Technical Report Documentation Page

1. Report No. FHWA/TX-94/1392-3	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle OPTIMIZING DETECTOR PLACEMENT FOR HIGH SPEED ISOLATED SIGNALIZED INTERSECTIONS USING VEHICULAR DELAY AS THE CRITERION		5. Report Date October 1994 6. Performing Organization Code
7. Author(s) Donald L. Woods and Lakshmi Manasa Koniki		8. Performing Organization Report No. Research Report 1392-3
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Study No. 0-1392
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Interim: September 1993 - August 1994 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

Research Study Title: Effective Detector Placement for Computerized Traffic Management

16. Abstract

On high speed approaches to an isolated intersection, providing for dilemma zone protection may result in sluggish operation and this, in turn, may result in higher delays. A trade-off analysis of detector placement is, therefore, essential for optimization of dilemma zone protection and reducing delays.

TEXAS Model (Version 3.2) was employed to determine optimal detector placement strategies on high speed isolated intersections. Traffic volumes varied between 200 vehicles per hour (vph) per approach to 800 vph per approach. Mean speeds of 90 km/h (55 mph), 70 km/h (45 mph), and 55 km/h (35 mph) were simulated. Detector placements were developed for mean as well as for 85th percentile speeds.

At approach volumes less than 500 vph per approach (250 vphpl), three detector layouts with the first or innermost detector located between 0 m (0 ft) to 18 m (60 ft) from the stop line, resulted in lower delays. However, at traffic volumes greater than 500 vph per approach (250 vphpl), three detector layouts, with the first detector between 24 m (80 ft) and 36 m (120 ft) from the stop line, resulted in lower delay. This trend exists for detector layouts for both mean and 85th percentile speed. Statistical analysis shows that no significant difference in delays for detector layouts with the first detector between 0 m (0 ft) and 18 m (60 ft) within that group. Detector layouts with the first detector placed between 24 m (80 ft) and 36 m (120 ft) from the stop line had no significant difference in delays within this group.

Regression analysis performed on delay and cycle length for different detector layouts showed a strong linear relationship between them. At low approach volumes, there was no effect of both mean and 85th percentile speeds on delay, whereas at higher approach volumes, 85th percentile speeds resulted in higher delay.

17. Key Words Fully Actuated Signal Control, Isolated Signalized Intersection, Detector Placement, Dilemma Zone, High Speeds	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 106	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

OPTIMIZING DETECTOR PLACEMENT FOR HIGH SPEED ISOLATED SIGNALIZED INTERSECTIONS USING VEHICULAR DELAY AS THE CRITERION

by

Dr. Donald L. Woods, P.E.
Research Engineer
Texas Transportation Institute

and

Lakshmi Manasa Koniki
Graduate Research Assistant
Texas Transportation Institute

Research Report 1392-3
Research Study Number 0-1392
Research Study Title: Effective Detector Placement for Computerized Traffic Management

Sponsored by the
Texas Department of Transportation
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

October 1994

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

This research provides a better understanding of inductance loop detector placement at isolated intersections which allows for more effective use of induction loop detectors by the Texas Department of Transportation and local governmental units in Texas. With the increasing development of freeway management systems, this research will provide the designer with practical information as to the optimal location of detectors at isolated intersections for dilemma zone protection and reduced delays.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Dr. Donald L. Woods (P.E. # 21315) was the Principal Investigator for the project.

ACKNOWLEDGMENTS

The research reported herein was performed as a part of a study entitled "Effective Detector Placement for Computerized Traffic Management" by the Texas Transportation Institute and sponsored by the Texas Department of Transportation. This study was conducted in cooperation with the U. S. Department of Transportation and the Federal Highway Administration. The authors wish to acknowledge Dr. Carroll J. Messer, Research Engineer, Texas Transportation Institute, for his valuable guidance during this research. Special thanks are also due to Dr. Clyde Lee, Dr. Randy Machemehl, and Dr. Tom Rioux (all of the University of Texas at Austin). They helped the authors to better understand the TEXAS Model.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

Table **Page**

SUMMARY

On high speed approaches to an isolated intersection, providing for dilemma zone protection may result in sluggish operation and this, in turn, results in higher delays. A trade-off analysis of detector placement is, therefore, essential for optimization of dilemma zone protection and reducing delays.

TEXAS Model (Version 3.2) was employed to determine optimal detector placement strategies on high speed isolated intersections. Traffic volumes varied between 200 vph per approach to 800 vph per approach. Speeds of 90 km/h (55 mph), 70 km/h (45 mph), and 55 km/h (35 mph) were simulated. Detector placements were developed for mean speeds as well as for 85th percentile speeds.

At approach volumes less than 500 vph per approach (250 vphpl), three detector layouts with the first or innermost detector located between 0 m (0 ft) to 18 m (60 ft) from the stop line resulted in lower delay, whereas at traffic volumes greater than 500 vph per approach (250 vphpl), three detector layouts with the first detector between 24 m (80 ft) to 36 m (120 ft) from the stop line resulted in lower delay. This trend exists for detector layouts for both mean and 85th percentile speed. Statistical analysis shows that there was no significant difference in delays for detector layouts with the first detector between 0 m (0 ft) to 18 m (60 ft) from the stop line within that group. Detector layouts with the first detector placed between 24 m (80 ft) to 36 m (120 ft) from the stop line had no significant difference in delays within this group.

Regression analysis performed on delay and cycle length for different detector layouts show a strong linear relationship between them. At low approach volumes, there was no effect of both mean and 85th percentile speeds on delay, whereas at higher approach volumes, 85th percentile speeds resulted in higher delay.

1.0 INTRODUCTION

1.1 BACKGROUND

High delays are experienced by traffic at signalized intersections when they wait for the green for a long period of time. The increase in delay seriously deteriorates the performance of the intersection. This problem is further compounded by high approach volumes and speeds.

High approach speed drivers have very little time to react to a traffic signal and decide whether to stop or proceed, especially when the signal display changes from green to yellow (1). This confusion often faced by drivers is termed the "dilemma zone problem." The number of rear-end accidents also increases due to this "unexpected" change in the signal (1).

Provision of green time required to reduce delays and dilemma zone problems is a function of the design of signal control systems. Pre-timed signal control is provided in situations where there is not much variation in vehicular demand. All the signal timing parameters, including cycle lengths and phase lengths, are determined based on past traffic trends and are kept constant. Different constant signal timing plans can be developed, however, at different times of the day to account for the variation in the traffic patterns by the time of the day (2). In actuated control, the signal timing is not pre-set but varies with the changes in the traffic demand and is usually the most efficient signal control in use today.

Actuated signals can be either semi-actuated or fully actuated signals, depending upon the traffic volumes on the major and cross street. Semi-actuated control involves actuation only on minor approaches where the cross street is a low volume street. Fully actuated signal control is adopted at the intersection of two high volume streets. Without proper information to the controller, a fully actuated signal cannot serve these high traffic demands efficiently. The controller should be able to receive accurate information regarding the actual traffic situation, so that it can process most of the traffic demand efficiently. In an actuated signal control system, this required information is provided by the vehicular detection system.

Detectors play the most important role in the actuated type of control and are defined as "devices for showing the presence or passage of vehicles or pedestrians" (3). The purpose of vehicle detectors follows (4):

1. To call for a phase when traffic is present;
2. To extend the phase during saturated flow conditions;
3. To extend the phase for random arrival flow; and
4. To gap-out the phase safely to minimize the "dilemma zone problem."

Inductive loop detectors, magnetic detectors, magnetometers, ultrasonic detectors, radar and microwave detectors are different types of detectors in use today (5). Of these, inductive loop detectors are the most widely used and known, but their operation is not well understood.

The number and type of loop detectors on an approach depend upon the function they are intended to serve. Single long loops are used on low speed, low volume approaches. On high speed approaches, short multiple loops are normally used, as they extend the green time allowing the vehicles to move through the intersection. This alleviates the dilemma zone problem to an extent. The detectors should be so located to collect information about the traffic conditions and allow for a suitable signal timing plan to be developed at the intersection. This serves to minimize delays and the number of accidents. Strategic placement of detectors, therefore, is one of the many important factors that is required to obtain successful actuated signal control (6).

1.2 PROBLEM STATEMENT

Placing detectors primarily to minimize the dilemma zone problems may work very well on high speed roadways in rural areas. As traffic volumes are low in rural areas, traffic delays experienced are not very significant. Applying the same dilemma zone setup in urban areas may result in sluggish operation. Because of denser traffic conditions, traffic experiencing high delays becomes a common scene. This situation is particularly a familiar feature on frontage roads and to some extent is also applicable on arterial streets. A tradeoff is therefore essential between the location of detectors for reducing dilemma zone problems and to reduce delays. A need, therefore, arises to optimize the placement of detectors in order to obtain the best performance of the signal in terms of minimizing delays at signalized intersections.

1.3 OBJECTIVE

This study sought to optimize detector placement on high speed, high volume approaches to isolated intersections in urban areas. Optimum detector placement will result in the least total vehicular delay.

2.0 LITERATURE REVIEW

This chapter presents background information on inductive loop detectors and how they work with traffic actuated signals. The different loop detector designs, fully actuated controller features and various parameters that constitute fully actuated signal timing are discussed. A review of the literature is also presented in order to obtain information about different detector placements in use today.

An inductive loop detector, as mentioned earlier, is the most commonly used detector type (5). It is installed as two or more turns (loops) of wire in a saw-cut slot in the pavement. These loops are placed where vehicle detection is required. The wire ends are taken to the curb to a ground box where they are connected to the cable that runs from the ground box to the detector unit in the controller cabinet.

When alternating current is passed through these turns of wire, an electromagnetic field occurs around the loop. A change in frequency results when a vehicle passes through this field. If the frequency change exceeds a preset threshold value, the detector unit "detects" the vehicle (3). The detector then places a call to the controller to provide green time to that approach and service the vehicle. Figure 1 illustrates the loop detector system.

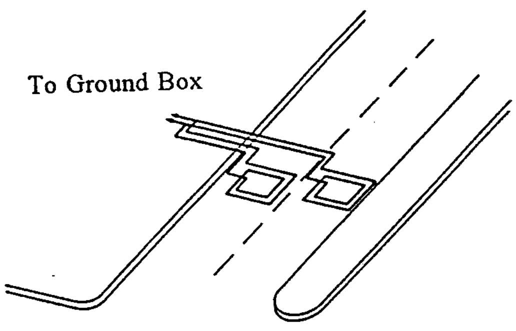


Figure 1. Loop Detector System (5)

2.1 TYPES OF INDUCTION LOOP DETECTOR DESIGNS

Sackman et al. classified loop detector systems in four different designs based on the type of function (7). Normal loop detector design consists of detectors which can operate either on pulse mode or presence mode. Extended-Call (EC) and Delay-Call (DC) detector designs are special types of designs intended to serve primarily turn movements and are usually features of stop line detectors. EC-DC detectors have both the extended-call and delay-call features incorporated. The following is a brief discussion of different types of loop detector unit designs.

2.1.1 Normal Loop Detector Designs

Based on the output signal from the detector unit to the controller when a detection occurs, detectors are said to operate in one of two different modes. They are either the pulse mode or the presence mode. The method of operation of these two detection modes are briefly discussed below.

Pulse Mode. In this mode of operation, when a vehicle traverses the loop, a short pulse lasting about one-tenth to one-fifteenth of a second is output by the detector unit, the duration of which is independent of the length of the loop and vehicle. Detectors on pulse mode are usually set with "locking memory." In other words, a call placed on pulse mode will be remembered by the controller, and this helps in bringing back the green as quickly as possible to that phase (8). The controller retains all calls until a gap-out or max-out has occurred on the conflicting phase, processes the calls retained, and then brings the green back to the subject phase. Pulse mode with locking memory is usually used for detectors on lanes primarily serving through traffic and for traffic counting (8).

Presence Mode. When the detectors operate in presence mode, the detector unit outputs a signal that lasts as long as the vehicle stays over the loop. The duration of the pulse is therefore a function of the length of the loop and vehicle and the speed of the vehicle. Detectors on presence mode usually operate with "non-locking memory," i.e., the call placed by the detector is not remembered by the controller. The call is held continuously as long as the vehicle is over the loop, and when a max-out or gap-out occurs on the conflicting phase, green is provided to the phase placing the call. This feature is usually used for detectors placed on turn lanes with right-turn-on-red or left turn lanes (8). With presence mode operation, the extension interval is kept very short.

2.1.2 Extended - Call Loop Detector Design

An extended-call operation is one in which the detector unit holds the call placed for a pre-set period of time using an adjustable timer incorporated in the detector unit (7). The time for which the call is extended can be designed to begin either when the vehicle enters the loop or when the vehicle leaves the loop. The maximum travel time is therefore equal to the sum of the time to hold the green, the extension time, and the gap timing set on the controller (8).

2.1.3 Delayed - Call Loop Detector Design

In this type of operation, the call is not placed or is delayed for a pre-set period of time (7). The delay time starts its count down once the vehicle is present on the loop. If the vehicle happens to leave the loop before the delay time is over, as usually occurs for the case of Right-Turn-On-Red (RTOR), the call is not placed to the controller. However, if the vehicle continues to dwell on the loop after the delay time has elapsed, then a call is placed to the controller to serve that phase (8).

2.1.4 EC-DC Loop Detector Design

This type of detector has both the call-extend and call-delay features. Using this feature, the maximum allowable headway that will hold the green is reduced which, in turn, reduces the delay to the vehicles in other conflicting phases. The detectors operate on presence mode and non-locking memory (8). When the EC-DC feature is used, all calls are delayed for a pre-set delay time, and when the delay time has elapsed, a continuous call is placed to the controller (presence mode call). This continues until a gap-out occurs which, in turn, depends on the extension time, passage time set on the controller, and the length of the loop. The delay feature of the first loop then prevents other calls from being placed.

Apart from the above mentioned loop designs, two other features, namely phase skip and phase recall, are invoked by switching "ON" the respective switches in the controller. The following is a brief description of the method of operation of these two actuated controller features.

2.1.5 Phase Skip

This is a special feature in actuated traffic control. In pre-timed signal control, the sequence in which the green is allotted to each phase is pre-determined. Whereas, in actuated control, though the type of phasing is set, the sequence in which the green is allotted depends on whether calls are placed to the controller during the current "cycle." Hence any phase can "clear to" any other compatible phase. In a particular cycle, in the absence of demand, a phase can be skipped altogether so that green is provided to the phase in demand by turning the skip phase "ON."

2.1.6 Phase Recall

This type of operation is employed primarily in semi-actuated operation. The recall switch present in the controller is turned "ON" for the major street phase so that the green is provided to that phase for time equal to minimum green. If the recall switches are "ON" for both major and minor street phases, the signal works like pre-timed control. When recall switches are "OFF," the signal works like a fully actuated signal if detectors are present on each approach (7).

Knowledge of all the above mentioned detector designs and special controller features is necessary to develop efficient signal timing at the intersection. Signal timing for a fully actuated control constitutes four main parameters: initial interval, or the preset minimum green; passage interval, or the vehicular extension or unit extension; the maximum green; and yellow and red clearance intervals. The yellow change interval and the all-red interval constitute the change interval timing which is the same as the change interval timing adopted in pre-timed traffic control. Figure 2 illustrates the relationship between these timing parameters of fully actuated control. Briefly discussed below are details of the signal timing parameters for fully actuated signal control.

