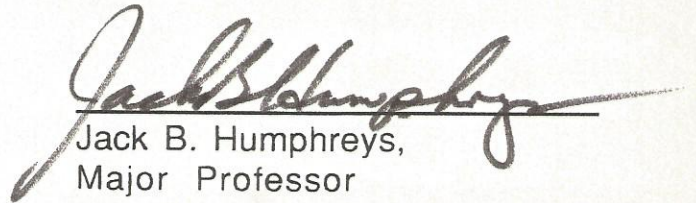


**EFFECT OF TURN SIGNAL USAGE ON DELAY
AT THREE-LEGGED INTERSECTIONS**

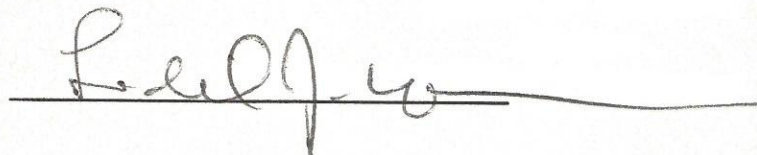
Michael H. Schrader

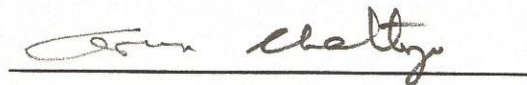
To the Graduate Council:

I am submitting herewith a thesis written by Michael H. Schrader entitled "Effect of Turn Signal Usage on Delay at Three-Legged Intersections." I have examined the final copy of this thesis for form and content and recommend that it be accepted for the degree of Master of Science, with a major in Civil Engineering.


Jack B. Humphreys,
Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:

Vice Provost
and Dean of The Graduate School

**EFFECT OF TURN SIGNAL USAGE ON DELAY
AT THREE-LEGGED INTERSECTIONS**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Michael H. Schrader
May 1990

ACKNOWLEDGEMENTS

The author would like to express his gratitude to those who helped contribute to the completion of this thesis. I am indebted to Jack Humphreys, Ph.D., my major professor, without whose, guidance, help and consultation this thesis would not be completed. Am am also indebted to Frederick Wegmann, Ph.D., and Arun Chatterjee, Ph.D., who served on my committee, for their complements and instructive criticisms, and for their support.

The author would also like to thank Anthony Todd and Tracy Ramsey, who assisted in data collection; Rich Margiotta, through whom the author was able to obtain a literature search of the Transportation Research Information Service (TRIS) database; and the Civil Engineering Department, for the use of equipment.

ABSTRACT

The purpose of this study was to test the hypothesis that turn signal usage reduces stopped delay. Specifically, to test the hypothesis that turn signal usage by a right turning vehicle on the through roadway of a three-legged intersection reduces stopped delay to a waiting vehicle on the intercepted roadway. A total of seven intersections, four in the Saint Louis, Missouri, area, and three in the Knoxville, Tennessee, area, were studied.

The data were evaluated using three different statistical analyses. A scatterplot of the average stopped delay per vehicle versus the percentage of turn signal usage by right turning vehicles was inconclusive. Both the binomial test and the Wilcoxin Rank Sum Test indicate that the hypothesis cannot be rejected for the 95% level of confidence.

TABLE OF CONTENTS

CHAPTER	PAGE
1. INTRODUCTION	1
Why Study Driver Behavior?	1
Purpose Of This Study	4
2. LITERATURE REVIEW	5
Introduction	5
Human Factors	5
Driver Behavior	7
Laws and Regulations	9
Summary	15
3. STUDY DESIGN	16
Scope Of This Study	16
General Considerations For Data Collection	36
Parameters and Guidelines Used in Data Collection	41
Methods	46
Data Collected	48
4. DATA ANALYSIS	49
Data Reduction	49
Results and Discussion	50
5. CONCLUSIONS	62
Validity of the Basic Hypothesis	62
The Need For Further Study	62
BIBLIOGRAPHY	64

APPENDIXES	.6 7
APPENDIX A	.6 8
APPENDIX B	.7 2
VITA	.7 5

LIST OF FIGURES

FIGURE	PAGE
2-1. Minimum distance from decision point to collision point vs. reasonable speed at decision point	13
3-1. Characteristics of turning movements and geometrics of intersections studied	18
3-2. Approach classification requirements	19
3-3. Geometrics of Intersection M-1	26
3-4. Geometrics of Intersection M-2	28
3-5. Geometrics of Intersection M-3	29
3-6. Geometrics of Intersection M-4	31
3-7. Geometrics of Intersection T-5	33
3-8. Geometrics of Intersection T-6	35
3-9. Geometrics of Intersection T-7	37
3-10. Location for determining signal usage	43
4-1. Percentage of turn signal usage by right turning vehicles on the through roadway for each data set . .	52
4-2. Average delay vs. the percentage of turn signal usage . . .	53
4-3. Delay caused by vehicles using turn signals and delay caused by vehicles not using turn signals	56

1. INTRODUCTION

WHY STUDY DRIVER BEHAVIOR?

Relieving Traffic Congestion

As the amount and severity of traffic congestion increases, more attention is being devoted by highway officials to solving traffic congestion problems. The most common suggestion for improving traffic flow is to modify the roadway environment, be it widening, signalization, turn restrictions, limiting access, or installation of medians. Although changes to the roadway environment are effective in reducing traffic congestion, in many cases they are too expensive, due to the limited financial resources of most agencies. Therefore, these physical changes may not be implemented, and thus many traffic problems may go unsolved.

However, the physical characteristics of the roadway facility are not the only cause of traffic congestion. The manner in which a vehicle is operated on the roadway can also affect traffic congestion. For example, inconsiderate drivers who queue their vehicles through an intersection cause traffic congestion. Because of such queuing, drivers on the other approaches to the intersection cannot proceed through the intersection due to the blockage. In other words, gridlock results. During peak hours, this gridlock is much more severe and widespread. Other examples of driver behavior which can and do create traffic problems include weaving between lanes (in the same direction), misuse of a two-way left

turn lane, and making turns where they are restricted (e.g. a left-turn where left-turns have been prohibited).

Thus, from a traffic engineering perspective, changing the physical roadway is not the only solution to traffic congestion problems. Changing driver behavior may be an inexpensive and viable method to reduce such congestion. By changing driver behavior, the roadway may operate much more efficiently, and thus can adequately provide for heavier traffic volumes. Furthermore, this increased capacity is provided at a minimal cost.

Safety

Safety is another primary reason to study driver behavior. By studying driver behavior, unsafe driver actions can be determined. Accidents occur on even the "safest" facilities, that is, facilities that are designed and constructed to the highest safety standards. Because these facilities have been designed and constructed with safety in mind, the probability of an inadequate roadway facility causing accidents is greatly reduced. One primary reason for accidents on a "safe" facility is driver behavior. Dangerous driving action, most notably tailgating, speeding, and weaving, in many cases make even the "safest" roadway dangerous and potentially lethal.

Thus, by studying driver behavior, the traffic engineer can determine which driver behaviors have a negative effect on safety. Then, those behaviors that adversely affect safety can be

discouraged through legislation and the proper enforcement of that legislation.

Summary

Why study driver behavior? By studying driver behavior, we are able to determine how it affects traffic flow, congestion, and safety. Educating drivers about the effects of their behavior may convince many drivers to alter their behavior away from actions that have an adverse effect on traffic flow and safety, and towards those actions that have a positive effect. Thus, by studying driver behavior, and persuading drivers to alter their driving habits, we can improve traffic flow and safety without expensive changes to the existing facilities.

Furthermore, by studying driver behavior and the results of that behavior, vehicular laws and the enforcement of those laws are justifiable. If education is ineffective at persuading drivers to refrain from behaving in a manner that has an adverse affect on traffic and safety, then persuasion through law enforcement becomes a necessity. Thus, vehicular regulations become justified as a necessary last resort in maintaining a safe and efficient roadway system.

In short, by studying driver behavior, the traffic engineer can ultimately improve traffic flow and safety while reducing the need for expensive capital improvements to the roadway facility, and thus the cost for achieving improved traffic operation.

PURPOSE OF THIS STUDY

This study was both a traffic flow study and driver behavior study. Its primary purpose was to determine if a relationship exists between a particular driver behavior and a particular traffic flow parameter. Specifically, the purpose was to test the hypothesis that the usage of turn signals decreases delay; in particular, the hypothesis that the use of turn signals by a right turning vehicle on the through roadway of a three-legged intersection reduces the stopped delay to a waiting vehicle on the intercepted roadway.

2. LITERATURE REVIEW

INTRODUCTION

After an extensive literature search, which included a computer search of the Transportation Research Information Service (TRIS) database, no mention of any previous study of the effect of turn signal usage on delay could be found. Therefore, due to the lack of literature found on this subject, it was concluded that no studies on this topic had been published. However, a limited amount of literature on topics closely related to the study topic was located. These related topics were in the areas of human factors in engineering and design, driver behavior patterns, and laws and regulations of driving.

HUMAN FACTORS

Extensive research has been conducted in the area of human factors. Much of this research revolves around physical elements of the transportation network, most notably the physical elements of the automobile (e.g. seat design, dashboard design, etc.) and the roadway environment. However, since this study is not concerned with physical elements, most of this research is not applicable to this study.

Human Factors in Highway Traffic Research

One excellent source of information on human factors engineering is Human Factors in Highway Traffic Safety Research.

edited by Dr. Theodore Forbes.. A psychology professor at Michigan State University, Dr. Forbes is one of the most respected names in the field of human factors engineering. The information presented in Dr. Forbes' book concerns physical improvements to the roadway environment, for example, better signing, better vehicles, and better roads, and the effect of those changes with respect to safety, and not with respect to efficiency. One chapter is devoted to motor vehicle laws and their value, as well as their effect on safety. However, this chapter only provides a general overview of how traffic laws, and their enforcement, have increased roadway safety. In short, the information presented in this book does not pertain to this study, and thus is of minimal value.

Institute of Transportation Engineers (I.T.E.) Handbook

Chapter 8 of the Traffic and Transportation Engineering Handbook, Second Edition, discusses human factors in the transportation field. Like Forbes' book, this chapter contains much useful information; also like Forbes' book, this information is primarily focused on the effect of human factors on highway safety. The information in Chapter 8 includes discussions of the driving task, the effects of alcohol, drugs, age and fatigue on driving performance and safety, as well as information on pedestrians, bicycles, and comfort levels for transit. However, this information does not pertain to this study.

Other Sources

Like Forbes' book and Chapter 8 of the I.T.E. Handbook, other sources exist which discuss the driver's physical ability, as well as the physical characteristics of the roadway environment and the vehicle, and the effect of these physical elements on safety. One source does mention, albeit briefly, a relationship between the driver and efficiency.

As a principal controlling element, drivers are primary determining factors in the system's successful operation. Skillful driving task performance, maintenance of vehicle control, safe and efficient guidance through roads and traffic, and proper navigation using an optimum mix of routes, represent ways in which driver performance enhances operations and safety.¹

In short, the manner in which a driver operates a vehicle will affect the efficiency of the traffic network, that is, how the network operates.

DRIVER BEHAVIOR

As with the area of human factors, much research has been done in the area of driver behavior. Some of this behavioral research pertains to the topic of turn signal usage.

Lansing Study

One of the earliest studies of turn signal usage was a 1958 study in Lansing, Michigan, of the turn-signalling behavior of 10,467

¹Greson J. Alexander and Harold Lunenfeld. "The Role of Driver Expectancy in Highway Design and Traffic Control." Civil Engineering Practice, Volume 4, 1988, p.429.

drivers at seven intersections. The conclusions drawn from this study were: women use turn signals more than men; left turns are signalled more frequently than right turns; the type of intersection affects turn signal usage; signal usage is independent of the time of day, the presence of preceding or following traffic, and the use of signals by preceding vehicles.¹ No mention was made in this study of the effect of turn signal usage on delay.

Hawaii Study

The focus of a 1984 Hawaii study was to determine the effect of non-use of turn signals on the lane preference of following drivers proceeding through an intersection. Specifically, this study determined the percentage of turn signal usage and the effect of non-use at signalized intersections with a lane drop at the far side of the intersection. Researchers found that a sizable percentage of left turning drivers failed to properly indicate their intentions to turn left, which had a significant effect on the lane choice of following through vehicles.² Like the Lansing study, this study also does not mention delays.

¹A. M. Barch, J. Nangle, and D. Trumbo. "Situational Characteristics and Turn Signalling." Highway Research Board Bulletin, Number 172, 1958, pp. 95-103.

²C. S. Papacostas. "Influence of Leading Vehicle Turn Signal Use on Following Vehicle Lane Choice at Signalized Intersections." Transportation Research Record, Number 996, 1984, pp. 37-44.

Other Studies

Several other studies exist which relate to turn signal usage. One of these is a 1968 study by Thomas H. Rockwell and Joseph Treiterer. In their study, Rockwell and Treiterer concluded that drivers use turn signals more frequently when driving in the city than when driving on an expressway, and that the more responsible a driver is, the more frequently he will use turn signals. These results seem rather obvious and less insightful than the results from the other studies, and so their usefulness is limited.

One interesting study concerns the effect of education on driver behavior, particularly turn signal usage. This study, by G.W. Blomgren, T.W. Scheuneman, and J.L. Wilkens, reports an increase in turn signal usage due to an educational message on a strategically placed sign. The Blomgren, Scheuneman, and Wilkens study also shows that women use signals more than men, and that left turners use signals more than right turners, a verification of the results of the Lansing study.¹

LAWS AND REGULATIONS

Literature concerning traffic laws and regulations can be classified into two general categories: existing vehicular laws, and evaluations of existing vehicular laws. An evaluation of existing laws is given in Forbes' book, as well as in a book edited by Talib

¹G. W. Blomgren, Jr., T. W. Scheuneman, and J. L. Wilkens. "Effect of Exposure To a Safety Poster on the Frequency of Turn Signalling". Traffic Safety and Research Review, Volume 7, Number 1, March 1963, pp. 15-22.

Rothengatter and Rudie de Bruin of the Traffic Research Centre at the University of Groningen, the Netherlands, that focuses on road user behavior. Other sources also evaluate existing traffic laws.

In the area of existing vehicular laws, sources are available for both the state and national level. For Tennessee at the state level, this source is Tennessee Laws Relating To Motor Vehicles. At the national level, the source for recommended vehicular laws is Uniform Vehicle Code and Model Traffic Ordinance. Both of these sources have information pertaining to turn signal usage at intersections.

