation Research Board (TRB) Circular 212(3), which modified the research by Reilly (4,5), Bellis(6), and Messer and Fambro(7) according to operational experience. The value for lane utilization factors when two lanes are available represents a 52.5% / 47.5% split. The value for lane utilization factors when three lanes are available assumes that approximately 37% of the volume is carried in the most heavily used lane.

Although the Highway Capacity Manual (2) indicates that lane utilization factors are applicable to parking lanes, TRB Circular 212(3) does not include lane utilization factors specifically for through lanes of limited length. Lane use studies were conducted by Miller (8), who suggested that the lane utilization factors in TRB Circular 212(3) would be inappropriate for determining the level of service of a signalized intersection with additional through lanes.

In fact, the degree to which additional through lane increases the capacity at the intersection depends on the extent to which it is used by through vehicles. For a given intersection, drivers' lane choices will determine lane utilization and saturation flows. Some previous research (9,10,11) proposes that the use of an additional through lane by through vehicles depends on drivers' perceptions of the travel time savings to be realized by using it. Akcelik(11) further indicates that perceived delays are due both to the length and the composition of the queue.

It was determined by Miller (8) that an average of 1.5 through vehicles per cycle use parking lanes. This average use by through vehicles is for approaches with three or more lanes and no vehicles parked within 100 feet upstream from the stop line. It also was concluded from these studies that one parked vehicle 500 ft downstream from the intersection has as much effect on lane use by through vehicles as one parked only 200 feet downstream. Thus, a parking lane must have a length beyond the intersection of more than 500 feet to achieve the average through vehicle use of more than 1.5 through vehicles per cycle.

McCoy and Tobin (12) also conducted lane use studies during peak periods. The approaches were on a two-lane, two-way street that had been widened at the intersections to add a left-turn lane and another through lane on the approaches. The lane use studies were conducted only during peak periods when the green times on the study approaches were fully utilized by lane utilization factors specifically for through lanes of limited length. Lane use studies were conducted by Miller (8), who suggested that the lane utilization factors in TRB Circular 212(3) would be inappropriate for determining the level of service of a signalized intersection with additional through lanes.

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From the studies of McCoy and Tobin (12), the use of through lanes fits a Poisson distribution with a mean that is a linear function of lane length and green time. A regression analysis was conducted by McCoy and Tobin (12), and hence the following relationship was found:

$$STR = 1.24 + 0.00058\ (Da + Db) - 0.021\ G$$

where

STR = mean number of through vehicles (passenger cars) discharging from an additional through lane per cycle,

Da = length of additional through lane in advance of stop line (ft.)

Db = length of additional through lane beyond stop line (ft),

G = green time for through and right-turn movement on approach (sec).

The above relationship is statistically significant, at the 1 per cent level.

From the above equation, the relationship between the use of additional through lanes by through vehicles, the length of an additional through lane and the green time for the through movement on an approach can be determined. The longer the length of an additional through lane, the higher is the use of the additional through lane by through vehicles. Conversely, the longer the time for the through movement on an approach, the lower is the use of the additional through lane by through vehicles.

A methodology was developed by Akcelik (11) to evaluate the increased capacity due to additional through lanes. The most important step in this methodology is to determine whether the additional through lane effects will occur or not. The effects of the additional through lane depend on the space available for queuing. When the space for queuing is limited, the saturation flow of the additional through lane is:

$$sl' = sl \times gl / g = D / (j \times g)$$

where

sl' = the saturation flow of the additional through lane when space for queuing is limited (veh/sec),

sl = the full saturation flow under normal conditions (veh/sec),

gl = the period which the full saturation flow (S1) will last (sec),

g = green time for the through vehicles on the approach (sec),

D = the length of the additional through lane in advance of the intersection (ft)

j = average queue space (ft/veh).

The steps used to apply this methodology are as follows:

(1) calculate full movement saturation flow using the normal estimation method.

(2) Calculate the critical queuing distance, Dc, from:

$$Dc = j \times q \times r \ \{n \times (1 - y)\}$$

where:

j = average queue space (ft/sec),

q = arrival flow rate (veh/sec),

r = effective red time (sec)

n = number of lanes available including the additional through lane,

y = flow ratio (= q/s, where s is the movement saturation flow calculated in (1) assuming no additional through lane effects).