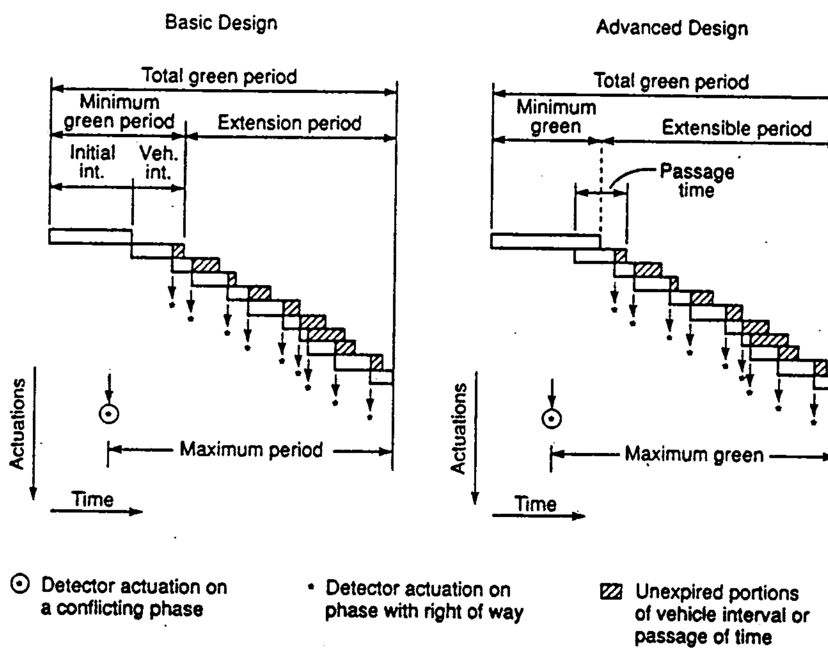


Figure 2. Fully Actuated Signal Timing Parameters (5)

2.2 SIGNAL TIMING FOR FULLY-ACTUATED CONTROL

2.2.1 Initial Interval or Minimum Green

The initial interval consists of the time set in the controller essentially to dissipate the queue of vehicles between the stop line and the first detector on the onset of green. The timing, therefore, is a function of the distance between the stop bar and the leading edge of the first detector on the approach. The initial interval in seconds can be determined by using the following equation as formulated by Roess et al. (2). The start up lost time is also accounted for and is assumed to be 4 seconds as shown in Equation 1.

$$Initial\ \ Interval\ \ seconds = 4 + 2 * (\frac{D'}{6}) \quad (Metric) \qquad (1)$$

$$Initial\ \ Interval\ \ seconds = 4 + 2 * \frac{D}{20} \quad (English) \qquad (1\text{-A})$$

where,

D' is the distance in meters between the stop bar and the first detector,
D is the distance in feet between the stop bar and the first detector.

This equation is applicable when there is no detector at the stop bar. With a stop-line detector, the need to have a minimum green is eliminated. However, in order to take into consideration driver expectancy and start-up lost time, many traffic engineers still use a minimum green time that varies between 2 to 15 seconds (8). Provision of high minimum green time ensures driver expectancy in case of detector failure, whereas a lower minimum green time allows for more efficient operation (i.e., reduce delay) (8).

2.2.2 Passage Interval or the Extension Interval

The extension interval is usually set to allow for the design vehicle to travel from the detector to the stop bar or between a pair of detectors (2). Passage time is "the added time up to which the phase will be extended when all the calls to the controller are dropped by the detector units" (8). As long as the time between vehicular actuation is less than this passage interval, the green extends for that phase up to the maximum green. If the time between successive actuation is greater than the passage interval, the phase "gaps-out," and conflicting calls are served by the controller. In the absence of conflicting calls and "rest-in-red" feature, the phase continues to hold the green on the last called phase in spite of a gap-out (8). The passage interval is a function of design speed of vehicles on the approach and is estimated based on Equation 2 (2).

$$Extension\ Interval,\ seconds = \frac{D'}{(0.278 * Speed)}\ (Metric) \quad (2)$$

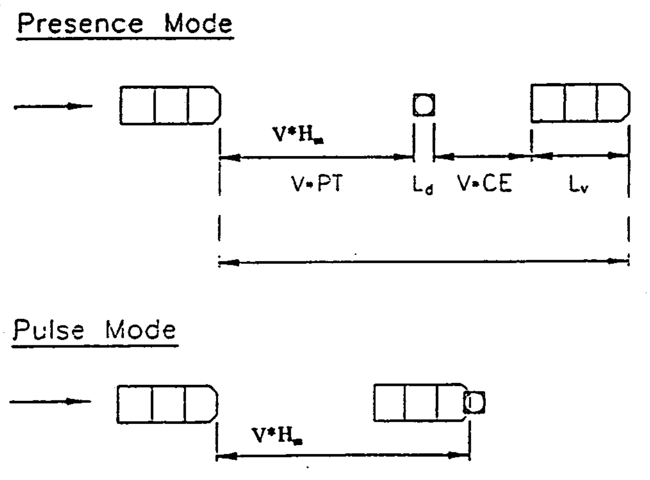
$$Extension\ Interval,\ seconds = \frac{D}{(1.47 * Speed)}\ (English) \quad (2\text{-}A)$$

where,

D' is the distance in meters between the stop bar and the detectors, and the speed is the speed of the vehicles in kilometers/hour,

D is the distance in feet between the stop bar and the detectors, and speed is the speed of the vehicles in miles per hour.

According to Bonneson et al., when the phase serves only one traffic lane, the maximum time separation (before the phase gaps out) is equal to the maximum allowable headway (8). If the phase serves more than one lane, then MAH, or maximum allowable headway, is interpreted as the time between successive calls and not necessarily as the time between vehicles in the same lane. The relationship between the H_m (MAH) and the passage time for pulse and presence detectors is shown in Figure 3. This is applicable only to a phase serving a single lane with a single loop detector.



where,
V = vehicle speed;
PT = passage time setting;
CE = call-extension setting;
H_m = maximum allowable headway;
Ld = length of detector; and
Lv = detected length of the vehicle.

Figure 3. Maximum Allowable Headway for Presence and Pulse Detector Modes

2.2.3 Maximum Green

The maximum green consists of the maximum time the phase can hold the green. This is set usually between 30 and 60 seconds. Kell et al. suggested a method for determining the maximum green time for a phase. In this method, the optimum cycle length and green times are determined in the same way as calculated for pre-timed traffic control. The calculated green intervals are then multiplied by a factor ranging between 1.25 to 1.5 to obtain the maximum green for a fully-actuated control (5).

Bonneson et al. (8) suggest guidelines for the setting of the maximum green. They recommend that the maximum green setting achieves three goals. These include minimization of the number of max-outs due to short maximum greens, satisfaction of driver expectancy, and minimizing delays to the traffic on conflicting phases. The moment at which the controller begins to time the maximum green and subsequent phase termination depends on whether a call is placed either on the current phase (phase that has the green) or another phase. Bonneson (8) identified four possible conditions and the respective timing of maximum greens.

In Case 1, a phase holding the green due to successive vehicular actuation ends by a max-out, if a call is placed on a conflicting phase. In this case, the maximum green timer starts timing as soon as a conflicting call has been placed. In Case 2, if the current phase is being extended by calls placed by vehicles, then in the absence of calls on the conflicting phases, the current phase continues to hold green as long as the condition is maintained. In the case of no calls on the current phase, but a call is placed on the conflicting phase, Case 3, the current phase terminates by gap-out, and the green is provided to the calling phase. Maximum green is not timed in this case. In Case 4 if there are no calls on either phase, the current phase continues to dwell in green.

2.2.4 Yellow and Red Clearance Intervals

The yellow and all-red intervals constitute the phase change timing parameters and are estimated as a function of driver reaction time, the deceleration requirements, and the intersection clearance times. Equation 3 is usually adopted to determine the phase-change interval (5)

$$CP = t + \frac{V'}{(2a')} + \frac{W' + L'}{V'} \quad (Metric) \qquad (3)$$

$$CP = t + \frac{V}{2a} + \frac{W + L}{V} \quad (English) \qquad (3\text{-A})$$

where,

CP = yellow plus red clearance, seconds
t = perception-reaction time (usually 1 second)
V = approach speed, ft/sec; V' = approach speed, m/sec;
a = deceleration rate, ft/sec^2; a' = deceleration rate, m/sec^2
W = width of the intersection, ft; W' = width of the intersection, meters
L = length of vehicle, ft; L' = length of vehicle, meters.

2.3 DETECTOR PLACEMENT

All of the above mentioned fully actuated signal timing parameters are a function of the placement of detectors on the inbound lanes of the approach to an intersection. Detectors are primarily placed to help the traffic travel smoothly through the intersection while taking into account the expectancy and safety of the drivers. As mentioned in Chapter 1, it is very important that the placement of detectors be such that they reduce the dilemma zone problem and delays at the intersection.

Many researchers have suggested different detector placements and different combinations of types of loop detectors to obtain efficient signal control. Some have suggested the length and mode of detector operation that they consider as the criteria to minimize the dilemma zone problem, while others have looked at the detector placements to minimize delays. The timing parameters were also given due consideration to obtain a better signal operation. In the following paragraphs, a review of the past research directed towards placing the detectors to reduce the problem of dilemma zone and delays at an intersection is presented.

In 1973, Rodgers (9) discussed the importance of detector placement at intersections and suggested that detectors be placed by considering the average speed of vehicles and the tolerable time separation between the arriving vehicles that hold the green (MAH). This is the passage timing discussed in the signal timing parameter section. Cribbins and Meyer (10) addressed the topic of multiple loop detectors. They tested different combinations of presence and pulse detectors under real life conditions and concluded that short presence loop detectors on the major approach along with a long loop on the minor approach results in least delay. However, why they chose to test these particular lengths of detectors is unknown.

Beirele in 1974 tried to minimize the dilemma zone problem by developing a method of placing multiple loops at intersections that provide sufficient stopping distances in case of a change in signal indication (11). The loops are placed based on the principle that there will be a speed reduction between successive loops in case the driver decides to stop. Beirele's method, however, fails to provide dilemma zone protection for speeds over 80 km/h (50 mph), and a trailing car might get trapped in the dilemma zone. Sackman et al. reported two other significant detector placement methods, namely the Winston - Salem method and the SSITE method (7).

The Winston-Salem method provides for dilemma zone protection to vehicles travelling up to 95 km/h (60 mph); however, it fails to provide sufficient protection to the trailing car, like Beirele's method. Though the SSITE method is supposed to provide protection for speeds up to 95 km/h (60 mph), only speeds up to 80 km/h (50 mph) were actually considered in the basic method (7).

Apart from the three above mentioned methods, Wu et al. in 1983 evaluated the detector placement method then used by the Texas State Department of Highways and Public Transportation (6). All four loop detector placements were tested by the TEXAS simulation model for different volumes, and speeds and were statistically analyzed in terms of their effects on vehicular delay. Wu concluded that there was no statistically significant difference between them.

Bullen was one of the very few who studied the effects of detector placement on vehicular delay (12). He used the EVIPAS simulation model in his work and concluded that detectors placed between 30 m (100 ft) to 60 m (200 ft) resulted in least delay. His study was limited, however, to single presence or pulse detectors and to two-phase signals at intersections.

Apart from detector placement, the importance of signal control parameters like vehicular extension, minimum green, and detector length was studied by Lin et al. using the RAPID simulation model (13). He concluded that shorter vehicular extensions should be used for longer detector lengths. His study was concentrated on presence mode of operation on low speed approaches. Tarnoff et al. also studied the effect of various control parameters on delay and concluded that a passage detector at 45 m (150 ft) in length resulted in least delay in their study (14).

3.0 STUDY DESIGN

This chapter presents the methodology used to obtain the desired study objective. The need for simulation and the theory behind the working of the Texas Model program are also discussed along with data entry and simulation details.

3.1 NEED FOR SIMULATION

To determine the detector layout that minimizes delay for a particular speed, researchers must test different combinations of detectors and their placement. Testing in actual traffic conditions is not only time consuming but also extremely expensive. Use of a simulation model not only offsets these difficulties but also provides reasonable results which can help engineers evaluate alternative design options, particularly when dealing with the placements of loop detectors for different approach speeds. Simulation models, however, usually have several limitations making it difficult to exactly represent actual traffic situations. The TEXAS Model for Intersection Traffic (Version 3.2) was identified as the most appropriate simulation model for carrying out this study. The operation of this program, including details of the data files, is discussed in detail below.

3.2 TEXAS MODEL FOR INTERSECTION TRAFFIC (VERSION 3.2)

The TEXAS Model for Intersection Traffic is a microscopic simulation program that "allows the user to evaluate in detail the complex interaction among individually characterized driver-vehicle units as they operate in a defined intersection environment under a specified type of traffic control" (15). Researchers can use the model to simulate traffic conditions at both isolated intersections and diamond interchanges. In this study, the isolated intersection program was employed to simulate traffic conditions at an independent intersection.

The TEXAS Model has the capability of simulating different types of traffic control at isolated intersections. These include stop control, yield control, pre-timed control, and semi and fully-actuated signal control.

The TEXAS Model has two main data entry files called GDVDATA and SIMDATA. These data entry pre-processor files have to be processed by GEOPRO, DVPRO, and SIMPRO processors of the model to obtain the desired output statistics. The Model also has an option of displaying the output graphically in real time by using another processor called DISPRO. The elements in each of the data entry files are briefly discussed below.

3.2.1 GDVDATA

GDVDATA is the Geometry-Driver and Vehicle data file containing all of the details relating to the geometry of the intersection, driver characteristics, and vehicle data. Operators enter details in the corresponding "fields" of the GDVDATA file. Each field stands for a particular feature. The range of values for each detail are specified along with the defaults in the program. Geometry and Driver-Vehicle data are input per approach basis in the GDVDATA file.

Geometry data include details of number of legs, number of lanes, length and width of lanes, and curb radii. The leg angle, its orientation with respect to the intersection center line, and details of U-turns, if any, can also be input. TEXAS also has an option of specifying particulars of lane closures or blocked lanes. The length of the lane blocked can be specified with respect to the beginning or ending of the lane. The left turn bays of X ft, for example, are specified as lanes open only X ft from the lane terminal or where the lane ends at the intersection.

The turning movement code describing the movement made by the vehicle moving from the inbound lane to the outbound lane are specified by typing the corresponding letters for each lane movement. Width of the median is also input. Driver and vehicular data include the number of driver classes (3 default), number of vehicular classes (12 default), and the minimum headway between vehicles.

The total hourly volume of traffic on the inbound approach of each leg along with details of the desired vehicular arrival distribution (Poison, Negative Exponential, Shifted Negative Exponential, Gamma, Erlang, etc.) with suitable parameters are specified. The percentage of traffic entering each lane upstream of the intersection and also the percentage of traffic going from each inbound lane to their respective outbound destinations are input. Also required are the speed limits on each leg along with the mean speed of vehicles and 85th percentile speed of the vehicles in order to simulate traffic conditions at the intersection.

The completed GDVDATA files are processed by the GDVPRO. When processed, the processor creates a file that is agreeable to the simulation processor. GDVDATA file also optionally creates the plot of the geometry of the intersection which can be viewed on the screen. The size of the plot required is specified in the GDVDATA file. Apart from all of the above, the duration of the start-up time or the time duration during which no statistics will be collected is entered in the GDVDATA file.