Uniform Vehicle Code

The Uniform Vehicle Code (UVC) is comprised of recommended traffic laws and regulations. The UVC was established to help promote the consistency and uniformity of traffic laws among the states, in order to prevent different states from having vastly different traffic regulations. One example of a nonuniform traffic law is when it is legal to pass on a two lane facility. In some states, such as Tennessee, a passing vehicle must be on the correct side of the roadway when the solid yellow line begins. In other states, such as Missouri, the beginning of solid yellow means that the passing vehicle should get back on the correct side of the roadway; however, it is not mandatory for the passing vehicle to be on the correct side of the roadway when the solid yellow line begins. Thus, the purpose of the UVC is to eliminate such an inconsistency and nonuniformity, so that a solid yellow no passing line in one state

means exactly the same as a solid yellow no passing line in an adjacent state.

Regulations concerning turning movement and the corresponding signal usage are found in §11-604 of the UVC. This section reads as follows:

(a) No person shall turn a vehicle or move right or left upon a roadway unless and until such movement can be made with reasonable safety nor without giving an appropriate signal in the manner hereinafter provided.

(b) A signal of intention to turn or move right or left when required shall be given continuously during not less than the last 100 feet traveled by the vehicle before turning.

(c) No person shall stop or suddenly decrease the speed of a vehicle without first giving an appropriate signal in the manner provided herein to the driver of any vehicle immediately to the rear when there is opportunity to give such signal.

(d) The signals required on vehicles by §11-605 (b) shall not be flashed on one side only on a disabled vehicle, flashed as a courtesy or "do pass" signal to operators of other vehicles approaching from the rear, nor be flashed on one side only of a parked vehicle except as may be necessary for compliance with this section.¹

It is quite conceivable that the distance of 100 feet mentioned in §11-604 (b) was determined from an equation relating the distance from the collision point to the decision point (in feet) to the computed reasonable speed at the decision point (in miles per hour). A graph of this equation is presented on page 65 of Traffic Performance At Urban Street Intersections, and is shown in Figure

¹National Committee on Uniform Traffic Laws and Ordinances. Uniform Vehicle Code and Model Traffic Ordinance, Revised-1987, p. 62.

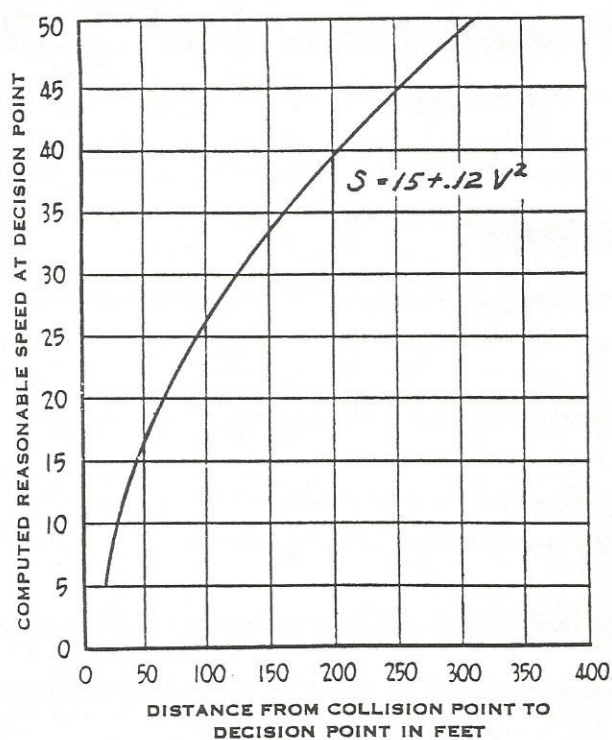
2-1.¹ According to this figure, if the point of decision is 100 feet from the point of collision (in this case, the intersection), then the vehicle should be traveling 27 MPH at the decision point in order to have enough stopping distance to avoid a collision. Many intersections have approach speeds between 25 and 30 MPH; thus, because many intersections have approach speeds near 27 MPH, the distance to the decision point (the point at which signals must be actuated) from the collision point (the intersection) should be in the vicinity of 100 feet. This value represents the minimum stopping distance for numerous intersections, and thus is a good value to select for design and regulation purposes, since it represents the most prevalent situation.

Tennessee Motor Vehicle Laws

Section 55-8-143, of Tennessee Laws Relating To Motor Vehicles states Tennessee law pertaining to the use of signals when turning, as follows:

(a) Every driver who intends to start, stop or turn, or partly turn from a direct line, shall first see that such movement can be made in safety and whenever the operation of any other vehicle may be affected by such movement shall give a signal required in this section, plainly visible to the driver of such other vehicle of his intention to make such movement.

¹Bruce D. Greenshields, Donald Schapiro, and Elroy L. Ericksen. Traffic Performance At Urban Street Intersections, 1947, p. 65.



S= stopping distance (feet)

V=vehicular speed

(Source: Greenshields, Schapiro, and Erickson. Traffic Performance At Urban Street Intersections. Yale University, New Haven, CT, 1947, p. 65)

Figure 2-1. Minimum distance from decision point to collision point vs. reasonable speed at decision point.

(b) The signal herein required shall be given by means of the hand and arm, or by some mechanical or electrical device approved by the department of safety, in the manner herein specified. . . .

(c) Such signals shall be given continuously for a distance of at least fifty feet (50') before stopping, turning, partly turning, or materially altering the course of the vehicle.

(d) Drivers having once given a hand, electrical or mechanical device signal, must continue the course thus indicated, unless they alter the original signal and take care that drivers of vehicles and pedestrians have seen and are aware of the change.

(e) Drivers receiving a signal from another driver shall keep their vehicles under complete control and shall be able to avoid an accident resulting from a misunderstanding of such signal.

(f) Drivers of vehicles, standing or stopped at the curb or edge before moving such vehicles, shall give signals of their intention to move into traffic, as hereinbefore provided, before turning in the direction the vehicle shall proceed from the curb.¹

Whereas the Uniform Vehicle Code stipulates that turn signals should be activated at least 100 feet from an intersection, Tennessee law mandates a minimum distance of 50 feet. As seen from Figure 2-1, this distance is sufficient stopping distance for vehicles traveling a maximum of 17 MPH. Not many intersection approaches have operating speeds in the vicinity of 17 MPH, and thus 50 feet is not an adequate representation of the stopping distance required at a typical intersection. On the other hand, for reasons previously stated, 100 feet is a believed to be a better

¹Tennessee Department of Safety. Tennessee Laws Relating To Motor Vehicles, 1987 Edition, pp. 222-223.

representation of the required stopping distance at a typical intersection.

SUMMARY

No literature was found that pertains to the effect of turn signal usage on delay. However, some literature indirectly relating to this topic was found. This literature can be divided into three areas: human factors, driver behavior, and laws and regulations. The literature pertaining to laws and regulations includes the Uniform Vehicle Code, which is comprised of recommended traffic laws and regulations, and Tennessee Laws Relating To Motor Vehicles. The Uniform Vehicle Code recommends that turn signals be activated a minimum of 100 feet from an intersection. Tennessee law states that turn signals be activated a minimum of 50 feet from an intersection.

3. STUDY DESIGN

SCOPE OF THIS STUDY

As previously stated, the purpose of this research was to test the hypothesis that the usage of turn signals reduces delay; in particular, the hypothesis that the use of turn signals by a right turning vehicle on the through roadway of a three-legged intersection reduces the stopped delay to a waiting vehicle on the intercepted roadway.

Requirements for Inclusion in the Study

3-Legged Intersection

The first requirement for inclusion in the study was that all intersections studied would be unsignalized 3-legged intersections. This restriction was established to simplify data gathering, for it is much easier to gather data on turning movements at a 3-legged intersection than at a 4-legged intersection due to the fact that there are twelve possible movements at a 4-legged intersection, and only six at a 3-legged intersection. Thus, due to the simplified geometrics of the intersections being studied, data were required for only three movements, which permitted data gathering by a single individual.

Turning Movements

The second requirement for inclusion in the study was the predominant turning movements at the study intersections. Because the overall premise of this research was to determine delay caused by right turning vehicles, the intersections studied were selected such that there was a high percentage of right-turning vehicles from the through roadway to the intercepted roadway. Although a high percentage of through traffic on the through roadway was not highly desirable, the major facility should have provided a driver with the option of proceeding straight through the intersection or turning right onto the intercepted facility. That is, traffic should not have been forced to divert from the mainline onto the stem facility, such as when the mainline becomes a one-way at the intersection with the one-way flowing into the intersection (Figure 3-1).

Traffic Volumes (Road Classification)

To be included in this study, intersections not only met the first two requirements, but also met a minimum road classification requirement. This third requirement was that the minor approach and the left major approach (left from the perspective of a waiting vehicle on the minor approach) of the intersection must be classified as a collector or higher, higher being any classification of roadway that carries a greater volume than a collector (Figure 3-2). This requirement was established to prevent the inclusion of low volume intersections where only a few vehicles on the intercepted

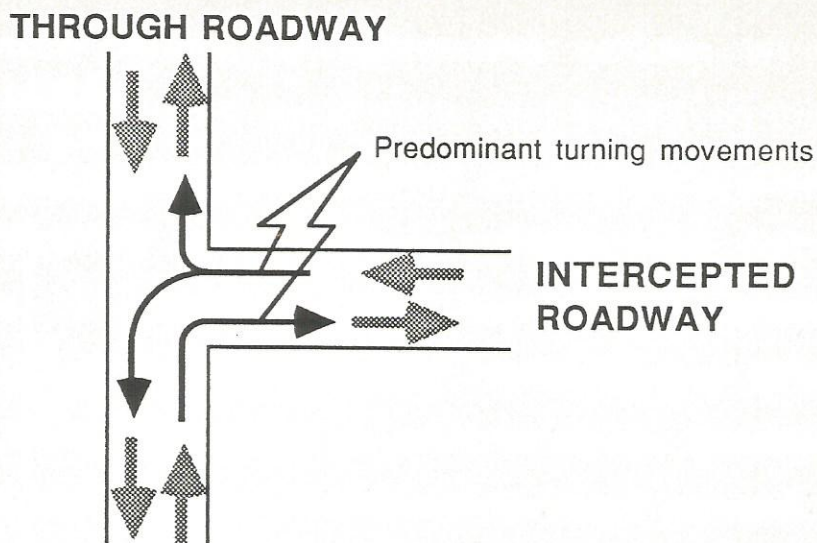


FIGURE 3-1A. DESIRABLE Vehicles on through roadway have the option of either turning right or proceeding straight. The opposite through approach may either be two-way or one-way away from the intersection. The predominant turning movements are right turns from the through roadway, and left and right turns from the intercepted roadway.

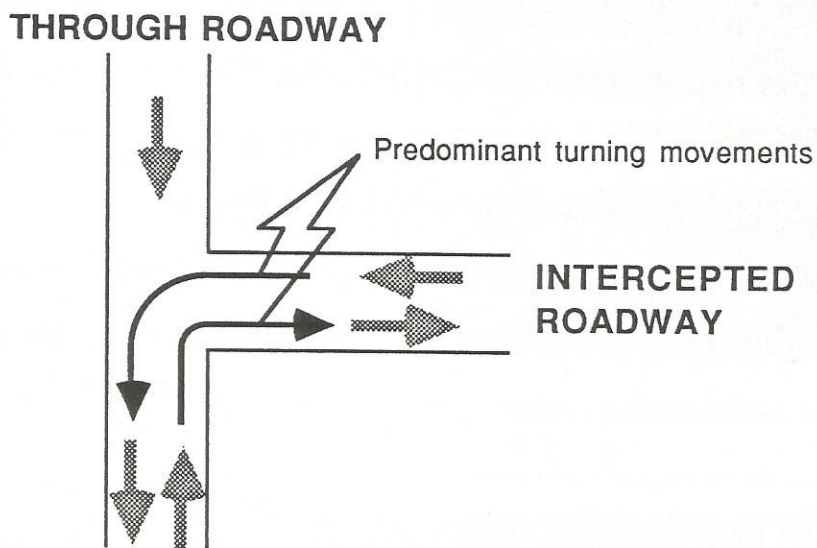
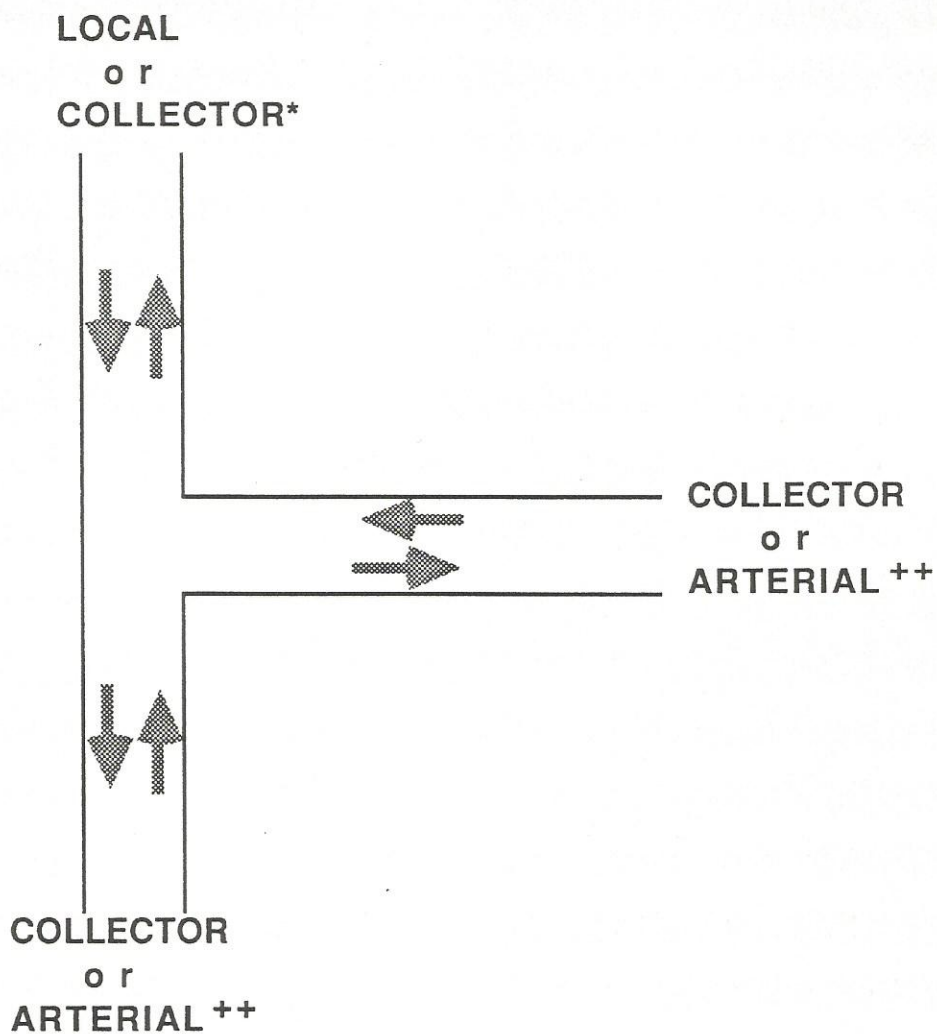


FIGURE 3-1B. UNDESIRABLE Due to the presence of the one-way through approach, traffic on the other through approach is diverted onto the intercepted roadway. In this situation, signal use is irrelevant, since drivers are not given a choice on whether or not to turn right onto the intercepted roadway. No intersection studied possesses these characteristics.