(3) Compare the available length of the additional through lane, D, with the critical distance, Dc, and hence determine whether the additional through lane effect occurs. If such an effect does not occur, the saturation flow is as calculated in (1). Otherwise, it is equal to the sum of sl' and the saturation flow of the other available lanes.

According to the above procedures, the increased capacity is calculated as the difference in the saturation flow before and after the additional through lane is implemented.

Akcelik's model assumes that each through lane will have an equal length of queue on the approach. The approach in Akcelik's model is different from that in the Highway Capacity Manual (2). Akcelik (11) calculates the increased capacity by adjusting the saturation flow. However, the Highway Capacity Manual evaluates the improved level of service by adjusting the volume.

Besides Akcelik, Bang (10) also developed a model to evaluate the effect of restricted length of an approach lane. The concept of this model is similar to Akcelik's. The saturation flow of an additional through lane is a function of its length and the green time for through vehicles on the approach. Therefore, based on Akcelik's and Bang's models, the capacity of an additional through lane can be increased to its maximum value of full saturation flow by either increasing the lane length or decreasing the green time.

2-2 The Required Length

The required length of an additional through lane includes two sections: in advance of and beyond the intersection. Both of these sections include tapers.

2-2-1 The Required Length in Advance of Intersections

The required length in advance of an intersection is the distance which is measured backwards from the stop line on the approach to the taper.

Leisch (13) has recommended two methods for the analysis of required length without explanation. The first is based on deceleration and the second is based on storage. Table 2-1 lists the recommended required length by Leisch (13). D_a, in Table 2-1, is the required length in advance of an intersection.

Table 2-1 Required Length in Advance of Intersection

Length Required For: *		
Deceleration		
Design Speed mph	D_a ft	.Divide approach volume by number of lanes in Wa
40	150	.Use volume per lane to calculate required storage space
50	200	
60	250	

*Use the larger of two values but not less than 200 ft.

For design speeds of 40, 50, and 60 mph, the tapers recommended by Leisch (13) are 175, 225, and 275 ft, respectively. Compared with the lengths of deceleration and auxiliary lane taper which are recommended by AASHTO at intersections (14), the total D_a values due to deceleration and corresponding taper in Table 2-1 are slightly lower.

According to the recommendations of Leisch (13), when an additional through lane is provided by elimination of parking in advance of the intersection, measuring back from the stop line on the approach, a distance, in feet, at least eight times the green interval in seconds (8G) should be provided, but not less than 250 feet.

The AASHTO A Policy on Geometric Design of Highways and Streets (14) does not specifically address this problem. But AASHTO (14) suggests that an auxiliary lane at an intersection should consist of three components: (1) deceleration length, (2) storage length, and (3) taper. Therefor, to have additional through lanes operate smoothly, the length of an additional through lane should be based on deceleration as well as storage requirements.

2-2-2 The Required Length Beyond Intersections

The required length beyond an intersection is the distance measured forward from the stop line on the approach to the taper. AASHTO in the, A Policy on Geometric Design of Highways and Streets (14), does not specifically deal with this problem either.

Leisch (13) recommended two methods for the analysis of this required length. The first is based on acceleration and the second is based on merging. Table 2-2 lists the recommended required length by Leisch (13). D_b in Table 2-2, is the required length beyond the intersection.

Table 2-2 Required Length Beyond Intersections

Length Required For: *		
Acceleration		Merging
Design Speed	D_b ft	$D_b = 12 \times G$
40	200	(G, Green Interval in seconds)
50	525	
60	900	

* Use the larger of two values but not less than 300 ft.

Source: Ref 13

For design speeds of 40, 50, and 60 mph, the tapers recommended by Leisch (13) are 200, 250, 300 ft, respectively. Guell (15) thinks that Leisch based these values on the concept of acceleration lanes, and hence considers it inappropriate to use the length for acceleration lanes as length requirements for additional through lanes.

Leisch's method based on merging may assume that a car enters the intersection every 2.1 sec during the green phase and that the storage length would be approximately 12 times the green phase when each vehicle occupies 25 ft of storage space. If this interpretation of the length based on merging is correct, some storage must occasionally take place within the intersection or within the taper.

Leisch (13) also recommended that when an additional through lane is provided by elimination of parking through the intersection, the length required beyond the intersection, should be for a distance in feet at least equal to 12 times the green interval in seconds (12G), but not less than 350 feet.