3.2.2 SIMDATA

The SIMDATA is a data entry file in which all the details required for the simulation including the total simulation time, type of signal control, signal timing parameters and other details, and the format of the output statistics are entered. TEXAS Model has the capability of simulating traffic conditions for a maximum time period of 65 minutes, of which the first five minutes are not used to collect the output statistics. The maximum effective simulation time, therefore, is one hour.

Using appropriate terminology, researchers can choose the type of signal control simulated. Once the type of signal control is chosen, all the related details, including the number of controller phases and signal timing information, are specified. Since this study is limited to actuated signal control, only data entry for an actuated signal control are discussed here. The NEMA controller of the TEXAS Model was chosen to simulate a fully actuated signal control at the intersection.

3.2.3 NEMA Controller of the TEXAS Model

The NEMA controller of the TEXAS model is chosen by typing NEMA 8 in the field corresponding to the type of signal control of the SIMDATA file. The controller has an option of simulating single ring or dual ring operation. The signal timing parameters are input similar to that of a fully actuated controller of the TEXAS Model. Apart from the basic signal timing parameters, special features include enabling minimum and maximum recall and "storage for demand."

Storage for demand, a term not common in the transportation parlance, serves the function of "MEMORY ON" and "MEMORY OFF." Depending on the type of detector mode (Pulse or Presence), the memory switch can be switched as "ON" or "OFF." For Memory "ON" function, the storage for demand is chosen as "YES," and Memory "OFF" function is chosen as "NO" against storage for demand. Any phase can be either skipped or placed on recall by entering "ON" or "OFF" for the respective switches.

The number of controller phases can then be specified along with the phase clear to data, which is the phase number to which the current phase clears. The number of detectors required and their placement (the leg, lane, and number of lanes each detector covers) are then specified. Also entered are the data relating to the detector length, their location with respect to the stop bar, and the function mode (presence or pulse). In this type of control, the maximum number of detectors that can be connected is 16.

The completed GDVDATA and the SIMDATA files are processed to get the desired output. The format of the output (132 columns or 85 columns width of output) and the data it should include, either on per movement basis or on per approach basis or both, can be specified in the SIMDATA.

3.2.4 TEXAS Model Output

The TEXAS Model output consists of a variety of MOEs. All these statistics are collected until the vehicle accelerates to the desired speed on the outbound leg of the intersection. As mentioned earlier, no statistics are collected for the first five minutes of the simulation time. The MOEs include Total Delay, Queue Delay, Stopped Delay, Delay below 16 km/h (10 mph), Vehicle-Miles of Travel (VMT), Travel Time, Time Mean Speed, Space Mean Speed, Average Maximum Acceleration, and Average Maximum Deceleration. The overall average for various delays for total number of vehicles processed are also included in the output file. MOEs are summarized either per approach or per lane, or both, depending upon the type of requirement specified in the SIMDATA file of the TEXAS Model.

The delay statistics are measured based on the actual simulated delay. The total delay is measured as the difference between the travel time for a vehicle travelling through the system and the time it would have taken to traverse the same distance at the desired speed of the vehicle. Stopped delay to a vehicle is measured as the time spent by a vehicle travelling at a speed less than 0.9 m/s (3 fps) and joining a queue of vehicles waiting to enter the intersection. The delay experienced by queued vehicles waiting to enter the intersection is measured as queue delay. For actuated control, the output also includes the number of max-outs, the number of gap-outs, and the percentage of green per phase.

Two special features of TEXAS include the REPRUN and the REPTOL options, the replicate run processors. In REPRUN, a user-specified number of replicate runs can be made. The model chooses different random speeds to make the runs and appropriately creates output files for each run with all the appropriate statistics.

In the REPTOL processor of the TEXAS Model, the program makes runs until a user-specified tolerance value is achieved. A minimum of 3 runs and a maximum of 10 runs can be made by the program. REPTOL is based on the criteria that "with a 95% confidence interval, the mean of the Overall Average Total Delay for the replicate runs is within a specified percentage of the Overall Total Delay for the population" (15). Output statistics for the REPTOL include statistics for each run and a file that includes the minimum, mean, maximum, variance, and standard deviation of each of the MOEs. These output files are spreadsheet compatible and importable.

3.3 STUDY INTERSECTION

A typical isolated intersection with the streets intersecting at 90° was selected as the study intersection. To simplify the study, identical geometry was assumed on all four approaches. Due to the high speed environment at the intersection, it was considered only appropriate to provide separate turn bays for left turning traffic at the intersection. Figure 4 depicts the details of the geometry of the study intersection.

Each approach to the intersection included three inbound lanes consisting of a through lane, a shared lane serving through plus right turning traffic and an exclusive left turn bay, and two outbound lanes. The length of the inbound lanes and that of the outbound lanes was assumed to be 245 m (800 ft). The curb radii of 10.7 m (35 ft) were provided such that, at high speeds, all types of vehicles will be able to maneuver smoothly and efficiently. Also, due to the high speed and high volume conditions, it was only considered appropriate to have ideal lane widths of 3.65 m (12 ft). A 4.9 m (16 ft) wide median divided the streets at the intersection.

3.4 SPEEDS

Since this study focussed on high speed isolated intersections, speeds greater than 55 km/h (35 mph) were considered. This study focused on speeds of 55, 70, and 90 km/h (35, 45, and

55 mph). These speeds were assumed to be the posted speed limits as well as the mean speeds. The 85th percentile speeds were computed as a sum of mean speed and a standard deviation of 8.8 km/h (5.5 mph).

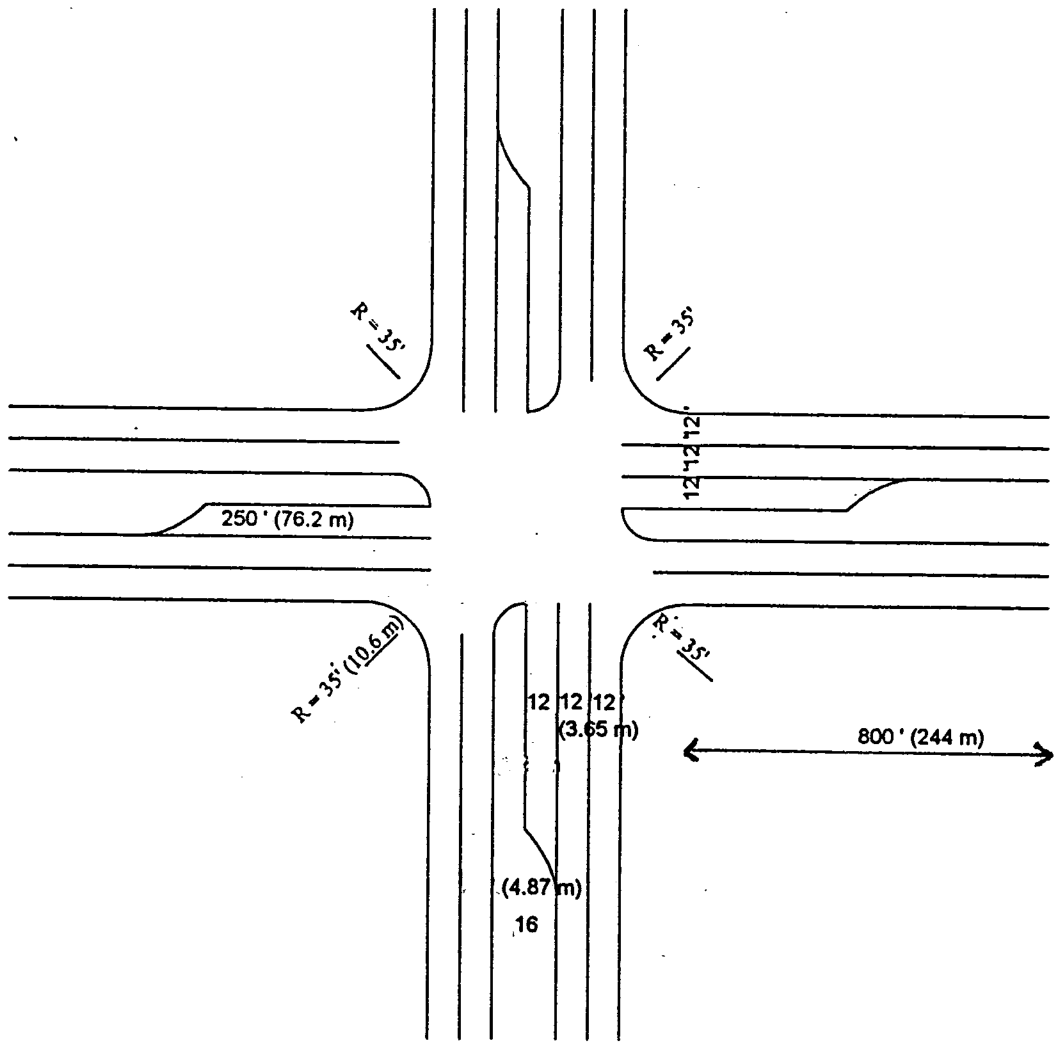


Figure 4. Geometry of the Study Intersection

3.5 TRAFFIC VOLUMES

The traffic volumes simulated in this study varied between 200 vph and 800 vph per approach. Researchers assumed ten percent left turns and right turning traffic.

The traffic headway distribution was assumed as shifted exponential and a random seed "0" was chosen. With this, the model automatically generates a random seed for performing the simulation. The initial start-up time during which the output statistics are not collected was assumed as 5 minutes and was entered into the GDVDATA file. Table A-1 of Appendix A shows a sample GDVDATA file of the TEXAS Model. This file corresponds to approach speeds of 90 km/h (55 mph) and volumes of 600 vph with 10% left and 10% right turning traffic.

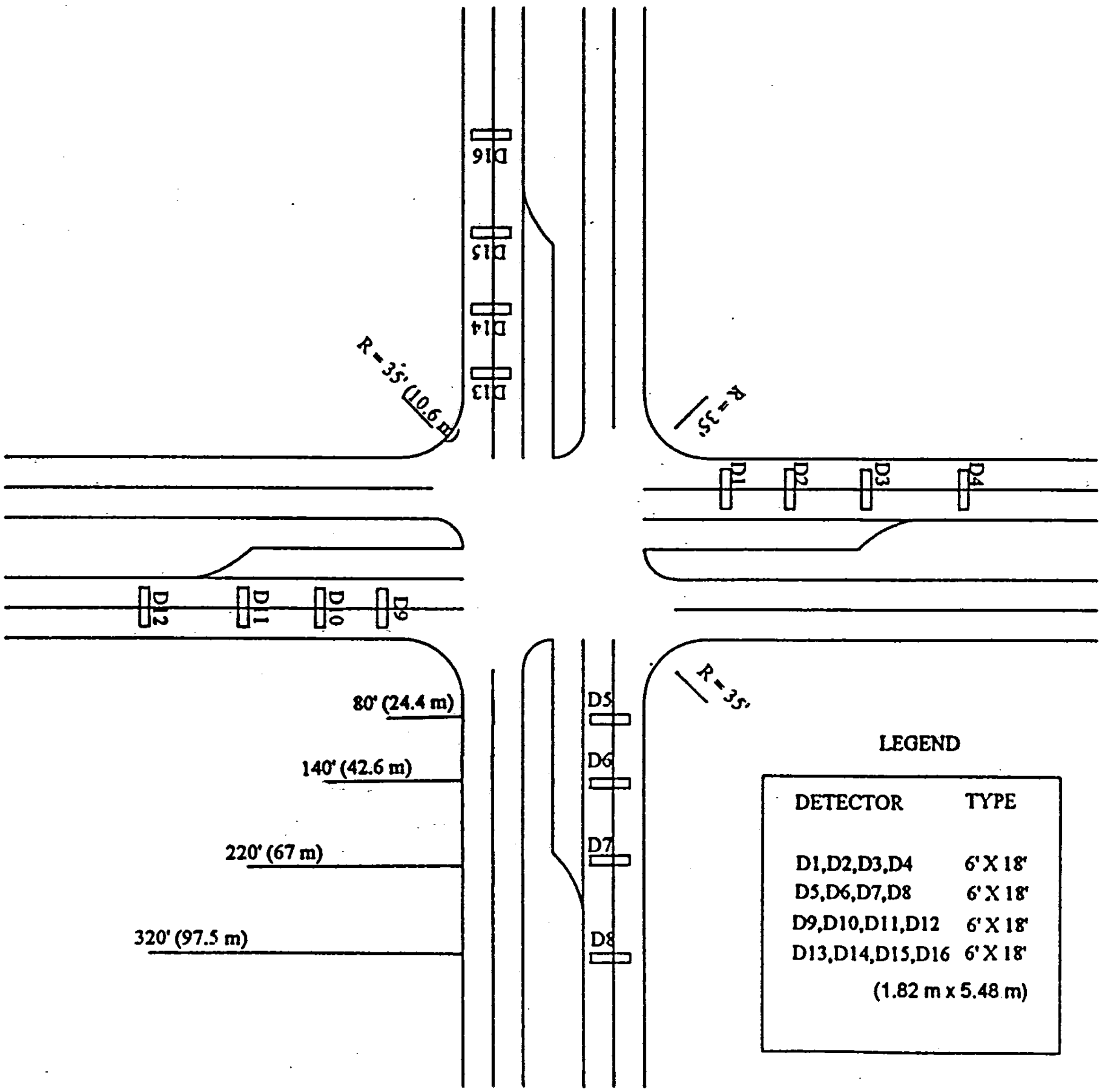


Figure 5. Current TxDOT Detector Layout for Speeds of 90 km/h (55 mph)