Figure 3-1. Characteristics of turning movements and geometrics of intersections studied.



* This approach must not be classified higher than a collector

++ These approaches should have the same classification, whether collector or arterial (This condition minimizes the amount of through traffic and maximizes the percentage of right-turning traffic from the through roadway onto the intercepted roadway)

Figure 3-2. Approach classification requirements.

roadway were delayed by right-turning vehicles on the through roadway.

Whereas the left through and intercepted approaches should not be classified lower than a collector, the right (from the perspective of vehicles on the intercepted approach) through approach should not be classified higher than a collector. This restriction was incorporated in order to try to eliminate delays to waiting vehicles on the intercepted approach caused by vehicles approaching from the right through approach, as delays caused by vehicles approaching from the right through approach are not within the scope of the study.

All classifications were based upon the functional classification definitions stated in Chapter I of A Policy on Geometric Design of Highways and Streets.¹ For simplification purposes, sub-classifications (e.g. major and minor) were omitted.

Presence of Driveways

For all intersections included in the study, there were no driveways along the left through approach within 100 feet of the intersection. Driveways along the left through approach within close proximity of the intersection may affect delay to vehicles on the intercepted approach because a waiting vehicle on the intercepted approach may not know the intentions of the approaching vehicle, and if that approaching vehicle does not enter the intersection but instead turns

¹ American Association of State Highway and Transportation Officials. A Policy on Geometric Design of Highways and Streets, 1984, pp. 1-18.

into a driveway, although the approaching vehicle did not enter the intersection, that vehicle nonetheless delayed the waiting vehicle on the intercepted approach because of uncertainty by the driver of the waiting vehicle of the intentions of the driver of approaching vehicle.

This restriction does not include low volume driveways and additional street approaches at the intersection itself, for in these cases, approaching vehicles still must enter the intersection. The intent of this restriction was to attempt to eliminate delays to vehicles on the intercepted approach by vehicles not entering the intersection.

Weather Conditions

Because weather can greatly affect driver and vehicular performance (for example, a vehicle on wet pavement requires a longer stopping distance for a given speed than that required for the same vehicle on dry pavement), all data were collected under similar weather conditions. For all data in this study, the weather conditions at the time of data collection were dry and sunny.

Pavement Conditions

Just as weather can affect driver and vehicular performance, so too can pavement type and condition. Drivers and vehicles tend to respond differently on high quality pavements (Portland cement concrete, asphaltic concrete) than on lower quality pavements (gravel, bituminous seal-coat). Thus, to effectively eliminate bias

due to pavement type, all approaches to the intersections included in this study were either Portland cement concrete or a high quality asphaltic concrete. Furthermore, all approaches to the intersections included in this study were in good condition. More specifically, the approaches were free of potholes, and either free of ruts or rutted insignificantly, as potholes and ruts also affect driver and vehicular response, and thus can also significantly affect any data collected.

Other Considerations

Many other factors may affect driver and vehicular performance, and ultimately all data collected at that intersection. These factors include the approach speed limit and the percent of trucks. However, these factors were not considered for two reasons. First, further stratification would have created a small sample, which could greatly bias the data. Second, these other factors were considered to have a negligible impact on delay when compared to the impact of the five factors previously mentioned.

Intersections Studied

A total of seven intersections meeting the six aforementioned limitations were selected to be studied. The seven intersections chosen are representative of a wide spectrum of intersections, as they differ in geometrics (e.g., Y-intersections v. T-intersections), traffic volumes and characteristics, and location (e.g., suburban v. urban). Thus, while all seven of the intersections studied are similar (because all meet the six limitations), they are by no means

identical. In fact, the similarity between the intersections studied ends with the fact that they all fulfill the requirements necessary to be included in the study.

Of the seven intersections studied, four are located in the Saint Louis, Missouri, area, and three are located in the Knoxville, Tennessee, area. This splitting of the study between two different states was done to reduce bias caused by a homogeneous sample, in this case drivers from a particular locality being a homogeneous group. The seven intersections studied and the characteristics of each intersection are listed in Table 3-1.

**Intersection M-1: S. Broadway & Kingston Drive, Lemay,
Missouri**

At this intersection, two approaches are arterials; the other is a collector. The north approach of South Broadway is a four lane arterial, with a posted speed limit of 30 miles per hour (MPH). This approach is also known as Missouri Route 231, and is a direct connection between the southern suburbs and downtown Saint Louis. The south approach of South Broadway, although as wide as the north approach, operates as a two-lane facility, due to curbside parking. This approach has a posted speed limit of 30 MPH and serves as a collector for several subdivisions, a major park, and an Armed Forces Reserve base. The intercepted approach, Kingston Drive, is also designated as Missouri Route 231. Kingston is an arterial with a speed limit of 40 MPH, and as Route 231, serves as one of two

Table 3-1. Characteristics of the intersections studied.

Intersection	Through Roadway			Intercepted Roadway			Location
	NAME	CLASS	SPEED LIMIT	NAME	CLASS	SPEED LIMIT	
M-1	S Broadway-Mo231	Arterial	30 MPH	Kingston Dr-Mo231	Arterial	40 MPH	LEMAY, MO
	S Broadway	Collector	30 MPH				
M-2	Chesterfield Airport	Collector	55 MPH	Old Olive St Rd	Collector	40 MPH	CHESTERFIELD, MO
M-3	Old Baumgartner	Collector	30 MPH	Milburn Rd	Collector	35 MPH	OAKVILLE, MO
M-4	Holly Hills Bl	Collector	30 MPH	Christy Bl	Collector	30 MPH	SAINT LOUIS, MO
T-5	Pleasant Ridge Rd. Pleasant Ridge Rd (N)	Collector Local	40 MPH 40 MPH	Callahan Rd	Collector	40 MPH	KNOX CO., TN
T-6	Westwood Rd Westwood Rd (N)	Collector Local	30 MPH 30 MPH	Sutherland Av	Collector	35 MPH	KNOXVILLE, TN
T-7	Tenn Rte 131 Hardin Valley Dr	Arterial Collector	40 MPH 40 MPH	Tenn Rte 131	Arterial	40 MPH	KNOX CO., TN

north-south arterials through south Saint Louis County, one of the fastest growing areas of Saint Louis County. Right turning vehicles from Kingston to South Broadway are channelized down a separate turning roadway, but still must come to a stop at South Broadway. There is sufficient sight distance in both directions on the intercepted roadway. The graphical representation of this intersection is shown in Figure 3-3.

Intersection M-2: Chesterfield Airport & Old Olive Street
Roads, Chesterfield, Missouri

The unusual feature of this intersection is the high approach speed. The speed limits on both Chesterfield Airport Road approaches is 55 MPH, although both may be classified as collectors; on Old Olive Street Road, another collector, the speed limit is 40 MPH. This intersection is located in the Gumbo Flats, a sizable flood plain of the Missouri River in west Saint Louis County. Chesterfield Airport Road, a three lane facility formerly U.S. 61, now serves as a frontage road for the south side of Interstate 64/ U.S. 40/ U.S. 61. Old Olive Street Road, the other end of which terminates at Chesterfield Airport Road, is a straight road that serves as a bypass of a 90 degree curve in Chesterfield Airport Road approximately one-half mile east of this intersection. Thus, the overwhelming majority of through traffic on eastbound Chesterfield Airport Road turns onto Old Olive Street Road in order to bypass the 90 degree

INTERSECTION M-1
S. BROADWAY & KINGSTON DRIVE
LEMAY, MISSOURI

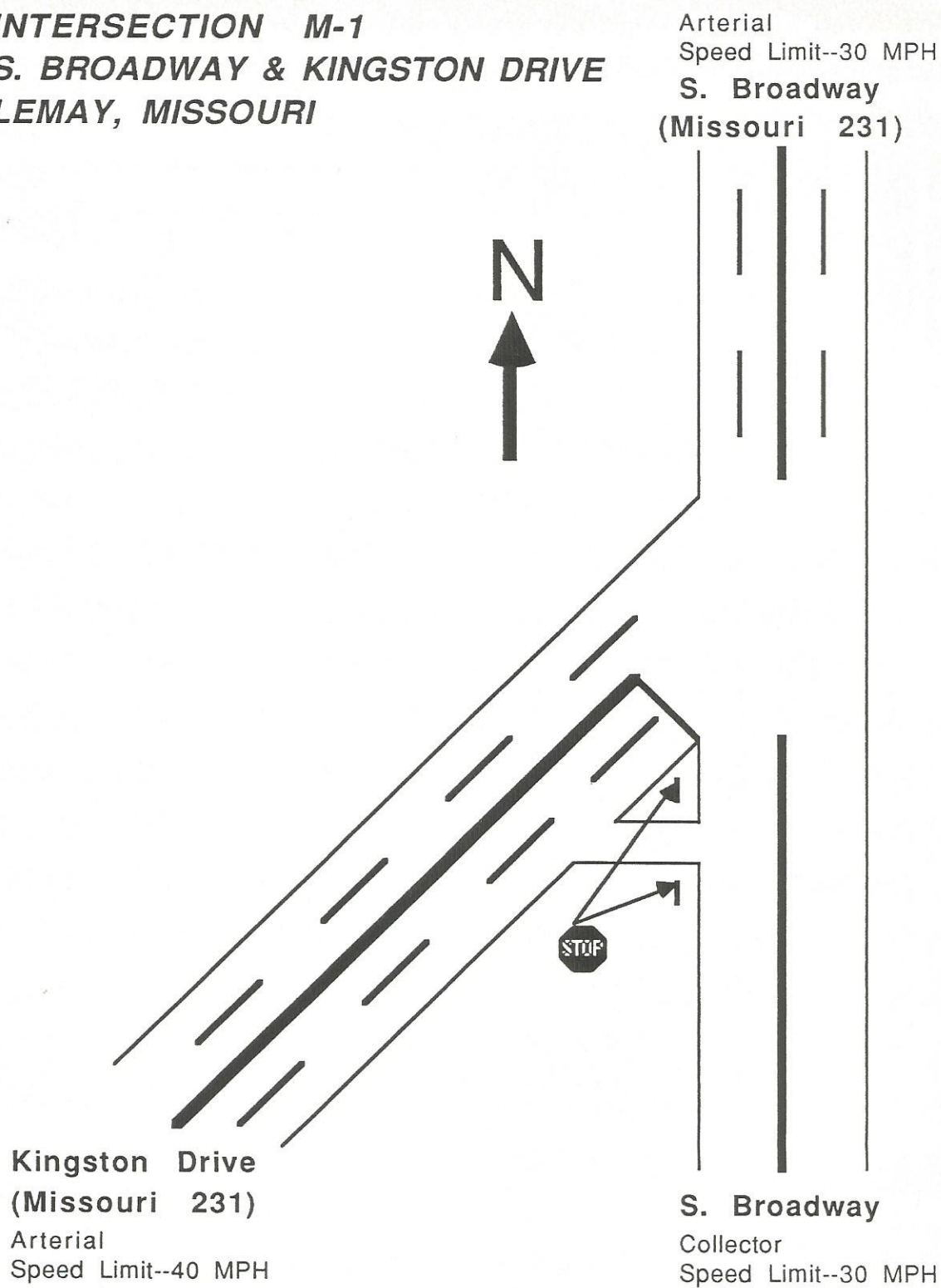


FIGURE 3-3. Geometrics of Intersection M-1.

curve. Because of its location in the Gumbo Flats, the sight distance at this intersection is adequate. A graphical representation of this intersection is shown in Figure 3-4.

Intersection M-3: Old Baumgartner & Milburn Roads,

Oakville, Missouri

This intersection is located approximately 600 feet south of Oakville Senior High School in south Saint Louis County. The eastern Old Baumgartner approach is steep and curvy, with a speed limit of 30 MPH. This approach provides a direct connection with Telegraph Road (Missouri Route 231), the major north-south arterial through Oakville. The western Old Baumgartner approach is straight and flat, and provides access to residential developments. Milburn Road, although straight, is hilly, with a 35 MPH speed limit. Milburn provides access to Oakville Senior High and many residences, as well as an indirect route to South County Center, a major indoor mall. All three approaches can be considered collectors. Sight distance from Milburn is sufficient to both the east (left) and west (right). A graphical representation of this intersection is shown in Figure 3-5.