A paper by Miller (8) found that the length given by Leisch (13) for additional through lanes beyond intersections may be too short to achieve the lane utilization factors proposed in TRB Circular 212. McCoy and Tobin (12) also indicate that the minimum lengths required beyond intersections developed by Leisch (13) may be too short to achieve the average utilization of more than 1.5 cars per cycle during peak periods. Indeed, to operate smoothly, the design of additional through lanes not only has to consider storage, but also other factors, such as design speed, profile grade and traffic mix.

Guell (15) developed a theoretical method to estimate the required lane length beyond an intersection. This method is based on the consideration of a line of vehicles waiting at an intersection for the signal to turn green. When a vehicle merges into a line of traffic, Guell (15) found that the headways would be less than the minimum desirable headway of 1.8 sec. This headway value is associated with uninterrupted flow at capacity (2000 passenger cars per hour per lane). Therefore, Guell (15) concluded that the vehicles on additional through lanes would wait until the primary lane had cleared and merged in behind it to minimize the possibility for rear end accidents.

Based on Guell's model, for full utilization of a 31 second green phase, the required length beyond the intersection will be more than 2,000 ft., not usually practical.

III. STATE OF THE PRACTICE SURVEY

For this study, a questionnaire was sent to all states in the United States to obtain data, evaluation methods and guidelines used for analyzing and designing additional through lanes.

The following lists the responses to the questionnaire which have been received:

1. Arkansas, Illinois, New York State, Oregon, South Carolina and Wisconsin use the Highway Capacity Manual (2) as a guideline to evaluate additional through lanes.
2. Hawaii and Wisconsin use the AASHTO A Policy on Geometric Design of Highways and Streets (14) as a design guideline.
3. South Carolina analyzes merging problems using the Manual on Uniform Traffic Control Device (16).
4. In Oregon, additional through lanes are considered when an intersection cannot maintain a satisfactory level of service. The analysis of capacity uses the procedures in the Highway Capacity Manual, 1985 (2).
5. In South Carolina, adding an additional through lane is determined by existing geometric and volume conditions, the conflict traffic, the size of the gaps in conflicting traffic streams and the capacity.
6. In Wisconsin, decisions to provide additional through lanes are based on analysis of delays caused if turning movements are not accommodated.
7. In Indiana, the need for additional through lanes is determined by conducting capacity analysis, evaluating downstream merge problems and upstream storage available.

8. In Missouri, the need for additional through lanes is evaluated, based on analyses of accidents and capacity. Accident data are provided from the statewide highway accident file.

9. In Seattle, three factors considered for additional through lanes are level of service, right of way costs and public transit needs.

10. In Montana, the biggest problem in providing additional through lanes is funding.

11. Additional through lanes are not normally used in Dallas and Milwaukee.

In summarizing the responses received, it appears that the Highway Capacity Manual and the AASHTO manual are the most frequently used references for design guidelines. In addition, the provision of additional through lanes should be based on analysis of some of the following aspects: level of service, capacity, traffic volume, geometric conditions, traffic, conflicts, delay, downstream merging, upstream storage, accidents, and costs.

IV. DISCUSSION

This section will discuss the information obtained from the review of the literature and current practices.

4-1 Analytic Considerations for Additional Through Lanes

According to the questionnaire responses received, decisions to provide additional through lanes are based on the following kinds of analysis:

1. level of service
2. capacity
3. traffic volume
4. traffic conflict
5. delay
6. geometric conditions
7. downstream merging
8. upstream storage
9. accident records
10. costs

The first five items above can be incorporated into a complete capacity analysis. This should analyze not only the capacity of the intersection, but also the capacity of the basic section between two intersections to include items 6, 7 and 8 above.

In fact, the provision of an additional through lane is based on comparison of the levels of service of the intersection and the basic section. Generally, for a basic section one only has to deal with the problem of space sharing, time sharing, and directional conflicts. That is the reason why intersections are usually the bottlenecks along highways. Therefore, a basic section can usually maintain an acceptable service level such as C or better when the nearby intersections are operating at levels such as D or E. In such a situation, it is not economical to construct a full lane but a short additional through lane may be justified. Before implementing an additional through lane, modifications such as a signal control, lane use, parking prohibition, bus stop removal, and pedestrian prohibition should be evaluated. Such alternatives may sometimes improve the operation of intersections and increase the capacity of intersections at low cost. If such improvements cannot produce desirable service levels at an intersection, than an additional through lane should be considered, subject to evaluations of geometric conditions, downstream merging, upstream storage, accident records, and construction costs.