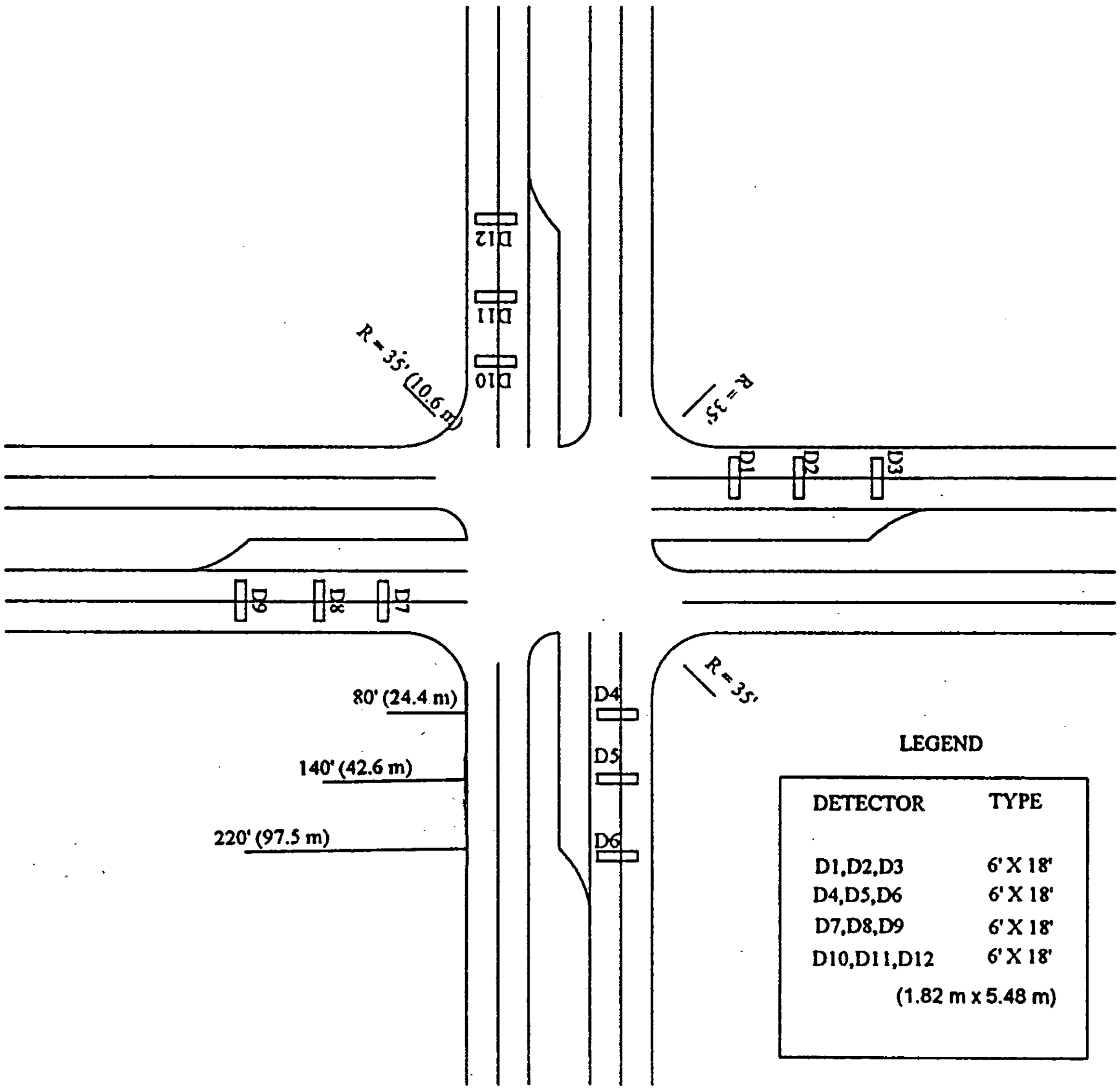


Figure 6. Current TxDOT Detector Layout for Speeds of 70 km/h (45 mph)

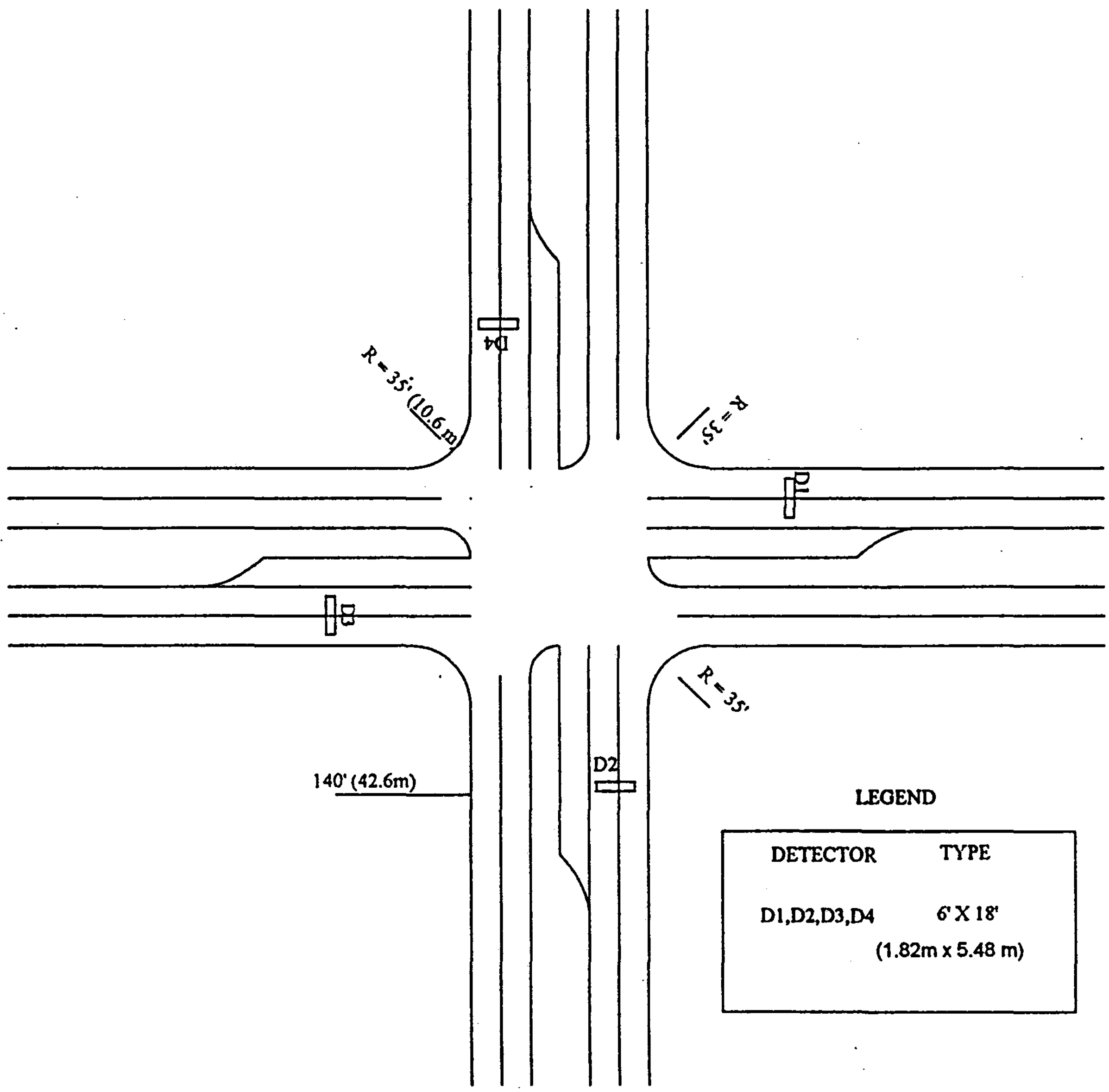


Figure 7. Current TxDOT Detector Layout for Speeds of 55 km/h (35 mph)

3.6 TXDOT DETECTOR LAYOUTS

The current TxDOT detector placement strategy consists of different types of detector layouts for different approach speeds (16). Figures 5-7 show the detector placement strategies for 90, 70, and 55 km/h (55, 45, and 35 mph) followed by TxDOT. Using a particular layout for a particular approach speed, the number and placement of detectors were changed to get different combinations of detector layouts. For each new layout, the signal timing parameters were then calculated.

Through traffic was assumed to be served by 1.83 m x 5.5 m (6' x 18') loops spanning across 2 lanes. Since the proposed study intersection consists of separate left turn bays, a 12 m x 1.83 m (40' x 6') loop was assumed on all four turn bays of the intersection at the stop bar. The size and location of this left turn loop detector remained constant on all four approaches. All the loop detectors serving through traffic were assumed to operate on presence mode and the left turn detectors on presence mode.

3.7 PHASING

The phasing for the actuated control consisted of dual-left leading for both the approaches. Figure 8 depicts the type of phasing at the study intersection.

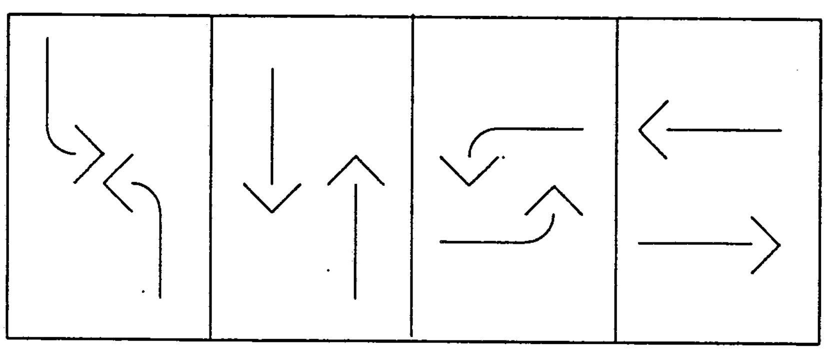


Figure 8. Phasing Sequence

3.8 SIGNAL TIMING

Various signal timing parameters for each detector layout were developed. The following is a brief description of the methodology adopted in estimating the signal timing.

3.8.1 Initial Interval

For each detector layout, the initial interval was calculated based on the distance from the stop line at which the first detector is placed. Equation 1 in Chapter 2 was used to calculate the initial interval. The initial interval for all left turn lanes was assumed as 7 seconds required to clear the queue of the left turning vehicles.

3.8.2 Vehicular Extension

Equation 2 was used to calculate the extension interval for each layout. The distance D in the equation was the greater of the following distances: 1) between the first detector and the stop bar, and 2) between a pair of detectors in the layout. For left turn phases, however, the extension interval was assumed to be 0.5 sec which is the minimum scan interval (time increment for simulation) in the TEXAS Model. The presence mode with the long loop makes this setting practical.

3.8.3 Yellow Change and Red Clearance Interval

The yellow change interval for a particular approach speed was calculated based on Equation 3. Since the geometry of the intersection was assumed constant throughout the study, the yellow and red clearance intervals were determined by linearly interpolating the values from Table 11-1 of the Manual of Traffic Signal Design (5, pp. 144) for approach speeds of 90, 70, and 55 km/h (55, 45, and 35 mph).

During the early part of the research, researchers realized that the signal timing input to the TEXAS Model had to be rounded off to the nearest scan interval used for simulation. For example, if the scan interval was assumed to be 1.0, then a calculated vehicle extension of 1.23 seconds would be rounded off to 1.0 second. With a scan interval of 0.5, the 1.23 seconds can be input as either 1 second or 1.5 seconds. In other words, with a scan interval of 0.5, a greater flexibility can be achieved in entering the input parameters, as they can be input in multiples of 0.5.

Due to this limitation, the signal timing parameters calculated based on the actual TxDOT layout, and fully-actuated controller of the TEXAS Model could not be input to the program as calculated. Researchers realized that using the wrong signal timing for the detector layouts would only give misleading results. Hence, a new detector placement pattern was developed while taking into account the safe stopping distance for vehicles travelling at different approach speeds.

3.9 DETECTOR PLACEMENT STRATEGY

In order to estimate the safe stopping distance from the stop bar for a particular approach speed, a perception reaction time of 1 second and a constant deceleration rate of 10 ft/ sec^2 (3 m/sec^2) were assumed. The dilemma zone was then estimated using Equation 4.

$$D' = (0.278 * V') * (t) + \frac{(0.278 * V')^2}{2 * d'} \quad (Metric) \qquad (4)$$

$$D = (1.47 * V) * (t) + \frac{(1.47 * V)^2}{2 * d} \quad (English) \qquad (4\text{-A})$$

where,

D = Dilemma Zone Potential Limit, ft;
D' = Dilemma Zone Potential Limit, m;
V = Speed, mph; V' = Speed, km/h;
t = Perception-Reaction Time, seconds;
d = Constant Deceleration Rate, ft/sec^2;
d' = Constant Deceleration Rate, m/sec^2.

The NEMA controller of the TEXAS Model, as mentioned earlier, can accept only 16 detectors connected to all the phases. As four 12 m x 1.83 m (40' x 6') loop detectors were assumed for the left turn bays at the intersections, the number of detectors that could be used to detect through traffic was limited to 12. This, in turn, implies that each approach can have only three detectors for through traffic, assuming that an equal number of detectors are to be placed on all the four approaches.

Due to this limitation, the detector layout adopted by TxDOT could not be simulated without modifications. New detector layouts based on the dilemma zone criteria were developed by limiting the number of through detectors to three.

Also, as the TEXAS NEMA Model cannot accept timing data in tenths of a second, it was considered appropriate to develop a detector layout which has a constant and rounded gap timing or extension interval between a pair of detectors. The through detectors were also assumed to be in presence mode of operation. Figure 9 illustrates the detector layout. The methodology used in determining various detector layouts is as follows. All loops are 1.8 m x 5.5 m (6' x 18').

1. The safe stopping distance or the dilemma zone potential limit (D) was estimated using Equation 4, for each of the approach speeds.

2. The first detector (Detector 1) or the innermost detector was placed at "x" distance from the stop bar.

3. Detector 3 or the outermost detector was placed at the beginning of the dilemma zone, D ft from the stop bar.

4. The distance between detector 1 and detector 3 was calculated, and detector 2 was placed at the midpoint of this distance (D1/2).

5. Initial interval was computed based on Equation 1 and passage interval for the distance D1/2 based on Equation 5. Due to the presence mode of the detectors, the length of the detection zone was reduced by a distance equal to the sum of the length of the vehicle (Lv) and length of the loop (Ld). The passage interval was, therefore, estimated for a distance of "x1" feet as shown in Figure 9.

$$Passage \quad Interval = \frac{(D1/2 - Lv - Ld)}{(0.278 * V')}, \; seconds \quad (Metric) \quad (5)$$

$$Passage \quad Interval = \frac{(D1/2 - Lv - Ld)}{(1.47 * V)}, \; seconds \quad (English) \quad (5\text{-}A)$$

where,

V and V' are the speeds in mph and km/h.

6. The computed extension interval was then rounded off to the nearest whole number, and a new distance "D ½" was computed. The length of the vehicle and the length of the loop were then added to get a new distance between detector 1 and detector 2 or between detector 2 and 3.

7. This distance was doubled to get the distance between detector 1 and detector 3 (D1). New distance "D_n" or the location of detector 3 was computed by adding "x" ft or "x'" m to D1.

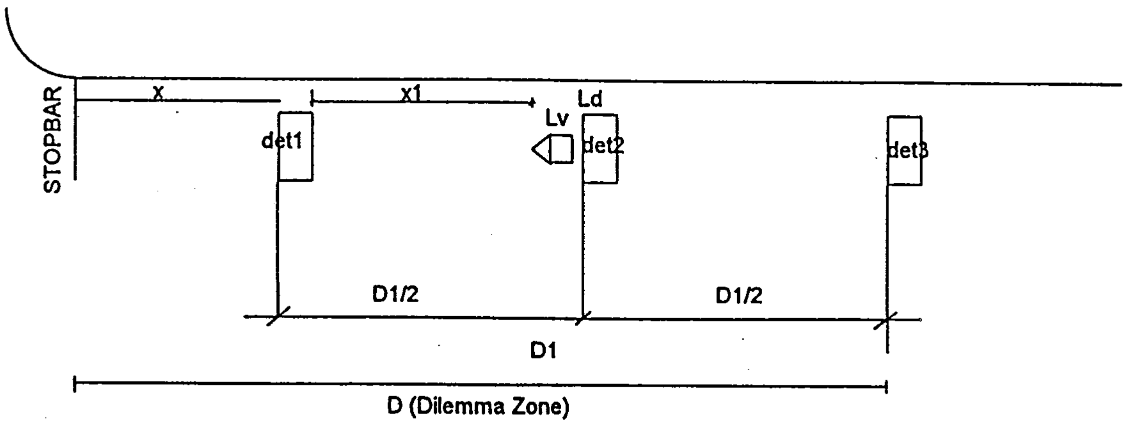


Figure 9. Estimation of Passage Interval and New Detector Layouts

The following Tables 1 through 3 show the original extension interval and the subsequent calculation of detector layouts for the mean speeds.. It should be noted that due to rounding off the extension interval, the last detector could not always be placed at the beginning of the dilemma zone as calculated. Also, the distance between the pair of detectors for different detector layouts differed due to the extension interval and location of detector 1. The speeds used to compute the dilemma zone in the above procedure were the mean speeds, i.e., 90, 70, and 55 km/h (55, 45, and 35 mph, respectively).