Intersection M-4: Holly Hills & Christy Boulevards, Saint

Louis, Missouri

An interesting feature of this intersection is the presence of two adjacent intercepted roadways, Carlsbad Avenue and Christy

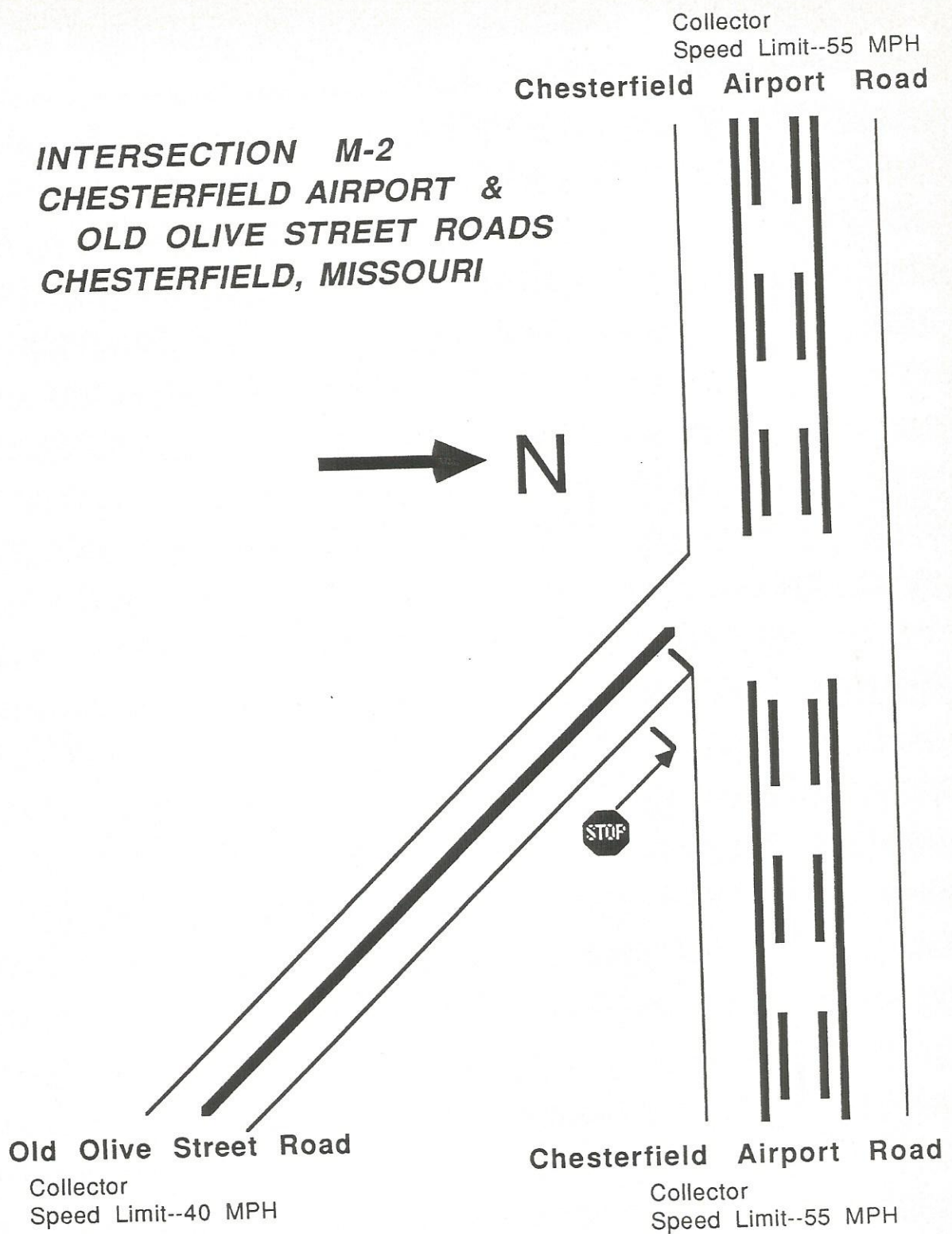


FIGURE 3-4. Geometrics of Intersection M-2.

**INTERSECTION M-3
OLD BAUMGARTNER &
MILBURN ROADS
OAKVILLE, MISSOURI**

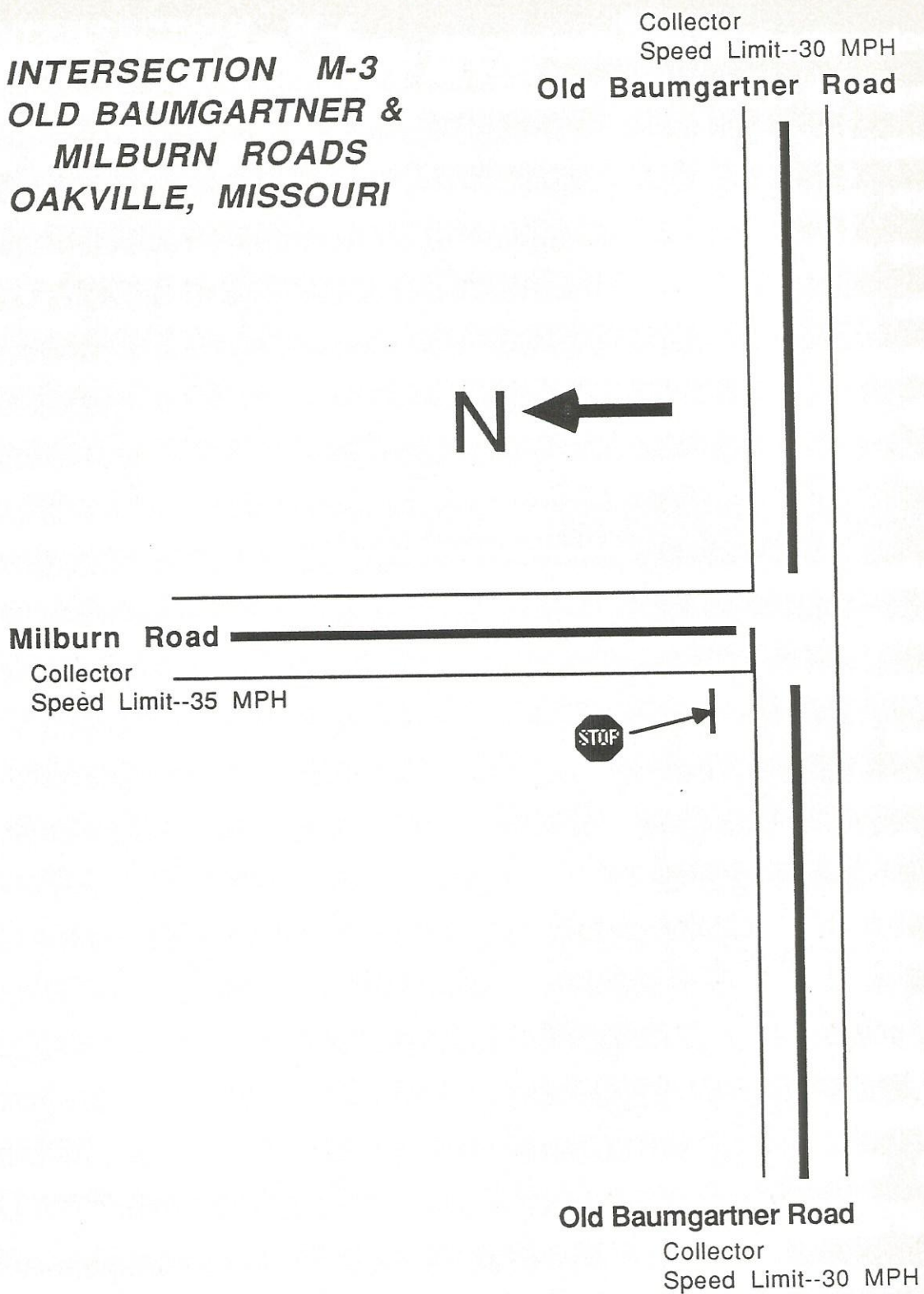


FIGURE 3-5. Geometrics of Intersection M-3.

Boulevard (Figure 3-6). Thus, geometrically this intersection does not classify as a three-legged intersection. While it could be argued that this intersection violates the driveway proximity restriction, this is not the case, as both Carlsbad and Christy intersect Holly Hills at a common intersection. Thus, a vehicle approaching from the east on Holly Hills must enter the intersection to turn onto either Carlsbad or Christy. Furthermore, because of the negligible volume on Carlsbad Avenue (approximately 5 vehicles per hour), this intersection functions as a three-legged intersection, and thus was included in the study.

Eastern Holly Hills is a four lane facility with a raised grass median. The speed limit on the eastern approach is 30 MPH. This approach provides a direct connection to Morganford Road, a major north-south arterial through south Saint Louis and south Saint Louis County, as well as an indirect connection to Interstate 55. Western Holly Hills, a four lane undivided facility with a speed limit of 30 MPH, provides a direct connection to Gravois Avenue (Missouri Route 30), a major arterial that runs southwest out of downtown Saint Louis. Christy Boulevard is also a four lane undivided roadway with a speed limit of 30 MPH. Christy provides direct access to Gravois and Kingshighway Boulevard, a major north-south crosstown arterial, and indirect access to Interstates 44 & 64 (via Kingshighway). Sight distance at the intersection is adequate in all directions, and all three approaches can be considered collectors.

INTERSECTION M-4
HOLLY HILLS & CHRISTY BLVDS
SAINT LOUIS, MISSOURI

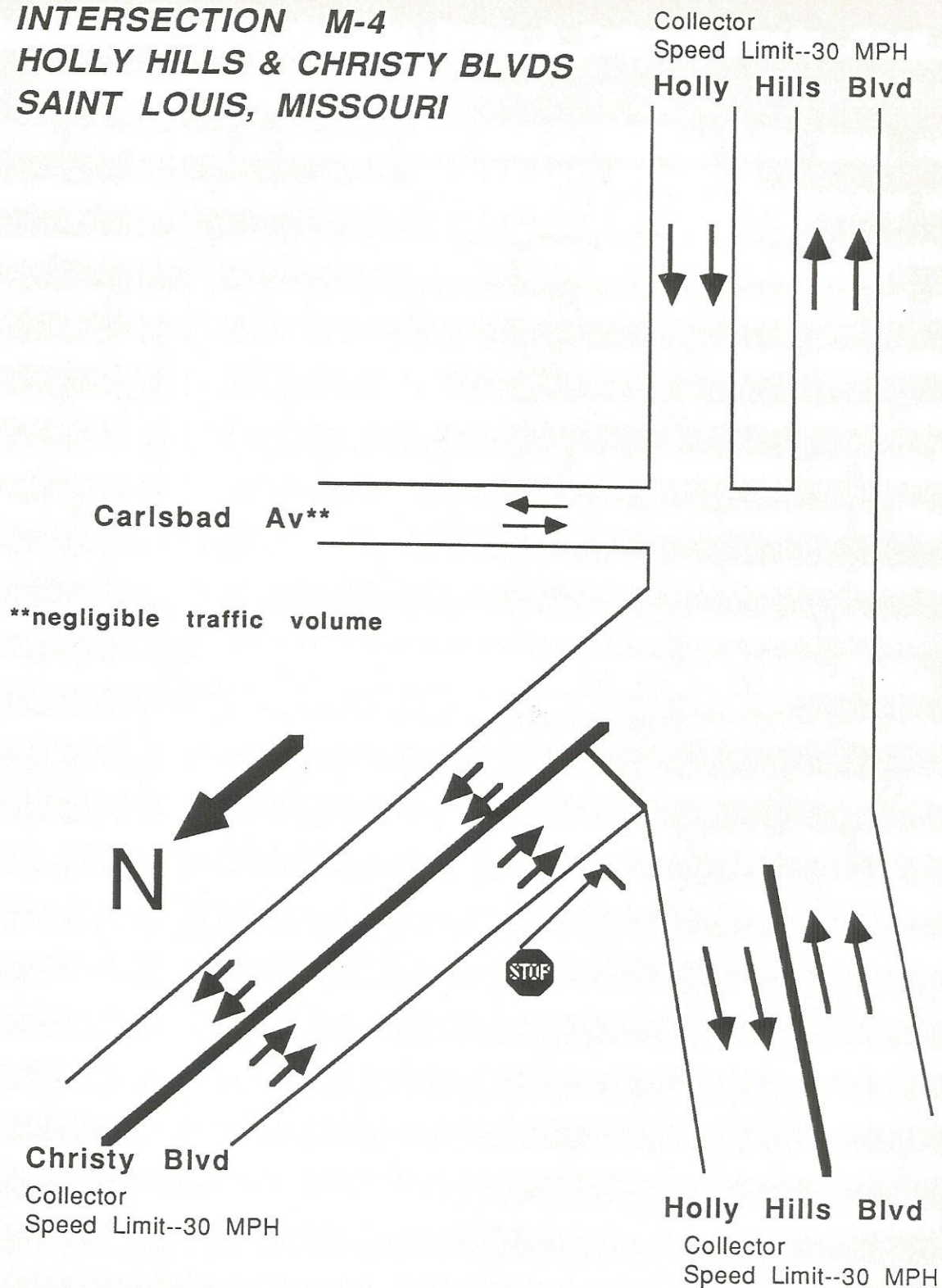


FIGURE 3-6. Geometrics of Intersection M-4.

**Intersection T-5: Pleasant Ridge & Callahan Roads, Knox
County, Tennessee**

This intersection is located near Clinton Highway (U.S. 25W), north of Knoxville, in Knox County. Although all approaches are two way, approximately 530 feet north of the intersection the northern through approach becomes one-way, with the direction of flow towards the intersection (Figure 3-7). However, drivers approaching from the south on Pleasant Ridge do have the option of either proceeding straight or turning right at the intersection of Callahan Road, and thus this intersection is not of the type depicted in Figure 3-1B, in which no option is available. Because the northern approach is one-way southbound 530 feet north of Callahan Road, all northbound traffic north of Callahan is local traffic that is accessing adjacent properties.