The following procedure may be used to determine whether an additional through lane should be provided:

1. Conduct complete capacity analyses for the intersection and the basic section.
2. Evaluate improvement alternatives with lower costs. These alternatives include signal control/cycle/phase, modification, lane use alternatives, parking and pedestrian prohibition, and bus stop modification.
3. Evaluate geometric conditions, downstream merging, upstream storage, accident records, and construction costs for adding an additional through lane, if the alternatives considered in step 2 cannot improve the operation of the intersection to a desirable service level.

4-2 Analysis of Increased Capacity

The literature review findings on capacity analysis are summarized as follows:

1. The Australian Road Capacity Guide (1) suggested that an additional through lane would be treated in the same way as a through parking lane.
2. The Highway Capacity Manual (2) indicates that the analysis procedures for signalized intersections are applicable to parking lanes.
3. Miller (8) argued that the Highway Capacity Manual (2) would be inappropriate for capacity analysis of a signalized intersection with additional through lanes.
4. Miller (8), McCoy and Tobin (12) found that an average of 1.5 through vehicles per cycle use additional through lanes when the lengths of additional through lanes are less than 1,200 ft.
5. The longer the length of an additional lane, the higher the use of this lane by through vehicles (12). The use of additional through lanes by through vehicles increases as the length of such lanes increases.
6. The longer the green time for the through vehicles on an approach, the lower the use of the additional through lane by through vehicles (12).
7. Akcelik (11) proposed that the capacity of an additional through lane is determined by the space needed for queuing.
8. Bang (10) developed a model to analyze the saturation flow of an additional through lane as a function of its length and the green time for through vehicles on the approach. This model is similar to Akcelik's.

From the above summary, it seems that there are considerable conflicts among these previous studies, based on different view points. Some studies deal with the saturation flow of additional through lanes, while others deal with adjustment volume of additional through lanes. These two aspects are both very important and should be incorporated jointly in methodologies of capacity analysis, such as the Highway Capacity Manual (2) and Akcelik's method (11).

From a saturation flow consideration the comparison between the Highway Capacity Manual (2), Akcelik's model (11), and Bangs's model (10) shows the following:

1. When the additional through lane effect does not occur, the procedure for computing the saturation flow in the Highway Capacity Manual (2) is similar to that in Akcelik's model (11).
2. When the additional through lane effect does occur, the procedure for computing the saturation flow in Bang's Model is the same as that in Akcelik's model.

The Highway Capacity Manual may assume that storage length is long enough or the green time is short enough, and hence the intersection would not have the additional through lane effect. Conversely, Bang may assume that the combination of the storage space and the green time would result in the additional through lane effect. Akcelik covers both situations, but the critical queuing length of his model is inappropriate because he assumed the queuing length would be equal for normal through lanes and additional through lanes. This assumption is a volume distribution assumption problem which will be discussed later.

Adjustment Volumes

The Highway Capacity Manual utilizes the lane use factors to adjust volumes since it assumes no additional through lane effect exists. However, Miller (8) and McCoy and Tobin (12) analyze this problem based on field studies. Generally, drivers would not choose the additional through lane unless they perceive resulting time savings. Therefore, only when the volume is high, the queuing long, the downstream distance long and the green time relatively short, would drivers choose to use the additional through lane. Thus the drivers' choices depend on the combination of volumes, queuing lengths, downstream length and signal phasing. In Miller's or McCoy and Tobin's studies the queue length for the collected data was not specified, although the authors specified that the surveys were conducted during peak periods.

The major problem with the adjustment volume in additional through lane analysis is one of lane distribution. The lane distribution changes according to the combination of traffic volumes, queuing lengths, downstream lengths, and signal controls. Some further studies are necessary to formulate the lane use as a function of traffic volumes, queuing lengths, downstream length, and signal controls.