The dilemma zone and the subsequent detector layouts were also determined for the 85th percentile speeds, i.e., 97, 80, and 65 km/h (60.5, 50.5, and 40.5 mph). Tables 4 through 6 show the new detector layouts based on the 85th percentile speeds of the vehicles.

DET1 at, ft (m)	Initial Interval, secs	D1 ft (m)	Passage Interval secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2+ Lv+Ld, ft (m)	D11 ft (m)	Dn ft (m)	Detector location from stop bar
Speed = 55 mph (90 km/h), P-R Time = 1.0 sec, Deceleration Rate = 10 ft/sec² (3 m/sec²), Stopping Distance = 408' (124 m)									
0 (0)	0	408 (124)	2.22	2	162 (49)	186 (57)	371 (113)	371 (113)	0', 186', 371' (0 m, 57 m, 113 m)
40 (12)	8	368 (112)	1.98	2	162 (49)	186 (57)	371 (113)	411 (125)	40', 226', 412' (12 m, 69 m, 125 m)
60 (18)	10	348 (106)	1.85	2	162 (49)	186 (57)	371 (113)	431 (131)	60',246', 432' (18 m, 75 m, 132 m)
80 (24)	12	328 (100)	1.73	1.5	121 (37)	145 (44)	291 (87)	371 (113)	80', 225', 370' (24 m, 68 m, 113 m)
100 (30)	14	308 (94)	1.61	1.5	121 (37)	145 (44)	291 (87)	391 (119)	100', 245', 390' (30 m, 75 m, 119 m)
120 (36)	16	288 (88)	1.48	1.5	121 (37)	145 (44)	291 (87)	411 (125)	120', 265', 410' (36 m, 80 m, 125 m)

Table 1. Determining Detector Layouts for a Mean Speed, Approach Speed of 90 km/h (55 mph)

DET1 at, ft (m)	Initial Interval, secs	D1 ft (m)	Passage Interval secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2+ Lv+Ld, ft (m)	D11 ft (m)	Dn ft (m)	Detector Location from Stop bar
Speed = 45 mph (70 km/h), P-R Time = 1.0 sec, Deceleration Rate = 10 ft/sec² (3 m/sec²), Stopping Distance = 285 ft (87 ft)									
0 (0)	0	285 (87)	1.76	2	132 (40)	156 (47)	313 (95)	313 (95)	0', 156', 312' (0 m, 47 m, 95 m)
40 (12)	8	245 (75)	1.46	1.5	99 (30)	123 (14)	246 (75)	286 (87)	40', 163', 286' (12 m, 50 m, 87 m)
60 (18)	10	225 (68)	1.31	1.5	99 (30)	123 (14)	246 (75)	306 (93)	60', 183', 206' (18.3 m, 56 m, 63 m)
80 (24)	12	205 (62)	1.16	1	66 (20)	90 (27)	180 (55)	260 (79)	80', 170', 260' (24 m, 52 m, 79 m)
100 (30)	14	185 (56)	1	1	66 (20)	90 (27)	180 (55)	280 (85)	100', 190', 280' (30 m, 58 m, 85.3 m)
120 (36)	16	165 (50)	0.85	1	66 (20)	90 (27)	180 (55)	300 (91)	120', 210', 300' (36.6 m, 64 m, 91 m)

Table 2. Determining Detector Layouts for a Mean Speed, Approach Speed of 70 km/h (45 mph)

DET 1 at, ft (m)	Initial Interval secs	D1 ft (m)	Passage Interval secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2 + Lv+Ld, ft (m)	D11 ft(m)	Dn ft (m)	Detector Location from Stop bar
Speed = 35 mph (55 km/h), P.R Time = 1.0 sec, Deceleration Rate = 10 ft/sec^2 (3 m/sec^2), Stopping Distance = 184 ft (56 m)									
0 (0)	0	184 (56)	1.32	1.5	77 (23)	101 (30.8)	202 (61.5)	202 (61.5)	0', 101', 202' (0 m, 30.8 m, 61.5 m)
40 (12)	8	144 (44)	0.93	1	51 (15.5)	75 (22.8)	151 (46)	191 (58)	40', 115', 190' (12 m, 35 m, 58 m)
60 (18)	10	124 (38)	0.74	1	51 (15.5)	75 (22.8)	151 (46)	211 (64)	60', 135', 210' (18 m, 41 m, 64 m)
80 (24)	12	104 (32)	0.54	1	51 (15.5)	75 (22.8)	151 (46)	231 (70)	80', 155', 230' (24 m, 47 m, 70 m)
100 (30)	14	84 (25.6)	0.35	1	51 (15.5)	75 (22.8)	151 (46)	251 (76.5)	100', 175', 250' (30 m, 53.3 m, 76 m)
120 (36)	16	64 (19.5)	0.15	1	51(15. 5)	75 (22.8)	151 (46)	271 (82.6)	120', 195', 270' (36 m, 59 m, 88 m)

Table 3. Determining Detector Layouts for a Mean Speed, Approach Speed of 55 km/h (35 mph)

DET1 at, ft (m)	Initial Interval, secs	D1 ft (m)	Passage Interval secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2+ Lv+Ld, ft (m)	D11 ft (m)	Dn ft (m)	Detector Location from Stop bar
Speed = 60.5 mph (97 km/h), P.R Time = 1.0 sec, Deceleration Rate = 10 ft/sec^2 (3 m/sec^2), Stopping Distance = 484 ft (147.5 m)									
0 (0)	0	484 (147.5)	2.45	2.5	222 (67.6)	246 (75)	493 (150)	493 (150)	0', 246', 493' (0 m, 75 m, 150 m)
40 (12)	8	444 (135)	2.23	2	178 (54.3)	202 (61.5)	404 (123)	444 (135)	40', 242', 444' (12 m, 74 m, 135 m)
60 (18)	10	424 (129)	2.12	2	178 (54.3)	202 (61.5)	404 (123)	464 (141.5)	60', 262', 464' (18.3 m, 80 m, 141 m)
80 (24)	12	404 (123)	2	2	178 (54.3)	202 (61.5)	404 (123)	484 (147.5)	80', 282', 484' (24 m, 86 m, 147 m)
100 (30)	14	384 (117)	1.89	2	178 (54.3)	202 (61.5)	404 (123)	504 (153.6)	100', 302', 504' (30 m, 92 m, 153.6 m)
120 (36)	16	364 (111)	1.78	2	178 (54.3)	202 (61.5)	404 (123)	524 (160)	120', 322', 524' (36 m, 98 m, 160 m)

Table 4. Determining Detector Layouts for 85th Percentile Speed, Approach Speed of 90 km/h (55 mph)

DET1 at, ft (m)	Initial Interval secs	D1 ft (m)	Passag e Interva l secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2+ Lv+Ld, ft (m)	D11 ft (m)	Dn ft (m)	Detector Location from Stop bar
Speed = 50.5 mph (80 km/h), P.R Time = 1.0 sec, Deceleration Rate = 10 ft/sec^2 (3 m/sec^2), Stopping Distance = 350 ft (107 m)									
0 (0)	0	350 (107)	2.03	2	148 (45)	172 (52.4)	345 (105)	345 (105)	0', 172', 344' (0 m, 52.4 m, 105 m)
40 (12)	8	310 (94.5)	1.76	2	148 (45)	172 (52.4)	345 (105)	385 (117)	40', 212', 384' (12 m, 64.6 m, 117 m)
60 (18)	10	290 (88)	1.63	1.5	111 (34)	135 (41.2)	271 (83)	331 (101)	60', 195', 320' (18 m, 59 m, 97.5 m)
80 (24)	12	270 (82.3)	1.49	1.5	111 (34)	135 (41.2)	271 (83)	351 (107)	80', 215', 350' (24 m, 65.5 m, 107 m)
100 (30)	14	250 (76.2)	1.36	1.5	111 (34)	135 (41.2)	271 (83)	371 (113)	100', 235', 370' (30 m,71.6 m, 113 m)
120 (36)	16	230 (70)	1.22	1	74 (22.5)	98 (30)	196 (60)	316 (96)	120', 218', 316' (36.6 m, 66 m, 96.3 m)

Table 5. Determining Detector Layouts for 85th Percentile Speed, Approach Speed of 70 km/h (45 mph)

DET1 at, ft (m)	Initial Interval secs	D1 ft (m)	Passage Interval secs	Rounded Passage Interval secs	D11/2 ft (m)	D11/2+ Lv+Ld, ft (m)	D11 ft (m)	Dn ft (m)	Detector Location from Stop bar
Speed = 40.5 mph (65.2 km/h), P.R Time = 1.0 sec, Deceleration Rate = 10 ft/sec^2 (3 m/sec^2), Stopping Distance = 237 ft (72.3)									
0 (0)	0	237 (72.3)	1.59	1.5	89 (27)	113 (34.4)	227 (69)	227 (69)	0', 113', 226' (0 m, 34.4 m, 69 m)
40 (12)	8	197 (60)	1.25	1.5	89 (27)	113 (34.4)	227 (69)	267 (81.3)	40', 153', 266' (12 m, 46.6 m, 81 m)
60 (18)	10	177 (54)	1.08	1	60 (18.3)	84 (25.6)	167 (51)	227 (69.2)	60', 144', 228' (18 m, 44 m, 69.2 m)
80 (24)	12	157 (54)	0.91	1	60 (18.3)	84 (25.6)	167 (51)	247 (75.3)	80', 164', 248' (24 m,50 m,75.6 m)
100 (30)	14	137 (42)	0.75	1	60 (18.3)	84 (25.6)	167 (51)	267 (81.4)	100', 184', 268' (30 m, 56 m, 81.2 m)
120 (36)	16	117 (36)	0.58	0.5	30 (9)	54 (16.5)	108 (33)	228 (69.5)	120', 174', 228' (36 m, 53 m, 69.5 m)

Table 6. Determining Detector Layouts for 85th Percentile Speed, Approach Speed of 55 km/h (35 mph)

3.10 OTHER DETAILS FOR NEMA CONTROLLER OF TEXAS MODEL

The signal timing parameters for each detector layout along with a maximum green of 60 seconds were then coded into the SIMDATA file of the TEXAS Model. The phase skip switch option of the model was entered as "ON" for all the four phases, while the recall switch was chosen as "OFF."

In actuated control, as the green time is allotted to a phase based on the calls placed to the controller, the phase "clear to" data were chosen in such a way that a particular phase can clear to any other phase. This was done by entering all the other three phases in the columns which the subject phase can clear. For example, if the subject phase is A, then phases B, C, and D were entered in the columns to which phase A can clear.

The TEXAS Model prompts for the number of detectors and the details of their placements on an approach basis. The distance at which the detectors were assumed to be placed was the distance between the edge of the curb (where the stop bar is located) and the leading edge of the loop detector. The distances were coded in to the TEXAS Model with a negative sign as a prefix, as TEXAS Model treats distances with a negative sign as distances upstream of the intersection.

The length of the detectors along with their mode of operation were then coded. As mentioned earlier, all detectors were assumed to operate on presence mode.

The phases to which each detector was connected were then entered. Each detector can be connected based on "AND" or "OR" logic. If OR is mentioned, then a controller phase is called when calls are placed by either of the detectors connected to the phase. A negative sign in front of the detector number means that the detector is not connected. If, for example "AND 1-2" is specified, then a call placed on detector number 1 will call the controller phase while a call placed on detector number 2 will not. This research employed the "OR" logic.

3.11 SIMULATION TIME

The total simulation time includes the start-up time and the actual simulation time. The start-up time was assumed as 5 minutes or 300 seconds (which is also the default value in the program) and the simulation was performed for 3600 seconds or 1 hour. In the SIMDATA, the total time period required for simulation was therefore entered as the sum of the two time periods or 3900 seconds (which is also the maximum allowable simulation time). A time increment "DT" of 0.5 seconds was employed. This is the "time step interval" during which the status of each driver vehicle unit is updated during the simulation process. Table A-2 of Appendix A shows a sample SIMDATA file. This file corresponds to the detector layouts estimated based on mean speed for approach speed of 90 km/h (55 mph).

New details were coded into the model and runs were made. It was noticed that detectors on presence mode have to have storage for demand as "YES." It was not possible to perform simulation runs using the TEXAS Model with detectors operating in presence mode and "storage for demand" as "NO." In other words, irrespective of the detector mode, the controller has to have storage for demand. Therefore, all the detectors were operating in presence mode with memory "ON."

4.0 RESULTS

This chapter presents the results of the simulation runs performed using TEXAS Model (Version 3.2). Discussion of the results and analysis of the results is also included.

4.1 GRAPHS FOR DETECTOR LAYOUTS BASED ON MEAN SPEEDS

The detector layouts from Tables 1 through 3 were coded into different SIMDATA files with appropriate signal timing parameters. These were then run against the GDVDATA files with corresponding approach speeds and for approach volumes ranging between 200 vph to 800 vph.

The REPTOL processor was employed to make the runs. A tolerance of 5 % was specified as the criteria for the replicate runs. In other words, the processor would perform simulation runs for each case until the Overall Average Delay was within a 5 % confidence of the Overall Average Delay for the population. A student t-distribution was employed by the processor to process the replicate runs. Also, REPTOL looked only at delay as the criterion to achieve the specified confidence.

The statistics from each run were written in a spread sheet compatible file. The output statistics were reduced, and graphs were plotted between Overall Average Delay and Approach Volumes for each detector layout.

From the TEXAS Model output, the number of "max-outs" and "gap-outs" per phase were also noted. Details of the number of "max-outs" and "gap-outs" were employed in estimating the approximate duration of the cycle lengths of the actuated control for each detector layout and volume. In order to estimate the approximate duration of cycle length in an actuated control, researchers employed Equations 6 and 7 below.

$$Number\ \ of\ Cycles = Number\ \ of\ Maxouts + Number\ \ of\ Gapouts \qquad (6)$$

$$Average\ \ Cycle\ \ Length = \frac{3600}{Number\ \ of\ Cycles},\ secs \qquad (7)$$

This procedure was repeated for detector layouts determined for different approach speeds. Cycle length thus determined for different detector layouts and for a particular speed were plotted against approach volumes. Figures 10 through 12 show the graphs plotted between Overall

Average Total Delay and Approach Volumes for detector layouts determined based on mean speeds of 90, 70, and 55 km/h (55, 45, and 35 mph). The corresponding cycle lengths plotted against approach volumes for different speeds are illustrated in Figures 13 through 15.

4.2 GRAPHS FOR DETECTOR LAYOUTS BASED ON 85TH PERCENTILE SPEEDS

The detector layouts obtained by using the 85th percentile speeds in Equation 6 were also entered into separate SIMDATA files with appropriate signal timing parameters. The GDVDATA files for approach speeds of 55, 70, and 90 km/h (35, 45, and 55 mph) were run with the coded SIMDATA files for each detector layout. It should be noted here that, though the detector layouts were estimated based on two different speeds, namely, mean and 85th percentile, the coded speeds in either case remained the same.