The Callahan Road and southern Pleasant Ridge Road approaches can be classified as collectors, and the northern Pleasant Ridge Road approach can be classified as local. The speed limit on all three approaches is 40 MPH. Southbound, the northern approach provides access from southbound U.S. 25W to the intersection; northbound, the northern approach provides only local land access. The southern approach provides a direct connection to a Wal-Mart and Knoxville, and an indirect connection to western Knox County and Oak Ridge. Callahan Road provides a direct connection to a Wal-Mart, Clinton Highway (both northbound and southbound), and Interstate 75. The entrances of the Wal-Mart are within 300 feet of

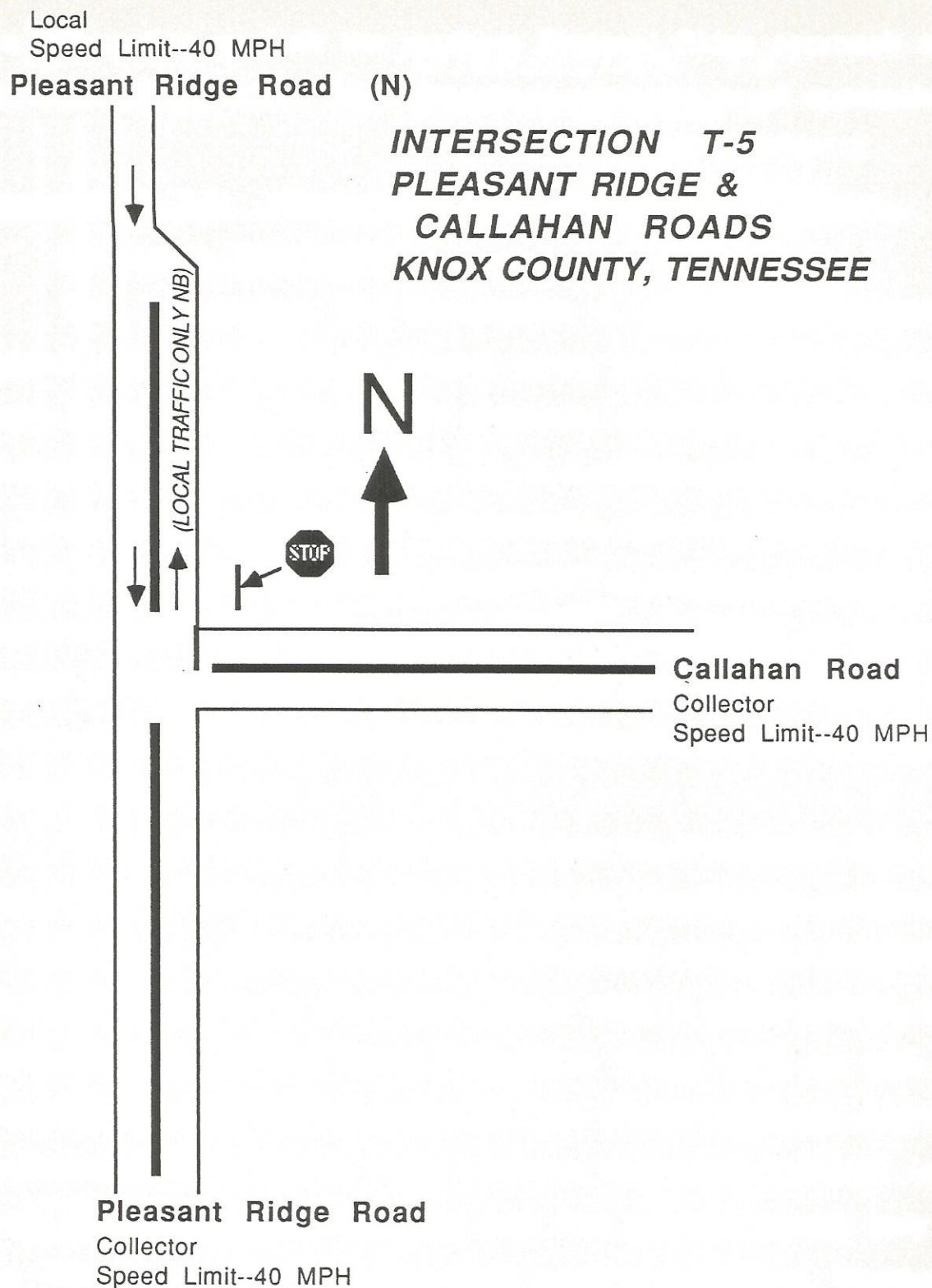


FIGURE 3-7. Geometrics of Intersection T-5.

the intersection on both the southern Pleasant Ridge approach and the Callahan approach. Sight distance is adequate for all approaches.

Intersection T-6: Westwood Road & Sutherland Avenue,
Knoxville, Tennessee

This intersection, like Intersection 4, possesses a physical characteristic which would prompt some to not classify it as a three legged. This intersection physically resembles a four-legged intersection. However, the fourth leg is a private driveway, and thus it is actually a three-legged intersection, as a private driveway with a negligible volume does not count as a roadway approach. In Figure 3-8, this intersection is graphically represented as a three-legged intersection, and the fourth leg, the private driveway, is not shown, as it does not affect how the intersection operates due to its negligible volume.

Sutherland Avenue, which approaches the intersection from the east, has a 35 MPH speed limit and can be classified as a collector. A straight road, Sutherland provides a direct route to Middlebrook Pike/University Avenue (Tennessee Route 169), a major arterial, and Concord Street/Neyland Drive (Tennessee Route 158), as well as indirect access to Interstate 40, U.S. 129 (Alcoa Highway), and the Central Business District. The northern Westwood approach is a local road with a 30 MPH speed limit that provides access only to the Westwood subdivision. One block south of Sutherland, Westwood terminates at Kingston Pike (U.S. 11/U.S. 70), the primary east-west

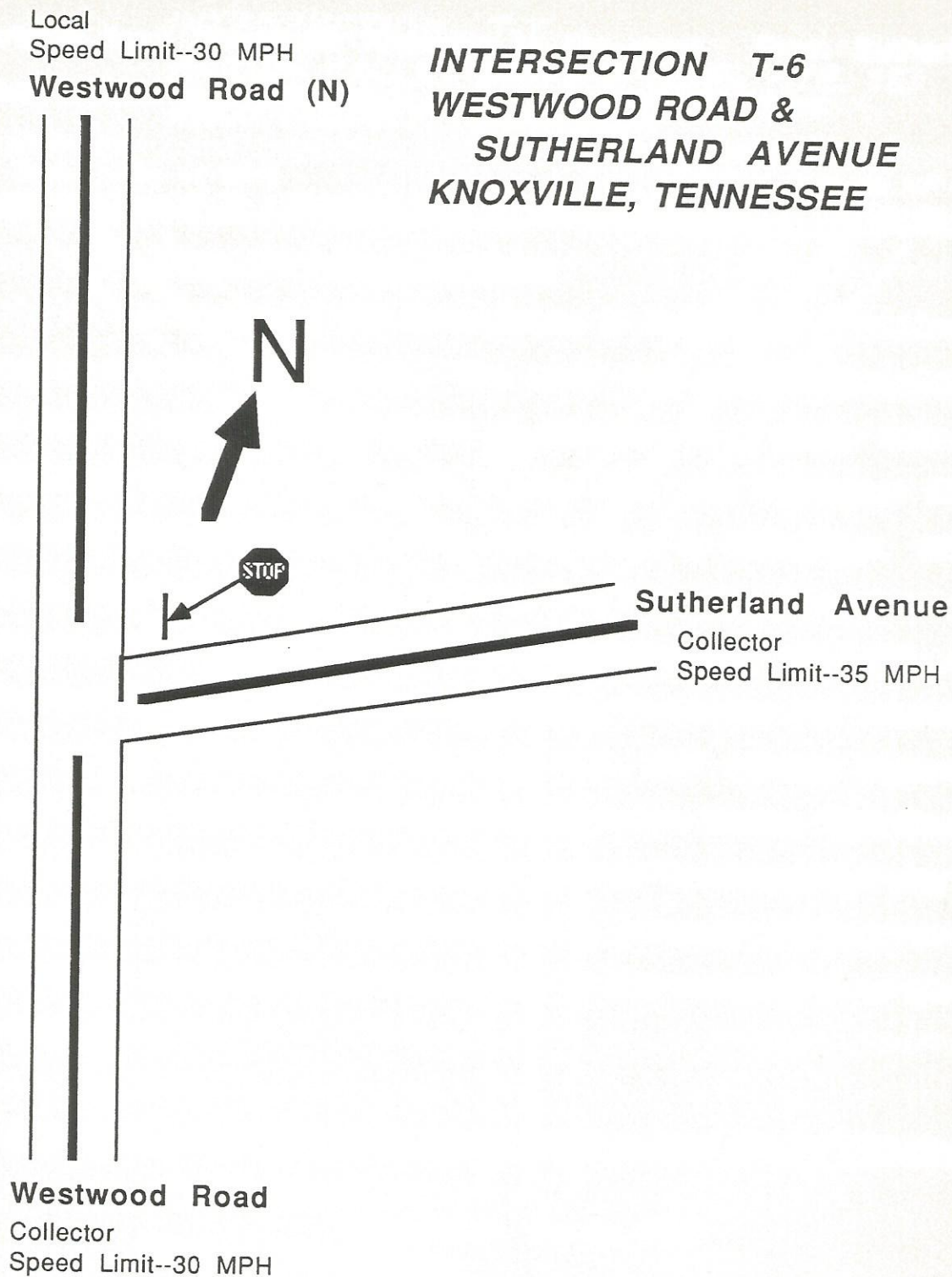


FIGURE 3-8. Geometrics of Intersection T-6.

arterial from downtown Knoxville to the west. From Sutherland Avenue, the sight distance is adequate in both directions.

**Intersection T-7: Hardin Valley Drive & Tennessee Route
131, Knox County, Tennessee**

A Y-intersection, this intersection is located in a semi-rural area of western Knox County. The speed limit on all approaches is 40 MPH. Hardin Valley Drive, a collector, is a direct route to Pellissippi Parkway (Tennessee Route 162), and Pellissippi State Technical College, as well as an indirect route to Oak Ridge. South of this intersection, Tennessee Route 131 intersects Tennessee 169 (Middlebrook Pike), Pellissippi Parkway, Interstates 40 & 75, and Kingston Pike. North of this intersection, Tennessee 131 intersects Tennessee 62 (Oak Ridge Highway), U.S. 25W (Clinton Highway), Interstate 75, U.S. 441 and Tennessee 33, before leaving Knox County and continuing eastward. Both approaches of Tennessee 131 may be classified as arterials. Sight distance is generally adequate in all directions. A graphical representation of this intersection is shown in Figure 3-9.

GENERAL CONSIDERATIONS FOR DATA COLLECTION

Bias Reduction

Because variables other than the six restrictions previously enumerated exist which can affect traffic flow, a sample may be

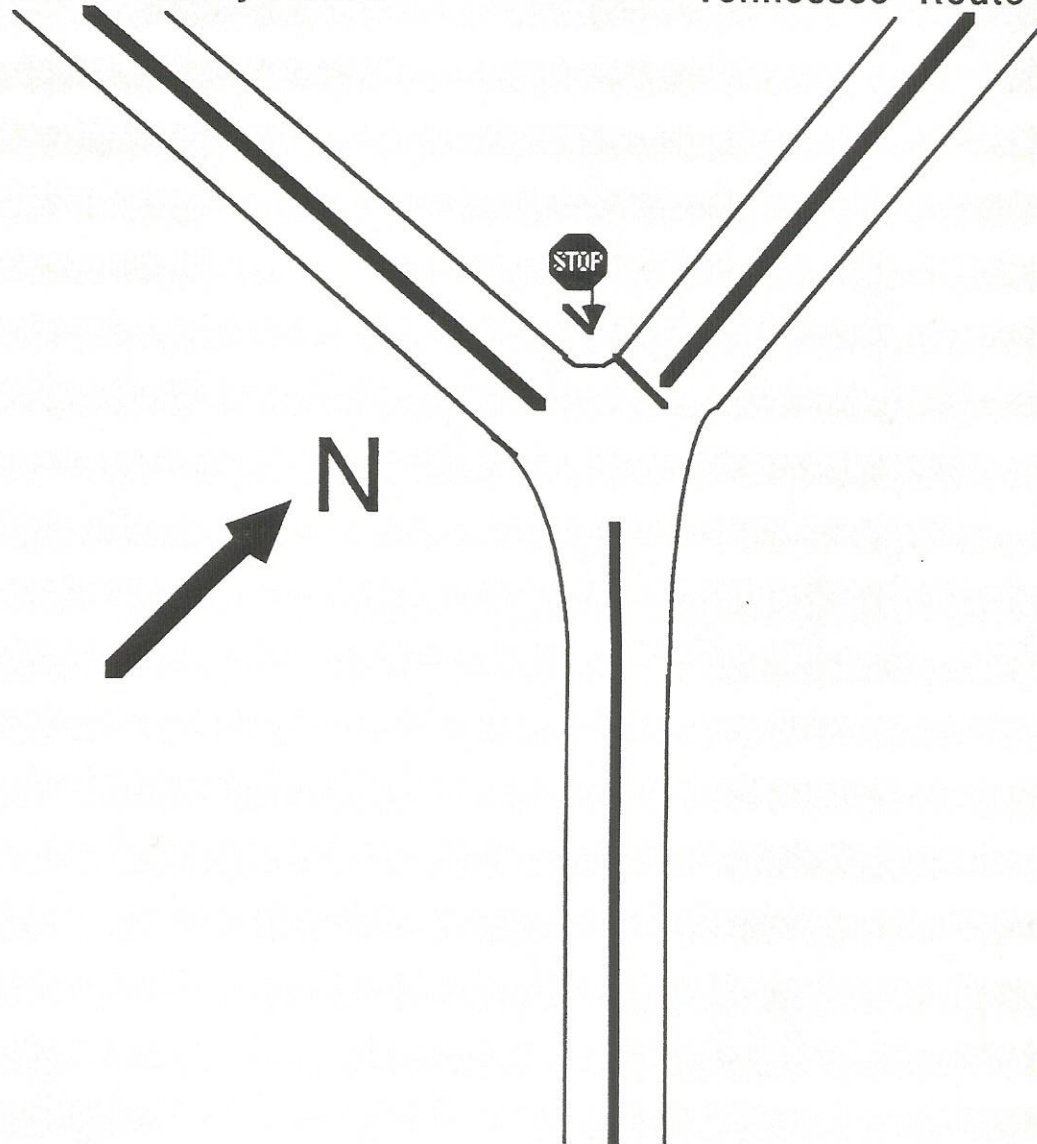
INTERSECTION T-7
HARDIN VALLEY DRIVE & TENN. RTE. 131
KNOX COUNTY, TENNESSEE

Collector
Speed Limit--40 MPH

Hardin Valley Drive

Arterial
Speed Limit--40 MPH

Tennessee Route 131



Tennessee Route 131

Arterial
Speed Limit--40 MPH

FIGURE 3-9. Geometrics of Intersection T-7.

biased due to these other variables. However, the manner in which a data group is collected can greatly reduce, if not eliminate, the bias caused by these variables. The most important of these additional variables (i.e. variables other than the five restrictions previously enumerated) which can bias data are the day of the week and the time of day. For example, if a data group is taken on Monday, the sample may not be representative of the actual conditions at that intersection, since traffic patterns on Monday may tend to be different than patterns on another day of the week. The same holds true for the time of day, for traffic conditions at two in the afternoon are probably not the same as conditions at eight in the morning. Thus, data were taken on different days and at various times among the sites to attempt to eliminate the effect of these biases.