As part of this study an evaluation of improved service levels due to additional through lanes was conducted. The methodology of this evaluation is based on the Highway Capacity Manual. This evaluation compares the service levels with and without additional through lanes when the associated basic section maintains a service level C for a multi-lane highway. Appendix A details this evaluation. The following results were obtained:

1. The service levels are all F for various signal control plans at the intersection without additional through lanes.
2. The operations will be improved with service levels B or C if the signal control plan is good.

The following is a summary of the above discussion:

1. The modification of the capacity analysis for additional through lanes is

separated into two parts: (1) saturation flows and (2) adjustment volumes.

2. The saturation flow is computed differently depending on whether the additional through lane effect does or does not occur.
3. Further research on lane use factors for adjustment volume is needed to formulate lane use as a function of traffic volumes, queuing lengths, downstream length, and signal controls.
4. Additional through lanes do improve the level of service of intersections from F to B or C when the service levels of the basic sections are C.

4-3 Required Lengths

This section discusses the required lengths in advance of and beyond intersections.

For a required length in advance of an intersection, Leisch (13) suggests choosing a longer distance somewhere between deceleration and storage lengths but AASHTO (14) suggests combining them for smooth operation, it is better to provide enough length for storage, deceleration, and taper. However, through vehicles may change lanes to the additional through lane when speeds are low. Therefore, the required length in advance of an intersection is dominated by storage requirements.

Leisch's approach to determining acceleration distance seems inappropriate. His approach to determining distance of merging provides a minimum length but with deficiencies. The method of using accelerations seems to give a short length of through lane and the method of using merging requirements as a criterion also provides only the minimum length of additional through lane. This minimum length is too short to achieve the lane use factors in the Highway Capacity Manual. Generally, the longer the required length beyond an intersection, the better the operation. Guell's model does provide a smooth operation but may cost too much. To trade off of service levels and costs, further research is necessary to find the relationship between the length beyond the intersection and the use of an additional through lane. However, the downstream length should be longer than the merging length suggested in Leisch's method.

V. CONCLUSIONS AND RECOMMENDATIONS

5-1 Conclusions

The following conclusions are based on the literature and current practices reviewed in this report.

1. To determine whether to provide additional through lanes one needs complete capacity analyses for the studied intersections and the associated basic sections; evaluations of some other improvement alternatives with low costs; and consideration of geometric conditions, downstream merging, upstream storage, accident records and construction costs for additional through lanes.
2. The capacity analysis for additional through lanes requires some modifications to better deal with the saturation flows and adjustment volumes.
3. The saturation flow computation depends on whether the additional through lane effect occurs.
4. The lane use factors in the Highway Capacity Manual need some modification.
5. Lane use is a function of green time, upstream storage length, downstream length, volume, and queuing length.
6. Intersection operation can be improved by additional through lanes from service level F to B or C when the service level of the basic sections are C.
7. The required length in advance of the intersection is dominated by storage requirements.
8. Leisch's model provides a minimum requirement for the length beyond an intersection.

9. The required length beyond an intersection is determined by the associated signal control, green time, and upstream storage.

5-2 Recommendations

Our recommendations are as follows:

1. To modify the volume adjustment module in the Highway Capacity Manual, additional data about volume distribution for normal and additional through lanes should be collected.
2. A field study should be conducted to determine the lane choice associated with different green time arrangements, upstream length, downstream length, queue length, and volumes.

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APPENDIX

APPENDIX A. EVALUATION OF IMPROVED SERVICE LEVELS

In the Highway Capacity Manual, Table 7-1 depicts the maximum service flow rates associated with level of service C as 1,300 and 1,150 passenger car per hour per lane when design speeds of multilane highways are 60 and 50 MPH respectively.

<u>EXAMPLE</u>

An intersection, on an East-West highway with a 60 MPH design speed, the traffic volume for west-bound is based on the above volume of two lanes on the basic section; but is separated into left turn, through, and right turn movements. The volumes for east, north, and south bound are assumed. The following is the list of traffic volumes used in this analysis for the 60 MPH design speed.