REPTOL processor with a 5% confidence level was employed and runs were made. The output data file of the replicate run processor of the TEXAS featuring minimum, mean, and maximum delays, queue lengths and stops were written into one single file for a particular case by the REPTOL processor. Details about max-outs, gap-outs, and percent green time allotted to each phase, however, were not written into one single file but as individual output files for each replicate run of the REPTOL. The number of "max-outs," "gap-outs," and "percent green time per phase" were therefore, noted for the last replicate run after which the Overall Average Delay converged within the specified confidence level of 5 percent.

The output statistics were analyzed, and graphs were plotted between the Overall Average Total Delay for each detector layout and respective speed and different approach volumes. Figures 16 through 18 show these graphs. The cycle lengths were also estimated based on Equation 5. Figures 19 through 21 show the graphs plotted between cycle lengths and approach volumes for each detector layout and speed.

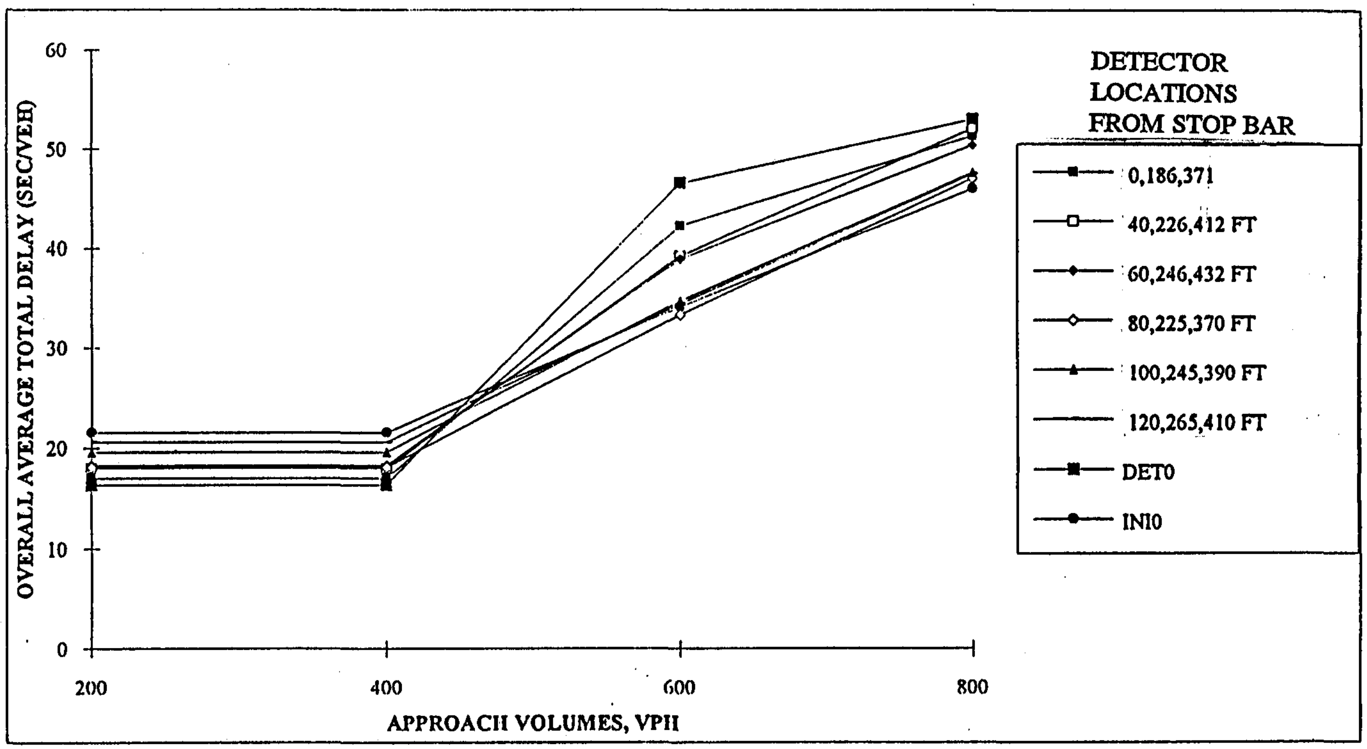


Figure 10. Average Total Delay vs Approach Volumes for 90 km/h (55mph) Mean Speed

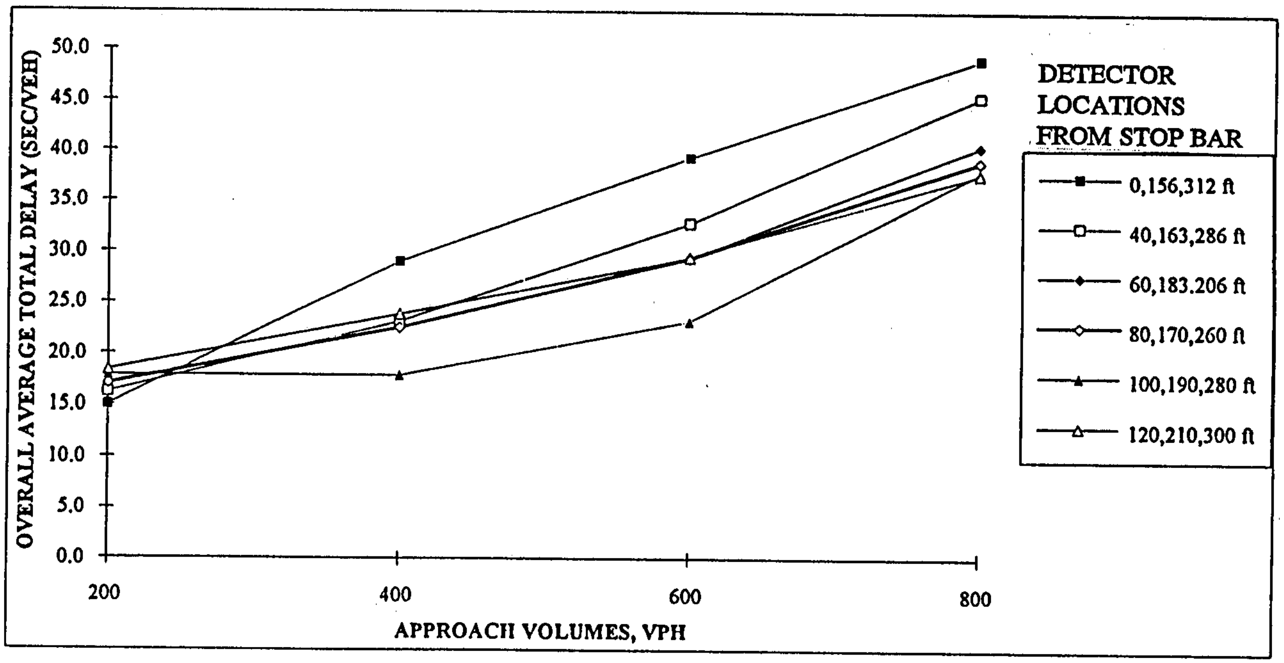


Figure 11. Average Total Delay vs Approach Volumes for 70 km/h (45 mph) Mean Speed

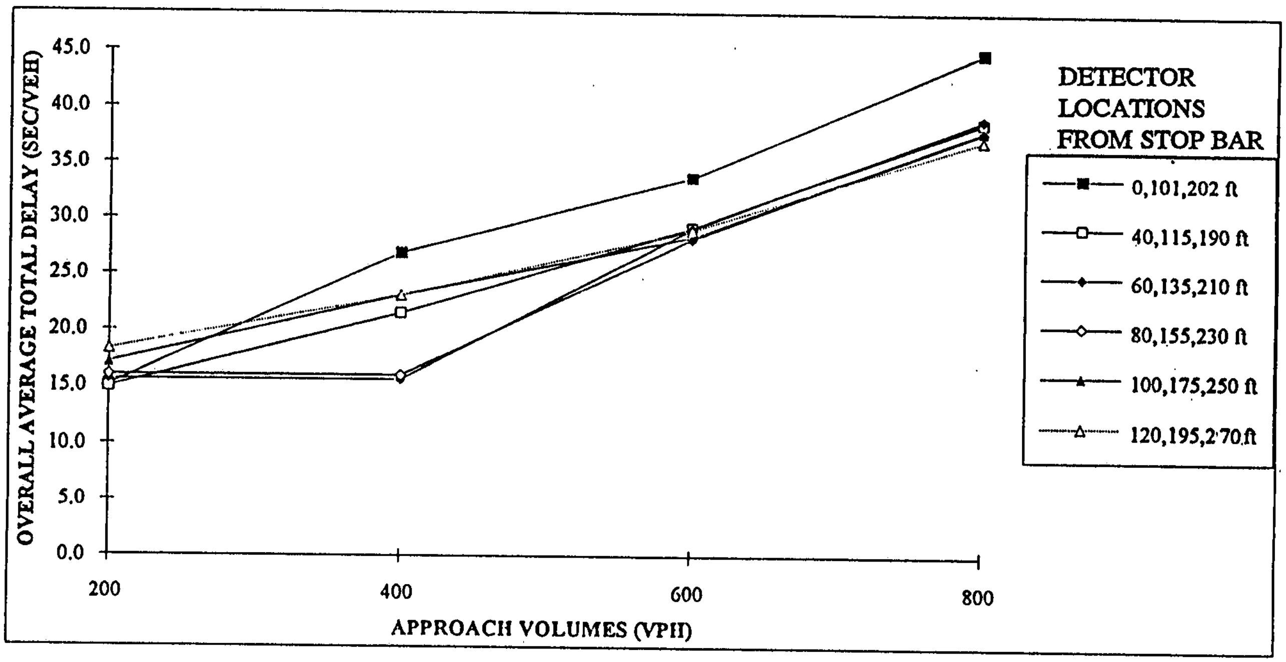


Figure 12. Average Total Delay vs Approach Volumes for 55 km/h (35 mph) Mean Speed