Although ideally data should be collected at any time on any day of the week, there are some practical limitations to when data should be collected. Furthermore, every effort should be made to collect the data when the intersection is operating under conditions which are the best representation of its typical operating characteristics.

Study Conditions

Day of the Week

All data were collected on weekdays, due to two primary reasons. First, traffic volumes may be higher on weekdays than on

weekends; therefore, one may be able to get a larger and thus a probably more representative sample of the traffic flow characteristics of the intersection on a weekday. Second, the percentage of non-local traffic, that is, traffic not familiar with the intersection, may be significantly higher on weekends. Thus, by evaluating the intersections on weekdays, not only may one receive a truer representation of the typical traffic flow at that intersection, but also a truer representation of typical driver behavior characteristics.

Time of Day

All data were collected in the afternoons and evenings. There were several reasons for this.

First, commuter traffic volumes may be higher in the afternoon than in the morning for a given unit of time (i.e. per hour, per 30 minutes, etc.), that is, afternoon commuter traffic may be more concentrated than morning commuter traffic. One explanation for this possible higher concentration of commuter traffic is that morning commuter traffic may be distributed over a wider time frame than afternoon commuter traffic. In the mornings, commuters may not all arrive at the same time; some may arrive earlier than others. On the other hand, in the afternoons, more commuters may leave at the same time, and thus commuter traffic may be more concentrated.

Not only may afternoon volumes be higher due to a higher concentration of commuters, they may also be higher due to a higher

number of non-commuters. In the mornings, most vehicular trips are probably home based work or home based school, as many retail establishments do not have business hours during the morning peak period. In the afternoons, the percentage of home based non-work trips may be much higher, as many retail establishments are open during the afternoon peak period. This possible increase may also be attributed to recreational drivers, as these types of drivers may be less likely to be present in the morning as in the afternoon. Because the number of home based other driver trips may be higher in the afternoon than in the morning, a sample taken in the afternoon may be less homogeneous than a sample taken in the morning. Because a sample taken in the afternoon may be more heterogeneous than a sample taken in the morning, the afternoon sample may be less biased than the morning sample. In other words, if a sample is taken when 90 percent of drivers are commuters, it cannot be conclusively determined whether the results applicable in general or just to commuters, whereas the results of a sample taken when no one type of driver is the dominant majority probably cannot be attributed to one particular group, but instead can be considered to be applicable to the intersection traffic in general.

Although all data were collected in the afternoon and evening hours, care was taken to avoid collecting two data sets from any particular intersection at the same time interval during the day, as that might tend to bias the data. Four distinctive time intervals were established to help prevent biasing of the data: afternoon, pre-

peak, peak hour, and pre-twilight. These intervals were defined as follows:

Afternoon, approximately from 12 noon until 2 pm;

Pre-peak, approximately from 2 pm until 4 pm;

Peak hour, approximately from 4 pm until 6 pm;

Pre-twilight, approximately from 6 pm until dusk.

The starting time for a particular data set, that is, the time at which data collection began for that data set, was the parameter used to determine the time interval. For example, if a technician were to collect data from 5:30 pm to 6:30 pm, that data set would be classified as peak hour, because that would be the time interval when data collection began. As stated previously, multiple data sets for a given intersection possess different time interval classifications, thus helping to effectively eliminate biasing of the results due to the time interval.

PARAMETERS AND GUIDELINES USED IN DATA COLLECTION

In order to maintain consistent data collection techniques, several guidelines were established to define the actions being studied. These guidelines established when the vehicle on the through approach was considered as having its signal on, and when the delay was considered as beginning and ending for the vehicle waiting on the intercepted approach.

Turn Signal Activated

An approaching vehicle on mainline was considered to have its turn signal on if the signal was on at least 100 feet from the intersection. This distance was not arbitrarily selected; rather, it is the recommended distance given in the Uniform Vehicle Code. Section 11-605(b), page 62, of the 1987 revision of the Uniform Vehicle Code states:

A signal of intention to turn or move right or left when required shall be given continuously during not less than the last 100 feet traveled by the vehicle before turning.¹

This 100 feet was measured along the edge of pavement or curb along the mainline approach on which signalling vehicles are travelling, on the same side of the roadway as the minor approach, as shown in Figure 3-10. The point at which turn signals were considered to be on or off (100 feet upstream of the intersection) was then marked with either a lathe adjacent to the roadway or a paint mark on the roadway itself.

Determination of Delay

A vehicle was considered to be delayed when: (1) the vehicle on the intercepted roadway was stopped and ready to proceed, and (2) a vehicle on the through roadway approaching the ready vehicle from the left (from the perspective of the ready vehicle on the

¹National Committee on Uniform Traffic Laws and Ordinances. Uniform Vehicle Code and Model Traffic Ordinance. Revised-1987, p. 62.

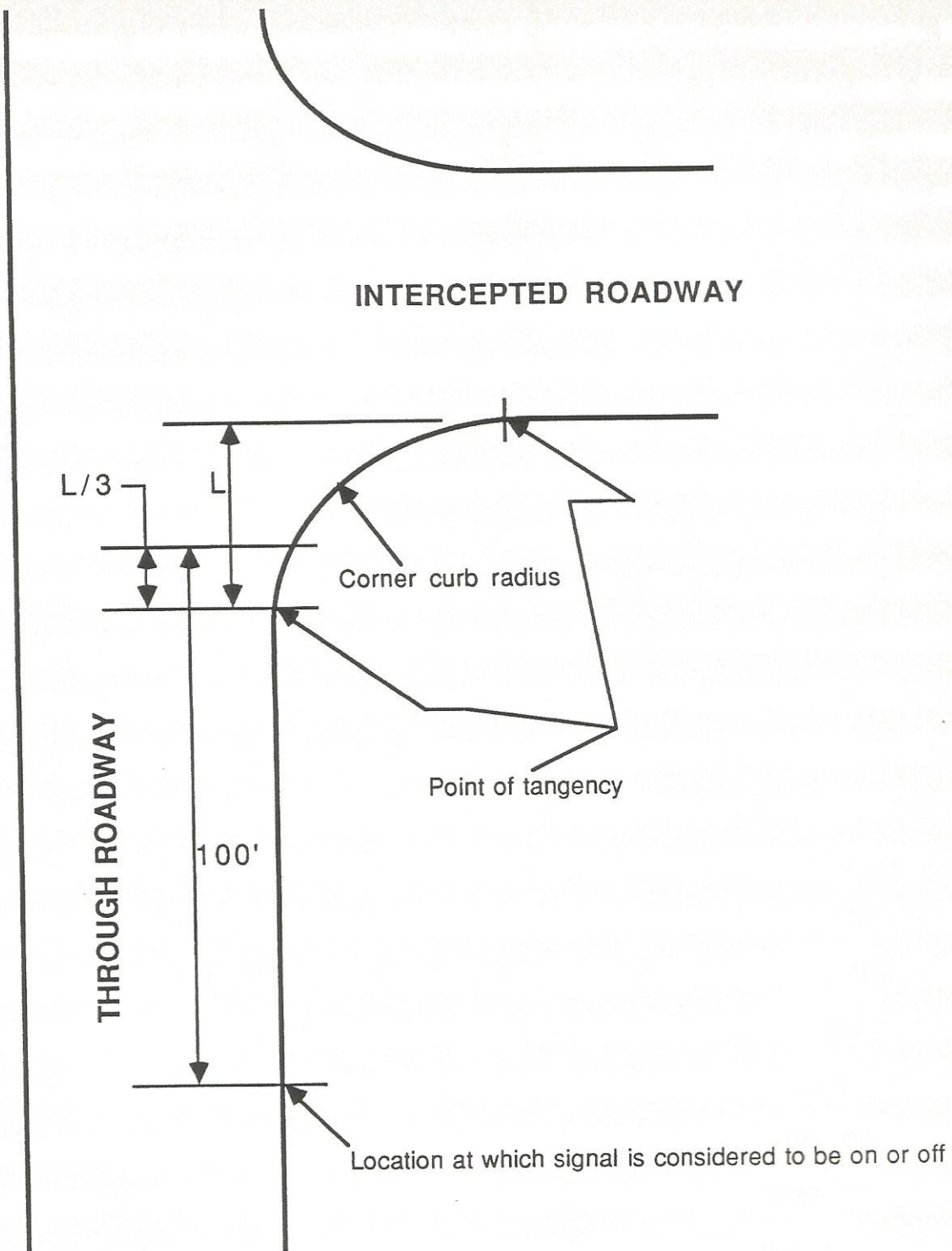


FIGURE 3-10. Location for determining signal usage

intercepted approach) was within 100 feet of the intersection. All delays were stopped delays to individual vehicles and were not total intersection delays. Furthermore, any delay to a ready vehicle affected by vehicles on the through roadway approaching from the right was not considered, regardless of whether or not the delay was initially caused by a vehicle approaching from the left. Finally, one and only one vehicle on the intercepted approach was considered to be delayed at any given time. Thus, if a queue exists on the intercepted roadway, only the vehicle at the stop bar was considered to be delayed.

Beginning of Delay

Two parameters were used to determine when a vehicle was delayed, that is, the beginning of the delay period. First, the vehicle on the intercepted roadway must have been "ready." A vehicle was considered to be ready when it was at the stop bar, or a de facto stop bar, stopped, and ready to proceed through the intersection. Second, a vehicle on the through roadway approaching the ready vehicle from the left must have been no more than 100 feet from the intersection. These two conditions must have existed simultaneously in order for the waiting vehicle to be considered delayed. If the vehicle on the intercepted approach was "ready" but there was not any approaching vehicle within the waiting vehicle's "zone of influence," that is, 100 feet, the waiting vehicle was not considered to be delayed. So too, if the approaching vehicle was within 100 feet of the intersection, but the vehicle on the

intercepted roadway was not ready, then the latter vehicle was not considered as delayed by the former vehicle.

One restriction applies to this definition of a delayed vehicle. If a vehicle on the intercepted approach was not "ready" when an approaching vehicle entered its zone of influence, then the vehicle on the intercepted roadway was not delayed by the vehicle on the through roadway. A vehicle on the intercepted roadway could only be delayed if it was ready to proceed into or through the intersection when an approaching vehicle entered its zone of influence. Thus, a vehicle that became ready once an approaching vehicle was already within 100 feet of the intersection was not considered to be delayed, even though the two parameters required for delay as stated previously existed. The reasoning behind this restriction was that, in general, once a mainline vehicle was within the zone of influence of the waiting vehicle, the intentions of the driver may have become apparent to the driver of the waiting vehicle when the approaching vehicle began decelerating.

Ending of Delay

Delay ended when the driver showed an intention to proceed into the intersection. For automobiles, motorcycles, and other small vehicles, this intention was considered to be shown when approximately one-half the vehicle crossed the stop bar. For trucks, this intention was considered to be shown when the tractor crossed the stop bar. Intent was used as the parameter because it minimized

the amount of delay caused by the acceleration of the vehicle from a stop.

Vehicle Causing Delay

The vehicle considered as causing the delay was the first vehicle to cause the delay. In other words, if delay began because of the first vehicle in an approaching queue, and other vehicles in the approaching queue further contributed to that delay, then the entire delay was said to have been caused by the first vehicle. In all cases, delay was considered to be caused by *only one approaching vehicle*. For each vehicle delayed, there was one and only one vehicle responsible for that delay. Thus, in the case of a queue of approaching vehicles, the lead vehicle was considered responsible for the delay to a "ready" vehicle on the intercepted roadway.

METHODS

Data were collected only for delay situations, that is, a situation where a vehicle on the intercepted roadway was "ready" and an approaching vehicle on the through roadway was within 100 feet of the intersection. Two different methods were used in the gathering of the data.

Stop Watch Method

With this method, a stop watch was used to measure the delay. This method provided for great flexibility in the selection of intersections, for a vehicle need not be parked at the intersection in

order to collect data. However, this method also required a very alert and attentive research team, for the probability of human error, such as forgetting to reset the stop watch or missing a delayed vehicle entirely, was high. All data for Intersections M-2 and M-3, and some data for Intersections M-4 and T-5 were collected using this method.

Esterline-Angus Event Recorder Method

With the method, all data were collected with an Esterline-Angus Event Recorder. Information on vehicles causing the delay was encoded in such a manner that the researcher was able to extract that information at a later time, rather than extract the information at the intersection as is required by the stop watch method. Delay data were also able to be determined at a later date using this method.

Like the stop watch method, the use of the event recorder had both advantages and disadvantages. The primary advantages were that this method reduced the responsibilities of the researcher at the site, and thus reduced the chance for error; this method provided for verification and rechecking of data that appeared to be erroneous. The disadvantages to this method were: the instrument must be connected to a vehicle's battery, and thus the number of intersections that may be studied was restricted to those that provide a safe and legal parking area for a vehicle; the instrument was cumbersome, and required at least 10 minutes to set up, as well as 10 minutes to put away, and had to be cleaned after every use.

All data for Intersections M-1, T-6, and T-7, as well as some data for Intersections M-4 and T-5, were collected using this method.

DATA COLLECTED

The vehicular data collected consist of the stopped delay to "ready" vehicles and information on whether or not the approaching vehicle had its turn signal on 100 feet from the intersection. All delay data were recorded in seconds. Data on turn signal usage concerns the number and percentage of vehicles causing delay that were using turn signals. No differentiation was made for the type of vehicle (i.e. auto, tractor-trailer, motorcycle, etc.) either causing the delay or being delayed.

4. DATA ANALYSIS

DATA REDUCTION

Percent Signal Usage vs. Delay

The first step in the analysis of the data was a correlation of the percentage of turn signal usage by all right-turning vehicles causing delay and the average delay to all "ready" vehicles delayed. For each data set, the percentage of all vehicles causing delay that used turn signals was determined, as well as the average delay to all vehicles delayed, whether delayed by vehicles using turns signals or vehicles not using turn signals. The results for an individual data set were analyzed with the individual results for all other data sets, and an inference about the correlation between the total percentage of turn signal usage by vehicles causing delay and the average delay to vehicles delayed was made.

Signal Usage and Non-Usage vs. Delay

The data were stratified to take into account whether or not the approaching vehicle on the through roadway was signalling a right turn. In other words, delays caused by vehicles not using turn signals were separated from delays caused by vehicles using turn signals. This stratification was done in order to test the hypothesis of this study, that is, that turn signal usage reduces delay. This was accomplished by determining the delay caused by vehicles using turn signals and the delay caused by vehicles not using turn signals, and

comparing them. However, the delays calculated did not take into account the direction the "ready" vehicle on the intercepted roadway turned.