	EB	WB	NB	SB
LT	69	117	60	60
T	1242	2106	200	280
RT	69	117	60	60

The following is the list of traffic volumes used in this analysis for a 50 MPH design speed:

	EB	WB	NB	SKB
LT	69	104	60	60
T	1242	1862	280	280
RT	69	104	60	60

Without additional through lanes, the lane use is shown as follows:

LANE	EASTBOUND		WESTBOUND		NORTHBOUND		SOUTHBOUND	
	MOV	WIDTH	MOV	WIDTH	MOV	WIDTH	MOV	WIDTH
1	LT	12	LT	12	LT	12	LT	12
2	TR	12	TH	12	TR	12	TR	12

With additional through lanes, the lane use is shown as follows:

LANE	EASTBOUND		WESTBOUND		NORTHBOUND		SOUTHBOUND	
	MOV	WIDTH	MOV	WIDTH	MOV	WIDTH	MOV	WIDTH
1	LT	12	LT	12	LT	12	LT	12
2	T	12	T	12	TR	12	TR	12
2	TR	12	TH	12				

Assuming no heavy vehicles, level grade, no parking, no bus stops, no pedestrians, peak hour factor 1.00, arrival type 3, the analysis results are listed in the following pages. However, it is necessary to note that a pseudo left turn lane exists during the analysis process, although the lane use has been assigned. The pseudo left turn lane occurs in the Highway Capacity Manual Procedure when conflict traffic is heavy enough to drastically reduce the service level. Therefore, the real service levels should be better than those shown in the following output tables.

For 60 MPH design speed without additional through lanes:

Cycle Length sec	Green Time Ratio	Timing of Protective LT	Delay sec	Los
120	0.7	4	N/A	F
120	0.6	4	N/A	F
120	0.5	4	N/A	F
120	0.7	6	N/A	F
120	0.6	6	N/A	F
120	0.5	6	N/A	F
90	0.7	4	N/A	F
90	0.6	4	N/A	F
90	0.5	4	N/A	F
90	0.7	6	N/A	F
90	0.6	6	N/A	F
90	0.5	6	N/A	F
60	0.7	4	N/A	F
60	0.6	4	N/A	F
60	0.5	4	N/A	F
60	0.7	6	N/A	F
60	0.6	6	N/A	F
60	0.5	6	N/A	F

Actuated control

For 60 MPH design speed with additional through lanes:

Cycle Length sec	Green Time Ratio	Time of Protective LT sec	Delay sec sec	LOS
120	0.7	4	23.2	C
120	0.6	4	58.4	E
120	0.5	4	N/A	F
120	0.7	6	22.6	C
120	0.6	6	57.2	E
120	0.5	6	N/A	F
90	0.7	4	18.6	C
90	0.6	4	52.0	E
90	0.5	4	N/A	F
90	0.7	6	21.1	C
90	0.6	4	46.8	E
60	0.5	4	N/A	F
60	0.7	6	N/A	E
60	0.6	6	47.3	E
60	0.5	6	N/A	F
Actuated Control			15.5 15.5	C C

For 50 MPH design speed without additional through lanes:

Cycle Length sec	Green Time Ratio	Timing of Protective LT	Delay sec	LOS
120	0.7	4	N/A	F
120	0.6	4	N/A	F
120	0.5	4	N/A	F
120	0.7	6	N/A	F
120	0.6	6	N/A	F
120	0.5	6	N/A	F
90	0.7	4	N/A	F
90	0.6	4	N/A	F
90	0.5	4	N/A	F
90	0.7	6	N/A	F
90	0.6	6	N/A	F
90	0.5	6	N/A	F
60	0.7	4	N/A	F
60	0.7	4	N/A	F
60	0.5	4	N/A	F
60	0.7	6	N/A	F
60	0.7	6	N/A	F
67	0.5	6	N/A	F
Actuated control			N/A	F

For 50 MPH design speed with additional through lanes:

Cycle Length sec	Green Time Ratio	Timing of Protective LT sec	Delay sec	LOS
120	0.7	4	16.8	C
120	0.6	4	27.7	D
120	0.5	4	N/A	F
120	0.7	6	16.9	C
120	0.6	6	27.2	D
120	0.5	6	N/A	F
90	0.7	4	13.4	B
90	0.6	4	22.6	C
90	0.5	4	N/A	F
90	0.7	6	16.2	C
90	0.6	6	22.7	C
90	0.5	6	N/A	F
60	0.7	4	19.6	C
60	0.6	4	18.3	C
60	0.5	4	N/A	F
60	0.7	6	N/A	E
60	0.6	6	18.8	C
60	0.5	6	N/A	F

Actuated control