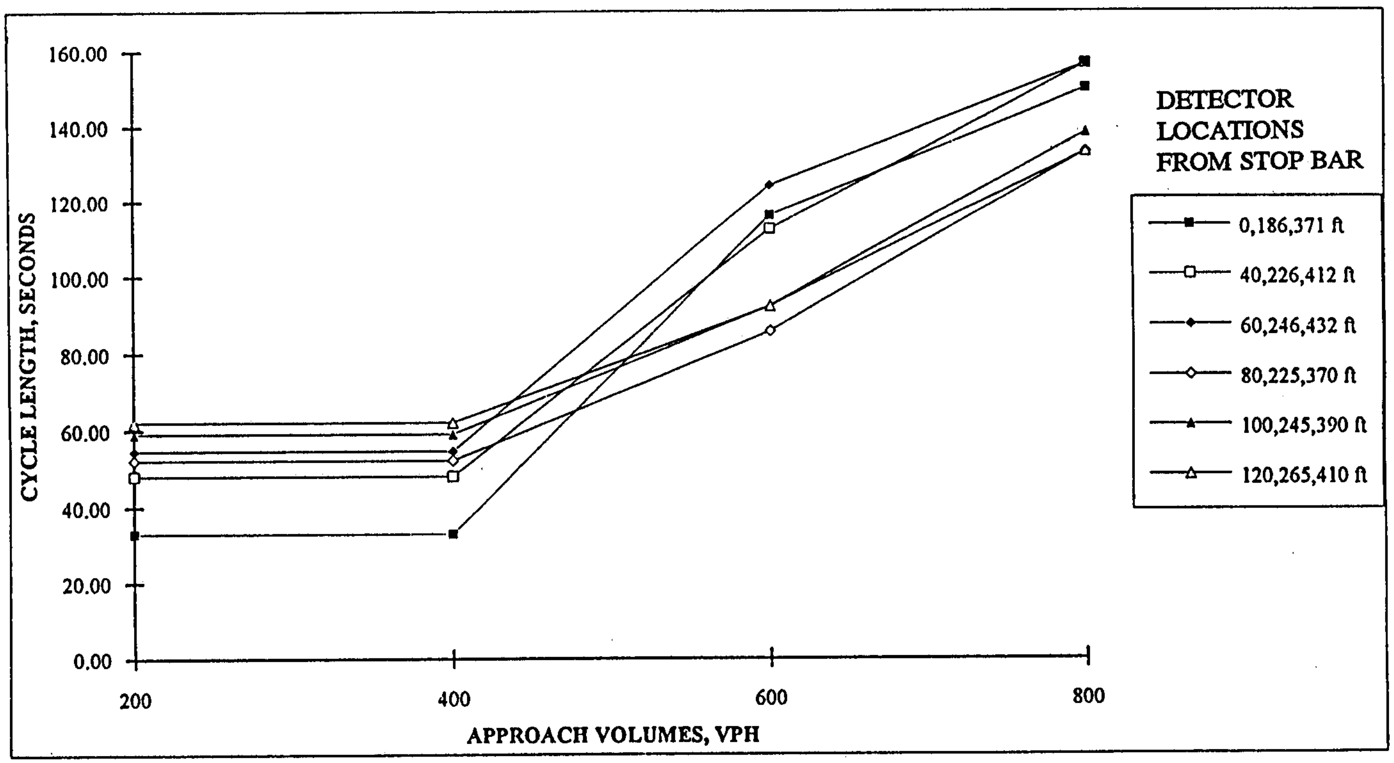


Figure 13. Cycle Length vs Approach Volumes for 90 kmh (55 mph) Mean Speed

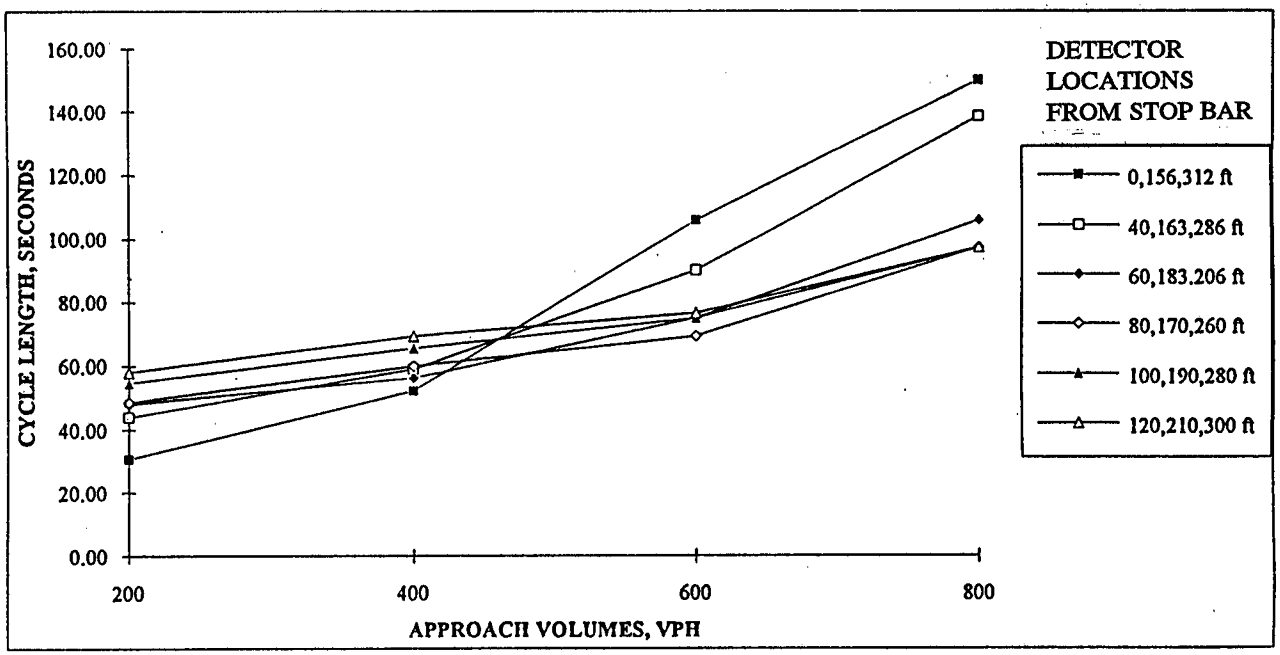


Figure 14. Cycle Length vs Approach Volumes for 70 km/h (45 mph) Mean Speed

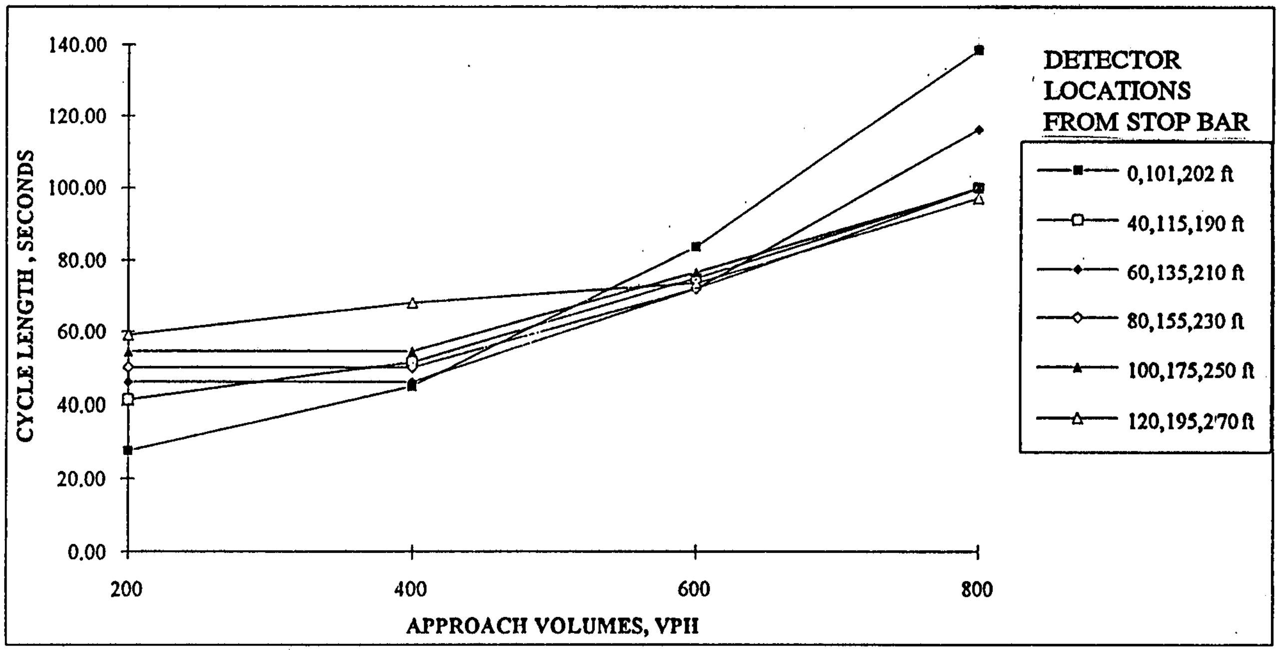


Figure 15. Cycle Length vs Approach Volumes for 55 km/h (35 mph) Mean Speed

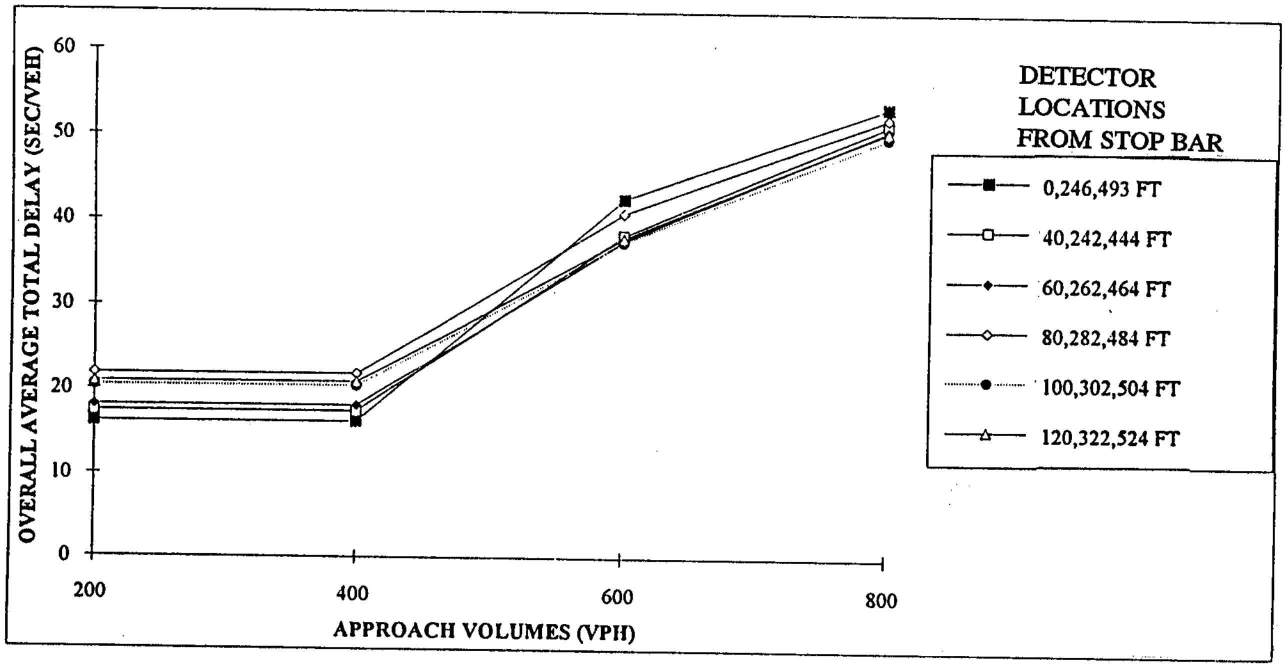


Figure 16. Average Total Delay vs Approach Volumes for 90 km/h (55 mph) 85th Percentile Speed

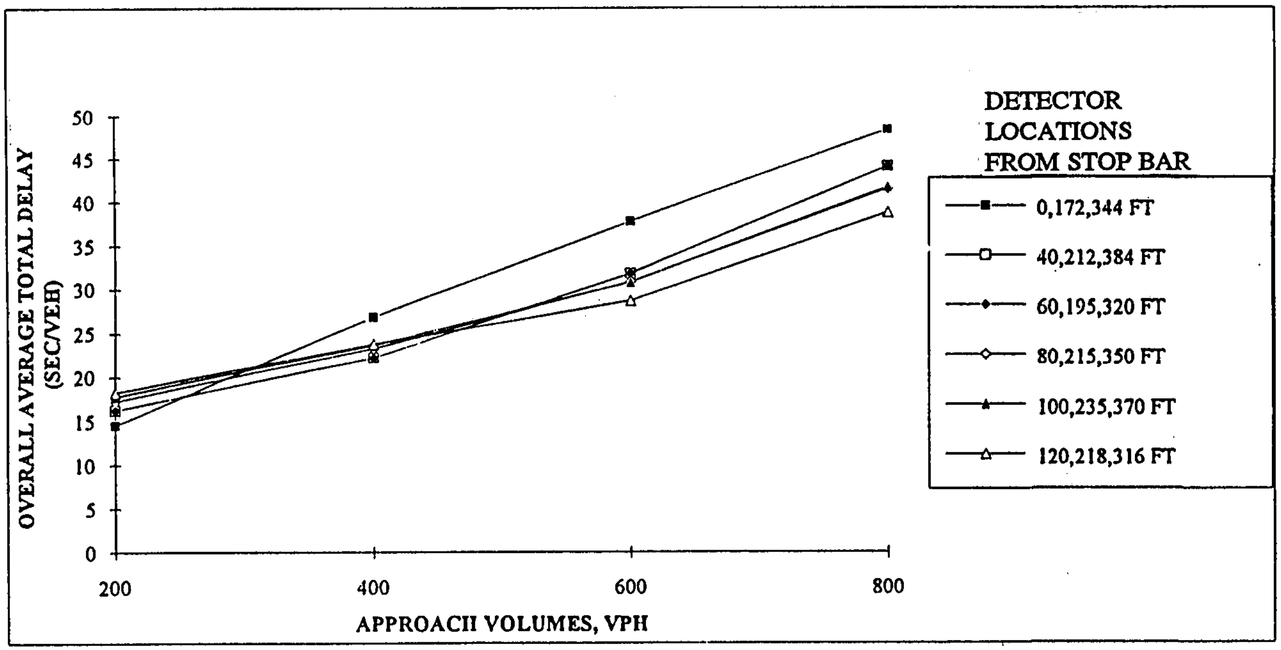


Figure 17. Average Total Delay vs Approach Volumes for 70 km/h (45 mph) 85th Percentile Speed

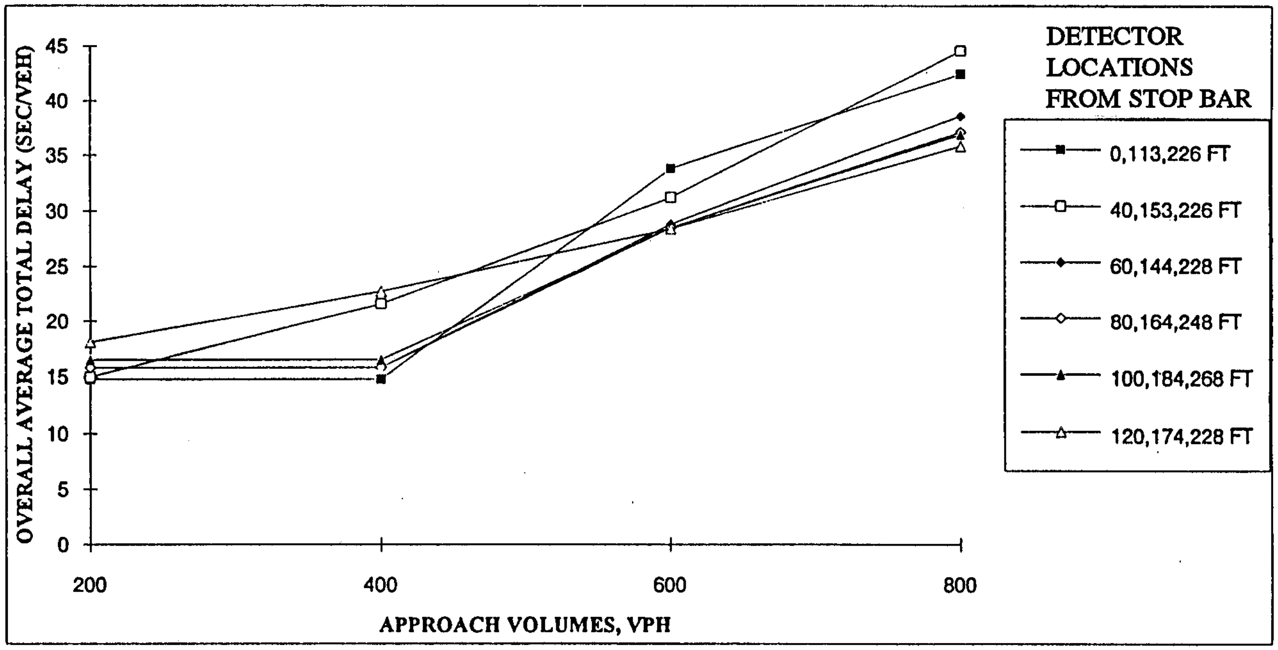


Figure 18. Average Total Delay vs Approach Volumes for 55 km/h (35 mph) 85th Percentile Speed

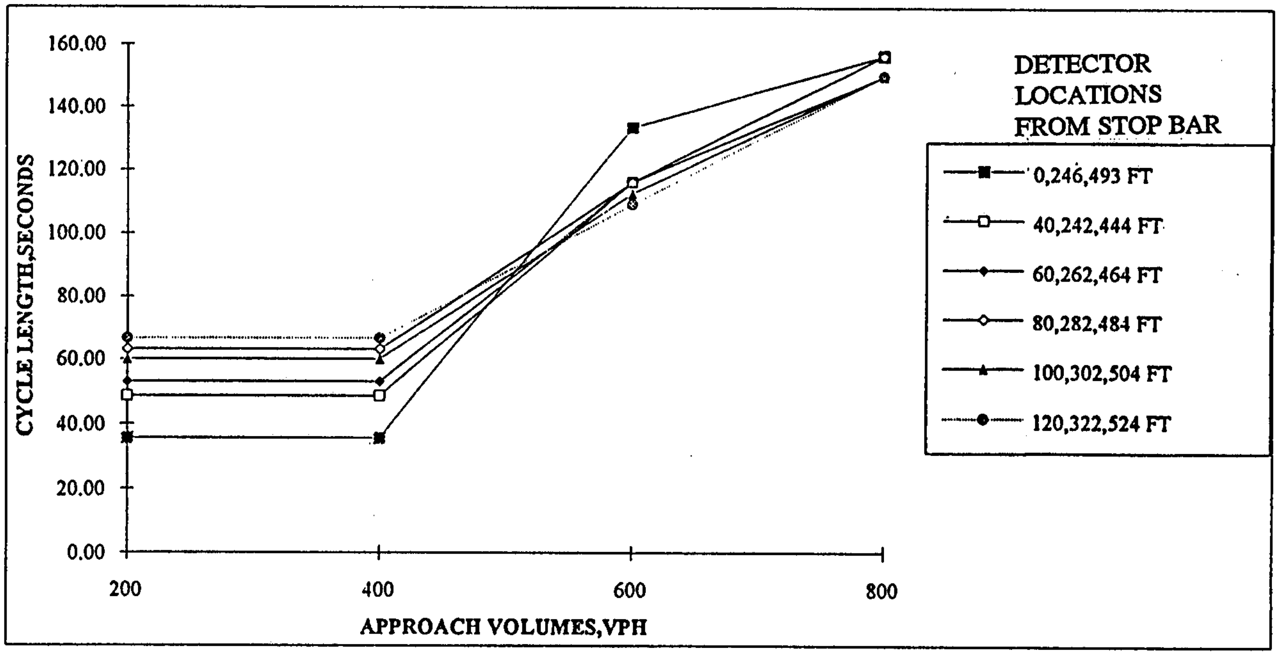


Figure 19. Cycle Length vs Approach Volumes for 90 km/h (55 mph) 85th Percentile Speed