Other Considerations

The data were encoded in such a manner as to permit the analysis of other considerations. An example of such a consideration is the direction in which the "ready" vehicle is turning. The data were encoded to differentiate between the delays to left-turning and right-turning vehicles. However, because the volume of right-turning vehicles from the intercepted approach was small when it existed, this differentiation was not considered for this study.

RESULTS AND DISCUSSION

A total of fourteen data sets were gathered at the seven intersections. The first nine of these data sets were gathered at the intersections in Missouri, and the remaining five were gathered at the intersections in Tennessee. The parameters from these data sets are shown in Table 4-1.

Percent Signal Usage vs. Delay

The percentage of right-turning vehicles on the through roadways that signalled the turn range from 25 percent to 75 percent. There was no immediate explanation for this wide variation. These data are graphically represented in Figure 4-1.

TABLE 4-1. Delay data.

Intersection	Data Set	Time of Day	Day of Week	Sample Size (n)	Percent Usage*	Average delay (s)		
						SIGNAL**	NO SIGNAL***	OVERALL
M-1	M-1-1	Pre-twilight	Monday	16	68.75	1.84	9.04	4.09
	M-1-2	Pre-twilight	Wednesday	24	58.33	4.12	4.28	4.19
	M-1-3	Peak hour	Friday	51	66.67	2.65	4.08	3.13
M-2	M-2-1	Pre-peak	Wednesday	8	75.00	2.13	4.08	2.62
	M-3-1	Peak hour	Wednesday	25	48.00	3.89	3.70	3.79
	M-3-2	Pre-peak	Thursday	25	56.00	2.98	4.21	3.52
M-4	M-4-1	Pre-twilight	Friday	8	25.00	2.46	3.08	2.92
	M-4-2	Peak hour	Monday	24	45.80	2.43	3.24	2.87
	M-4-3	Pre-peak	Monday	23	43.50	4.16	2.68	3.32
T-5	T-5-1	Peak hour	Tuesday	36	63.89	1.46	2.85	1.96
	T-5-2	Afternoon	Friday	13	38.46	2.24	3.51	3.02
	T-6-1	Pre-peak	Thursday	29	37.93	3.90	3.32	3.54
T-6	T-6-2	Peak hour	Friday	50	44.00	3.29	4.26	3.84
	T-7-1	Peak hour	Thursday	31	48.39	2.30	3.66	3.00

*percentage of turn signal usage by right turning vehicles on the through roadway

** average delay caused by vehicles using turn signals

*** average delay caused by vehicles not using turn signals

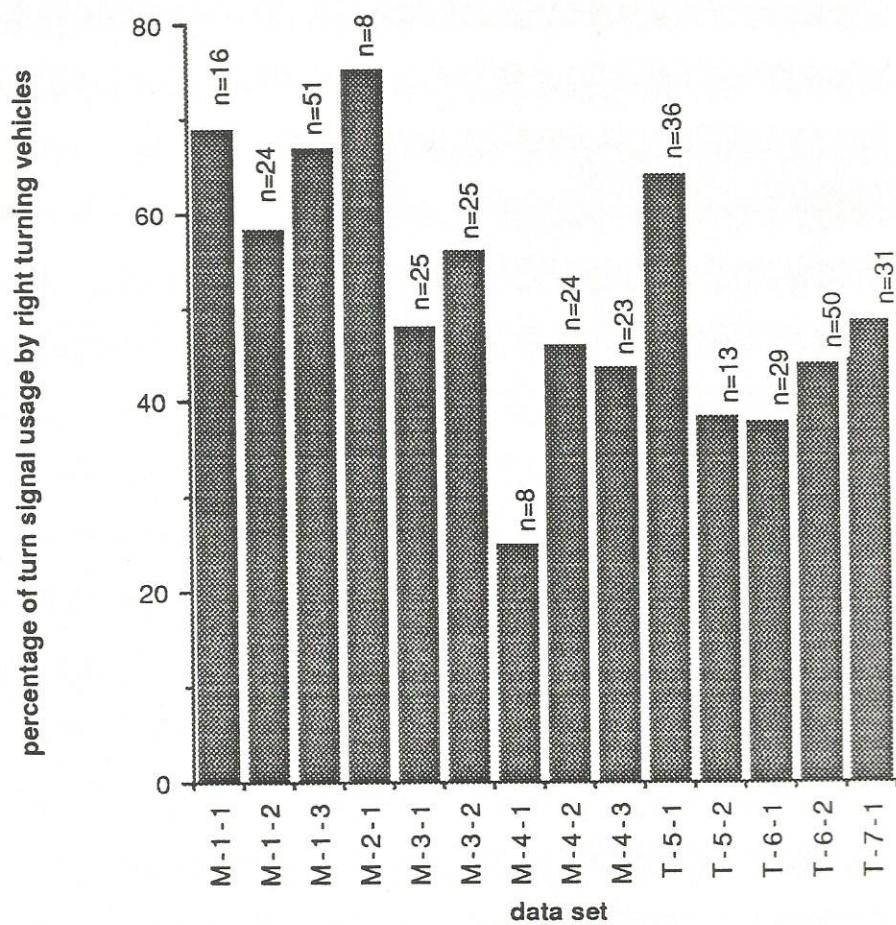


Figure 4-1. Percentage of turn signal usage by right turning vehicles on the through roadway for each data set.

A scatterplot was made to show if any correlation exists between the percentage of turn signal use by right turning vehicles on the through roadway and the average stopped delay to "ready" vehicles on the intercepted roadway. This scatterplot is shown in Figure 4-2. As can be seen from the figure, the plot is widely scattered, and only a weak correlation, if any, between the percentage of turn signal usage and delay is suggested.

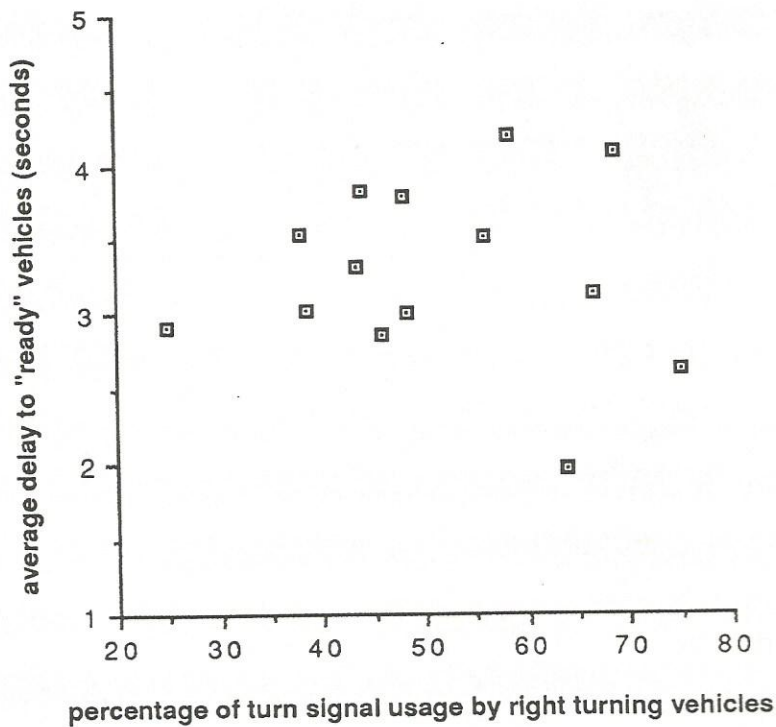


Figure 4-2. Average delay vs. the percentage of turn signal usage

Several regression equations were plotted for the data in Figure 4-2, and a statistical correlation factor (R) was computed for each regression curve. When an exponential regression equation was plotted for the data in Figure 4-2, the resulting correlation factor, or R value, was 0.12. Because the R value of the exponential regression equation was 0.12, this curve showed little correlation between the percentage of turn signal usage and the delay to "ready" vehicles, since an R value of 0.00 indicates no correlation, while an R value of 1.00 indicates a full correlation.

Linear and logarithmic regression equations were also plotted for the data in Figure 4-2. Both the linear and logarithmic regression equation had an R value of 0.06, which indicated a correlation one fourth as strong as the correlation expressed with the exponential equation.

Signal Usage and Non-Usage vs. Delay

Because of the weakness of the correlation expressed by the regression equations, several other statistical tests were employed to test the hypothesis that signal usage reduces delay. These statistical tests involved the comparison of stopped delays caused by vehicles using turn signals with delays caused by vehicles not using turn signals, instead of a general analysis of the percent usage versus the average stopped delay. In other words, the delay data for each data set were stratified into two categories, in this case turn signal usage and turn signal non-usage, and a comparison was made between the two categories.

Figure 4-3 is a graphical representation of the delay caused by vehicles using turn signals and the delay caused by vehicles not using turn signals for each data set. For data set M-1-1, the delay caused by vehicles using turn signals is much less than that caused by vehicles not using turn signals, which agrees with the basic hypothesis of this study. The average delay per vehicle caused by vehicles not using signals is at least 1 second greater than that caused by vehicles using signals for data sets M-1-3, M-2-1, M-3-2, T-5-1, T-5-2, and T-7-1. Thus, the results from one half of the data sets suggest strongly that the hypothesis is true. For data sets M-4-1, M-4-2, M-1-2, and T-6-2, the delay caused by vehicles not using signals is greater than that caused by vehicles using signals, although the difference is not very large. Nonetheless, the results from these data sets also indicate that the hypothesis is true. However, the results from data sets M-3-1, M-4-3, and T-6-1 are contradictory with the hypothesis. For each of the data sets, the delay caused by vehicles not using turn signals is less than the delay caused by vehicles using turn signals, the opposite of the basic assumption of the hypothesis. Despite the existence of the three contradictory data sets, Figure 4-3 strongly suggests that turn signal usage reduces delay; thus the need for a statistical analysis to determine if the hypothesis is indeed true.

Figure 4-3 shows several interesting phenomena. Data sets M-1-1 and M-1-2 were collected at the same time on different days of the week. Although both show that the delay to "ready" vehicles on

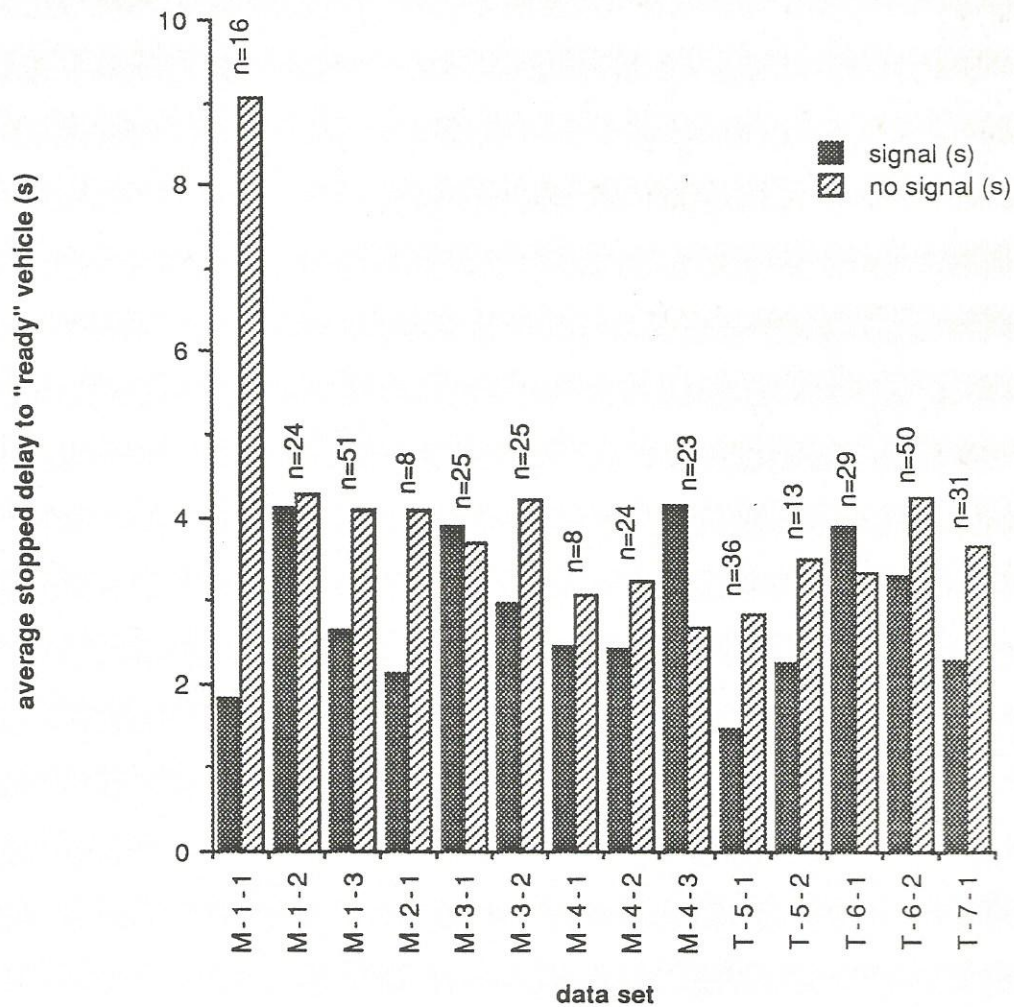


Figure 4-3. Delay caused by vehicles using turn signals and delay caused by vehicles not using turn signals.

the intercepted roadway caused by right-turning vehicles on the through roadway using signals is less than the delay caused by right-turning vehicles not using signals, the magnitude of this difference for data set M-1-1 is much greater than that for data set M-1-2. Although data sets M-4-1 and M-4-2 have vastly different sample sizes and were collected on different days of the week at different times of day, the magnitudes of the delays for both data sets is nearly identical. On the other hand, data sets M-4-2 and M-4-3 were collected at different times on the same day of the week and contrast sharply, as M-4-3 shows the delay caused by vehicles using signals to be higher than the delay caused by vehicles not using signals. Similar to data sets M-4-1 and M-4-2 are data sets T-5-1 and T-5-2. Although collected at different times of day on different days of the week with different sample sizes, data sets T-5-1 and T-5-2 show an almost identical difference in delays between delays caused by vehicles using signals and delays caused by vehicles not using signals. These interesting phenomena are a verification that the results are independent of a particular time of day, day of the week, sample size, or intersection, that is, the results are valid for different intersections, for different times of day, for different days of the week, and for different sample sizes.

Possible Contributions to Variance of Data

Several factors exist which may have made a small, if any, contribution to the variance of the data. These factors may provide some rationale for the existence of some of the aforementioned

"interesting phenomena," as well as for the three data sets that contradict the hypothesis.

Human Limitations

Physical human limitations may have contributed to the variance of the data, regardless of the method by which the data were collected. With the Esterline-Angus Event Recorder Method, these human limitations pertain to reaction time, that is the amount of time physically required to record the data, and properly encoding the data. With the Stopwatch Method, these limitations pertain to starting the stopwatch, reading and writing down the data, and resetting the stopwatch. The human body is capable of performing these functions in a given minimum amount of time, and if traffic conditions are such that less time than this physical minimum is needed, then problems and errors, such as misreading data, not being able to collect data on all applicable vehicles, and resetting and ending the counter at the incorrect time, are possible.

Alteration of Driver Behavior

Every effort was made by the researcher to be as inconspicuous as possible when collecting data. Nonetheless, in several instances, a driver at an intersection would alter his behavior upon seeing the researcher. In one case, a driver stopped in the middle of the intersection to inquire of the researcher what he was doing. In most of the cases when driver behavior was altered, the driver became more cautious; however, in several instances, the

driver took more risk, such as a rapid acceleration maneuver dogged", to use the non-technical terminology. It cannot be determined how much effect, if any, this alteration of driver behavior had on the data, but this effect must still be recognized as a possible contributor to the variance of the data.

Distractions to Researcher

Unfortunately, on several occasions the researcher became distracted. Most of the time, the researcher was distracted by local residents asking what the researcher was doing. In one instance, the distraction came from a police officer asking if the researcher was having car problems. As with the alteration of driver behavior, it is not known how much, if at all, distractions to the researcher affected the data. Nonetheless, researcher distractions must be taken into consideration when evaluating the variance of the data.

Statistical Tests

As expressed earlier, due to the weakness of the correlation expressed by the regression equations, several other statistical tests were employed to determine if the differences between the delays caused by vehicles using turn signals and the delays caused by vehicles not using turn signals were random variation or an effect of turn signal usage.

Binomial Test

The binomial test is one of the simplest, and thus weakest, tests of statistics. The binomial test determines the probability of a particular combination of outcomes for a variable for which only two outcomes are possible. For example, the probability that if a coin is flipped 15 times and heads failed to appear would be determined using the binomial test. In the case of the example, when the coin is flipped, there are only two possible outcomes, heads or tails; in the case of this study, the outcomes are signal usage reduces delay and signal usage doesn't reduce delay. If a relationship between signal usage and delay does not exist, then the probability for either outcome is 0.50, that is, for a particular data set, there is a 50-50 chance that delay will be reduced when signals are used.

Using this hypothesis, a binomial test was performed. Results of three of the fourteen data sets indicate no decrease in delay when signals are used. The binomial probability of this occurrence is 0.029. Thus, the hypothesis that turn signal usage reduces stopped delay cannot be rejected at the 95% level of confidence. The calculations for this test are given in Appendix A.

Wilcoxon Rank Sum Test

One major disadvantage of the binomial test is that it does not take into account magnitudes of the differences in the stopped delays. Thus, a second statistical test was performed to determine if not only the frequency of delay reductions was significant, as

shown by the results of the binomial test, but also if the magnitudes of these reductions were significant. Thus, a Wilcoxon Rank Sum Test was performed to determine if the differences in magnitudes between the delays caused by vehicles using signals and the delays caused by vehicles not using signals was significant.

The Wilcoxon Rank Sum Test was chosen as the device for this evaluation instead of the T test because the Wilcoxon Test is valid for non-parametric samples such as this. The results of the Wilcoxon Test show that the probability of the distributions of stopped delays caused by vehicles using turn signals and not using turn signals being identical, in other words, that turn signal usage by a right-turning vehicle on the through roadway does not have an effect on the stopped delay of a waiting vehicle on the intercepted roadway is 0.005. Thus, the hypothesis that turn signal usage reduces stopped delay cannot be rejected at the 95% level of confidence.. The calculations for this test are given in Appendix B.

Summary of Statistical Analyses

Both statistical analyses indicate at a 95% level of confidence that the hypothesis that turn signal usage reduces stopped delay cannot be rejected. The strongest verification of this hypothesis comes from the Wilcoxon Rank Sum Test, which is inherently stronger than the binomial because it takes into account the magnitude of the differences in delay.

5. CONCLUSIONS

VALIDITY OF THE BASIC HYPOTHESIS

From this study, it can be concluded that the basic hypothesis of this study, that increased turn signal usage by right turning vehicles on the through roadway does reduce stopped delay to "ready" vehicles on the intercepted roadway, cannot be rejected. A scatterplot of the percentage of turn signal usage versus delay suggests a weak correlation. Furthermore, two statistical analyses, the binomial test and the Wilcoxon Rank Sum Test, indicate that the hypothesis cannot be rejected at the 95% level of confidence. In short, the statistical analysis supports the hypothesis of this research, which is that turn signal usage by right turning vehicles on the through roadway at an unsignalized three-legged intersection reduces stopped delay to waiting vehicles on the intercepted approach.

Three factors may have contributed to the variance of the data: (1) the physical limitations of the researcher pertaining to reaction time, (2) altered driver behavior due to the driver's detection of the researcher at the intersection, and (3) distractions to the researcher from inquiring minds.

THE NEED FOR FURTHER STUDY

One suggestion for future study is a general analysis in which a large heterogeneous sample is used. The results could then be compared to the results of this study, which used a small

heterogeneous sample, for verification of the results. In other words, determine if the conclusion that can be drawn from a different and larger sample is the same as that drawn from this sample. Furthermore, a larger sample may provide a stronger regression correlation between the percentage of turn signal usage and stopped delay, which could be useful in traffic analysis.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Alexander, Greson J., and Lunenfeld, Harold. "The Role of Driver Expectancy in Highway Design and Traffic Control." Civil Engineering Practice, Volume 4. Lancaster, PA: Technomic Publishing Company, 1988, pp. 429-455.
- American Association of State Highway and Transportation Officials (AASHTO). A Policy on Geometric Design of Highways and Streets. Washington, D.C.: AASHTO, 1984.
- Barch, A. M.; Nangle, J.; and Trumbo, D. "Situational Characteristics and Turn Signalling." Highway Research Board Bulletin, 1958, Number 172, pp. 95-103.
- Blomgren, G. W., Jr.; Scheuneman, T. W.; and Wilkens, J. L. "Effect of Exposure To a Safety Poster on the Frequency of Turn Signalling." Traffic Safety and Research Review, Vol. 7, Number 1, March 1963, pp. 15-22.
- Foot, H. C.; Chapman, A. J.; and Wade, F. M. (editors). Road Safety: Research and Practice. Eastbourne, U. K.: Praeger Publishers, 1981.
- Forbes, T. W. (editor). Human Factors in Highway Traffic Safety Research. New York: John Wiley and Sons, 1972.
- Freund, John E. Modern Elementary Statistics, Third Edition. Englewood Cliffs, NJ: Prentice-Hall, 1967.
- Greenshields, Bruce D.; Schapiro, Donald; and Ericksen, Elroy L. Traffic Performance At Urban Street Intersections. New Haven, CT: Yale University, 1947.

- Institute of Transportation Engineers. Transportation and Traffic Engineering Handbook, Second Edition. Englewood Cliffs, NJ: Prentice-Hall, 1982.
- National Committee on Uniform Traffic Laws and Ordinances. Uniform Vehicle Code and Model Traffic Ordinance. Revised 1987. Evanston, IL: National Committee on Uniform Traffic Laws and Ordinances, 1987.
- Ott, Lyman. An Introduction To Statistical Methods and Data Analysis, Third Edition. Boston: PWS-Kent Publishing, 1988.
- Papacostas, C. S. "Influence of Leading Vehicle Turn Signal Use on Following Vehicle Lane Choice at Signalized Intersections." *Transportation Research Record*, Number 996, 1984, pp. 37-44.
- Rothengatter, J. A., and de Bruin, R. A. (editors). Road User Behaviour: Theory and Research. Assen, The Netherlands: Van Gorcum & Company, 1988.
- Tennessee Department of Safety. Tennessee Laws Relating To Motor Vehicles, 1987 Edition. Charlottesville, VA: The Michie Company, 1987.

APPENDIXES

APPENDIX A

A DESCRIPTION OF THE BINOMIAL TEST

As stated in Chapter 4, the binomial test determines the probability of a particular combination of outcomes for a variable for which only two outcomes are possible. In order to be considered a valid binomial experiment, an experiment (study) must have the following properties:

- 1. The experiment consists of n identical trials.**

This study had fourteen identical (in the fact that the study parameters were the same for all) trials.

- 2. Each trial results in one of two outcomes, either success (yes) or failure (no).**

For this study, the two outcomes for each trial were: turn signal usage does not reduce delay, or turn signal usage does reduce delay.

- 3. The probability of success on a single trial is p , and p remains the same from trial to trial.**

For this study, a success was considered to be no reduction of delay due to turn signal usage. If the hypothesis that turn signal usage does not reduce delay

is valid, then the probability of p (turn signal usage did not reduce delay) for every trial is 0.5.

4. The trials are independent; that is, the outcome of one trial does not influence the outcome of any other trial.

This property is valid for this study, for each data set was independent of all others.

5. The random variable x is the number of successes observed during the n trials.

In the case of this study, x equals the number of data sets where turn signal usage did not reduce delay.

(Source: Lyman Ott. An Introduction To Statistical Methods and Data Analysis, Third Edition. PWS-Kent Publishing, Boston, 1988, p. 89)

Substituting into the binomial equation,

$$P(x) = \frac{n!}{x! (n-x)!} p^x q^{n-x}$$

where:

n = number of trials

p = probability of success on a single trial

q = probability of failure on a single trial

x = number of successes in n trials

$P(x)$ = probability of x successes in n trials

gives,

$$P(x) = \frac{14!}{x! (14-x)!} 0.5^x 0.5^{14-x}$$

For this study, P(3 OR LESS) is desired.

$$P(3 \text{ OR LESS}) = P(0) + P(1) + P(2) + P(3)$$

$$P(0) = \frac{14!}{0! (14-0)!} 0.5^0 0.5^{14-0}$$

$$P(0) = 0.000061$$

$$P(1) = \frac{14!}{1! (14-1)!} 0.5^1 0.5^{14-1}$$

$$P(1) = 0.0008545$$

$$P(2) = \frac{14!}{2! (14-2)!} 0.5^2 0.5^{14-2}$$

$$P(2) = 0.0055542$$

$$P(3) = \frac{14!}{3! (14-3)!} 0.5^3 0.5^{14-3}$$

$$P(3) = 0.000061$$

$$P(3 \text{ OR LESS}) = 0.000061 + 0.0008545 + 0.0055542 + 0.000061 = 0.0286865$$

Thus, the probability that if turn signal usage does not affect delay only three of fourteen trials would show that delay did not decrease when turn signals were used is 0.0286865.

APPENDIX B

A DESCRIPTION OF THE WILCOXON RANK SUM TEST

The Wilcoxon Rank Sum Test is a method to test if two populations are identical. The Wilcoxon Rank Sum Test provides a method to test non-normal samples with different variances. The basic assumptions for this test are that both samples be independent and random.

The null hypothesis for this test is that the two populations are identical. The method to test the null hypothesis involves combining the sample and ranking the values in ascending order. If several values are identical, that is, tied, then the average of the ranks of those values is used for all the tied values. The test statistic is the sum of the ranks of the values in the first sample. The test statistics is then compared to a tabular value for a given confidence level to determine the validity of the null hypothesis.

For this study, the use of this statistical test is shown in the following example.

$$H_0: \mu_1 = \mu_2$$

$$H_A: \mu_1 > \mu_2$$

Population 1: delays caused by vehicles not using turn signals

Population 2: delays caused by vehicle using turn signals

Test Statistic: $z=(T-\mu_T)/\sigma_T$

where: T = sum of the ranks of sample 1
 $\sigma^2_T = n_1 n_2 (n_1 + n_2 + 1)/12$
 $\mu_T = n_1 (n_1 + n_2 + 1)/2$
 n_1 = size of sample 1
 n_2 = size of sample 2

For a given confidence level, α , reject H_0 if $z > z_\alpha$

Sample 1 (No Signals) {RANK} Sample 2 (Signals) {RANK}

9.04	{28}	1.84	{2}
3.08	{12}	2.46	{7}
3.24	{13}	2.43	{6}
3.70	{18}	3.89	{19}
4.28	{27}	4.12	{23}
4.21	{25}	2.98	{11}
4.08	{21.5}	2.13	{3}
4.08	{21.5}	2.65	{8}
2.68	{9}	4.16	{24}
2.85	{10}	1.46	{1}
3.32	{15}	3.90	{20}
4.26	{26}	3.29	{14}
3.66	{17}	2.30	{5}
3.51	{16}	2.24	{4}

$T=259$

$\mu_T=203.0$

$\sigma^2_T=473.537$

$\sigma_T=21.761$

$z= 2.573$

$\alpha= 0.05$

$z_\alpha= 1.645$

Since $z > z_{\alpha}$, then reject H_0 . Thus, it can be concluded for a 95% level of confidence that the delays caused by vehicles using turn signals is less than the delays caused by vehicles not using turn signals.

VITA

Michael Howard Schrader was born on April 12, 1966, in Saint Louis, Missouri. He attended elementary school in that city, and graduated from Saint Louis University High School in May 1984. In August of that year, he entered the University of Missouri-Columbia. He received his Bachelor of Science in Civil Engineering from the University of Missouri-Columbia in December 1987. Upon graduation, Michael was employed as a structural engineer for the McDonnell Douglas Corporation in Saint Louis for one year. In January 1989, Michael began his study towards a Master's Degree at the University of Tennessee, Knoxville. He obtained this degree in May 1990.

Michael is a member of Chi Epsilon, the American Society of Civil Engineers, the Transportation Research Board, and the Institute of Transportation Engineers. Upon graduation, he will be employed by the Public Works Department of the city of Springfield, Illinois. Michael plans to wed Tracy Ramsey of Saint Louis in June 1990.