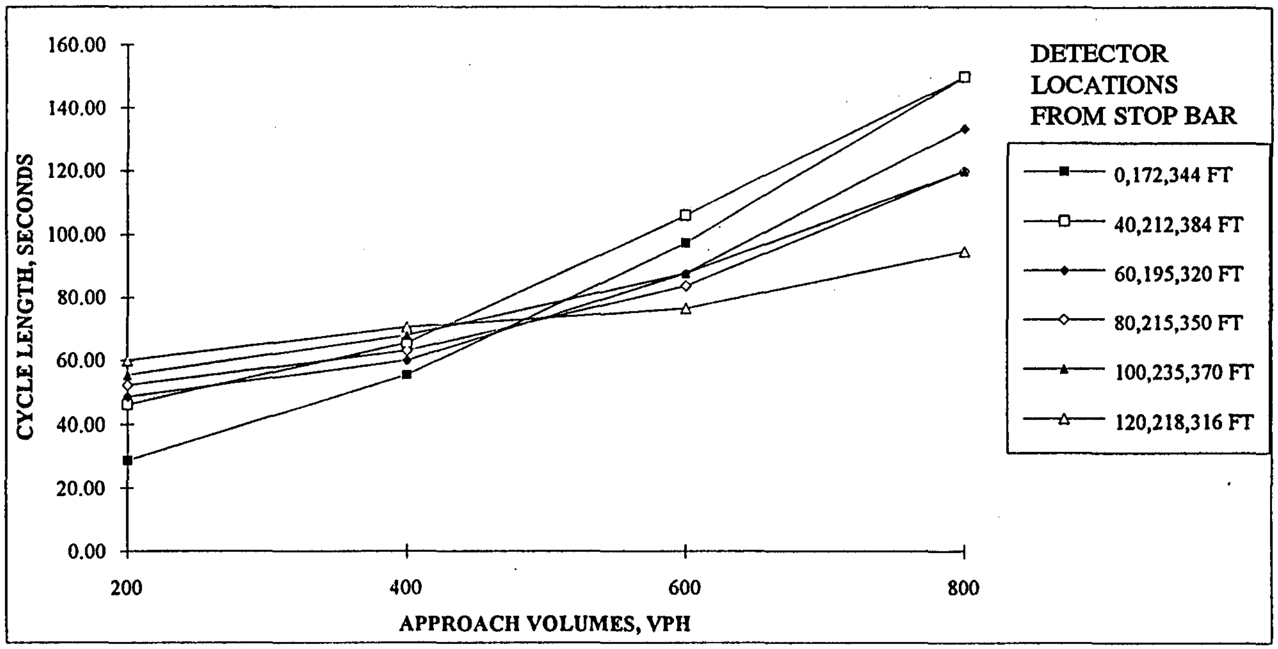


Figure 20. Cycle Length vs Approach Volumes for 70 km/h (45 mph) 85th Percentile Speed

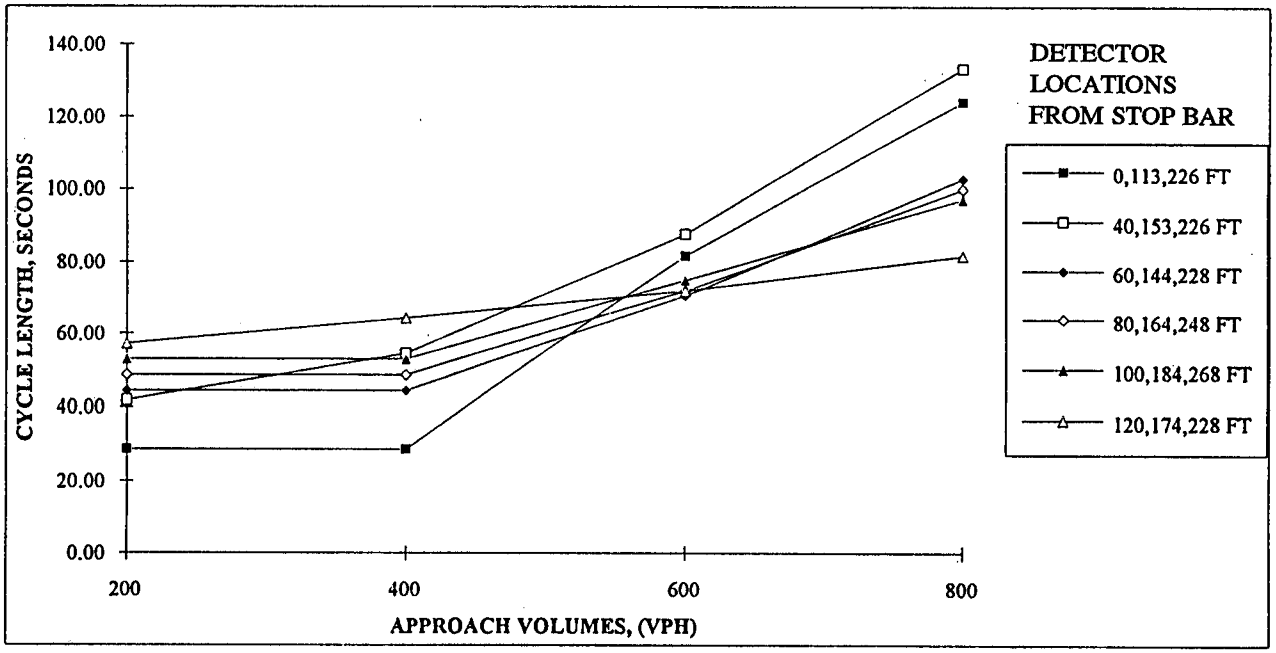


Figure 21. Cycle Length vs Approach Volumes for 55 km/h (35 mph) 85th Percentile Speed

4.3 ANALYSIS OF RESULTS

4.3.1 Detector Layouts Estimated Based on Mean Speed of 90 km/h (55 mph)

Figure 10 shows that the delay increased for each detector layout with increase in volumes. The overall delay can be classified into two volume ranges: volumes less than 400 vph per approach, and volumes 600 vph and above.

The MUTCD (17) specifies a minimum of 600 vph for the main street and a minimum of 200 vph for the greater of the cross street volumes to warrant a signal. The graphs were therefore marked at 200 vph, the minimum approach volume to meet the MUTCD requirements. Note that this is the warrant for urban conditions. Other warrants can have lower approach volumes.

For approach volumes less than 400 vph, the detector layout consisting of detectors at 0 m, 57 m, and 113 m (0 ft, 186 ft, and 371 ft) from the stop bar resulted in lowest delay. The minimum green for this case was 0 seconds (from Table 1) with the first detector placed at the stop bar. However, the same layout resulted in highest delay, as can be seen in Figure 10 for approach volumes greater than 600 vph.

This behavior is possible because at low volumes, the phase was always gapping out; thus, undue delay was not caused to vehicles waiting on other approaches. At high volumes, however, the first detector and probably the subsequent detectors were covered by the vehicles due to large queues. Since the detectors were in presence mode, a call is continuously placed to the controller which was remembered by the controller, thereby resulting in the phase continuously maxing out. The green time available to the phase was extended unnecessarily by vehicles after they cross the stop bar detector. As identical volumes and detector layouts were assumed on all the four approaches, delay substantially increased. This observation confirmed field observations on multiple loop detection systems.

Tables B-1 through B-12 of Appendix B show the replicate run output of the TEXAS Model. Tables B-1 through B-3 show the mean delays for detector layouts determined using the mean speed; whereas, Tables B-7 through B-9 show the mean delays for detector layouts estimated based on 85th percentile speed. The details of max-outs and gap-outs per phase are shown in Tables B-4 through B-6. Tables B-10 through B-12 depict max-outs and gap-outs for detector layouts estimated based on mean and 85th percentile speeds, respectively. Table B-4 shows that, for the through phase, a large number of gap-outs and max-outs occurred.

Table 1 shows that, due to the rounding off of the extension interval, the separation distance between a pair of detectors is greater for the first three detector layouts (57 m (186 ft)) and is 44 m (145 ft) for the other three detector layouts namely: a) detectors at 24.3 m, 68.6 m, and 112.8 m (80 ft, 225 ft, and 370 ft), b) detectors at 30.4 m, 74.7 m, and 119 m (100 ft, 245 ft, and 390 ft), and c) detectors at 36.6 m, 80.7 m, 125 m (120 ft, 265 ft, and 410 ft) from the stop bar.

These detector layouts resulted in higher delays at higher volumes. The cause for increase in delay, however, could be either due to the location of the inner most detector from the stop bar or due to the inter-detector spacing.

Also, the resulting delays at a particular approach volume were clustered. A statistical analysis was performed in order to determine if there was a significant difference between different loop detector layouts, which is described later.

By comparing Figure 1 and Figure 4, it can be seen that the detector layout that resulted in lower cycle lengths resulted in lower delays and vice versa. As mentioned earlier, the cycle lengths were estimated not on average max-outs and gap-outs but from the output statistics for the last replicate run in each case.

4.3.2 Detector Layouts Estimated Based on Mean Speeds of 70 km/h (45 mph)

Figure 11 shows the Overall Average Delay obtained for different detector layouts based on 70 km/h (45 mph) mean speed. The delays increased as the approach volumes increased for different detector layouts. At low approach volumes, layouts with detectors close to the stop bar resulted in lower delays and vice versa. At higher approach volumes, layouts with the first detector at 24 m (80 ft) to 30 m (100 ft) resulted in lower delay. Detector layout consisting of detectors at 36.6 m, 64 m, and 91 m (120 ft, 210 ft, and 300 ft) from the stop bar resulted in lowest delay. The corresponding plot of cycle lengths against various approach volumes is shown in Figure 14.

4.3.3 Detector Layouts Based on Mean Speeds of 55 km/h (35 mph)

From Figure 12 it can be seen that the detector layouts with the first detector at the stop bar resulted in highest delay for approach volumes 600 vph and above, and the detector layout with detectors at 36.6 m, 51.8 m, 67 m (120 ft, 195 ft, and 270 ft) resulted in lowest delay. Due to high minimum greens, however, the same detector layout resulted in higher delays at approach volumes less than 600 vph. Figure 15 shows the cycle length vs approach volumes for detector layouts estimated for mean speeds.

4.3.4 Detector Layouts Determined Based on 85th Percentile Speeds

From Figures 16 through 18, it can be seen that similar patterns as mentioned above can be observed for all three speeds. As the gap timing increased, higher delays were experienced at higher volumes. For 90 km/h (55 mph) approach speeds, the detector layout with the first detector located at the stop bar resulted in lower delays for volumes less than 400 vph, and for higher volumes, detector layouts with the first detector varying between 30 m to 36.6 m (100 to 120 ft) resulted in lower delays. Table 9 of Chapter 5 summarizes the optimal detector layouts for a particular approach volume and speed.

4.4 RELATION BETWEEN DELAY AND CYCLE LENGTH FOR DIFFERENT DETECTOR LAYOUTS

From Figures 10 to 21, it can be seen that delay and cycle lengths increased as approach volumes increased for different speeds. The delays across all speeds and speed criteria (mean and 85th percentile speeds) were pooled and plotted against the cycle lengths. Regression analysis was then performed to test if there was a relation between delays and cycle lengths obtained for different detector layouts. Figure 22 shows the result of the regression analysis. There is a linear relationship between delays and cycle lengths.

4.5 DUNCAN'S NEW RANGE MULTIPLE TEST

In order to determine if there was significant difference in delays due to different detector layouts, Duncan's New Range Multiple test was performed (18). Table 7 presents the results of the statistical analysis for different detector layouts. For each approach volume, the mean average total delay was compared for different detector layouts. This was done for detector layouts obtained by using both mean speed and 85th percentile speeds. The common feature among various detector layouts for different speeds was that the location of the first detector was varied between 0 m (0 ft) (at the stop bar) to 36.6 m (120 ft). The numbers 1 ,2, 3, 4, 5, and 6 in Table 7 correspond to detector layouts that have the innermost detectors at 0 m (0 ft), 12 m (40 ft), 18 m (60 ft), 24 m (80 ft), 30 m (100 ft), and 36 m (120 ft) from the stop bar, respectively.

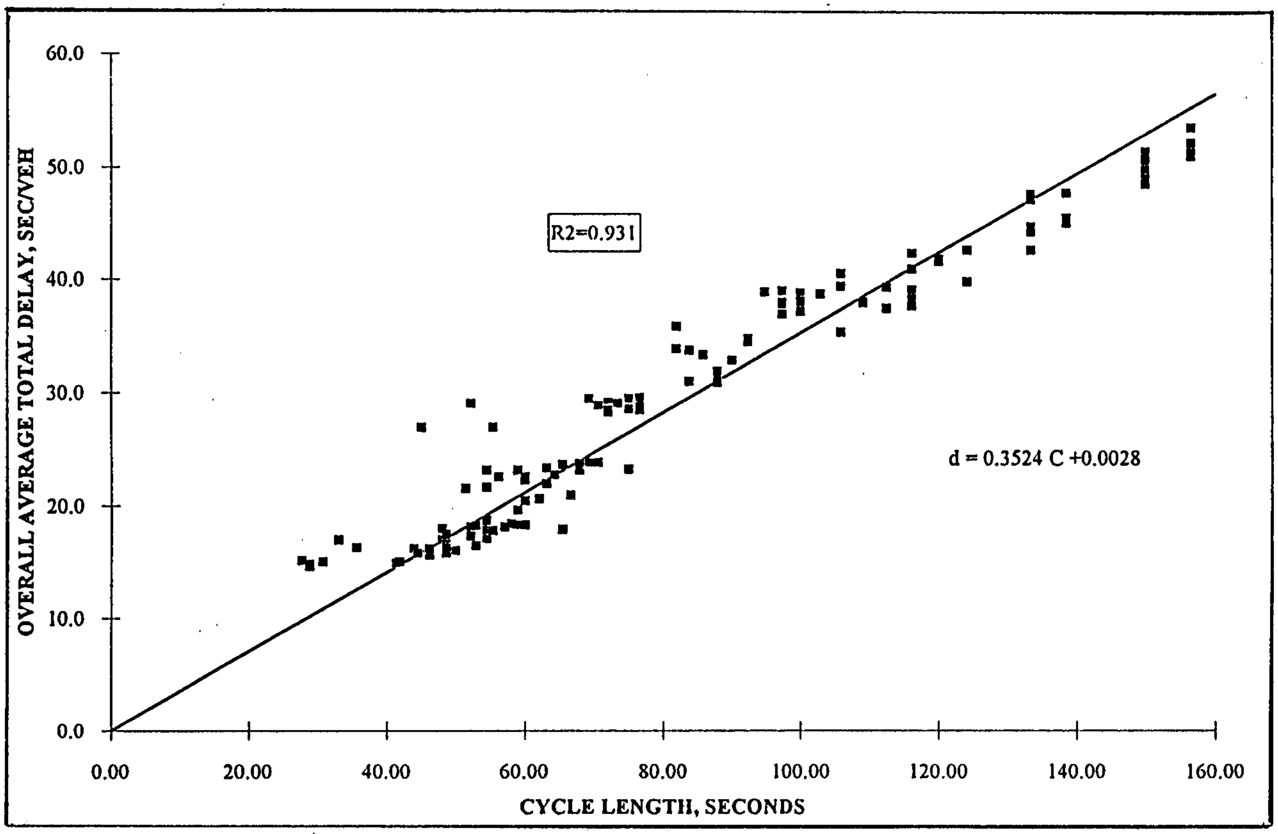


Figure 22. Relation Between Overall Average Delay and Cycle Length, for Different Detector Layouts

Table 7. Duncan's New Multiple Range Test for Different Detector Layouts Based on Overall Average Total Delay

Speed, km/h (mph)		Volume, vph *			
		200	400	600	800
55 (35)	Mean	(1,2,3) (5,4)	(3,4) (5,6)	(2,3,4) (5,6)	(2,3,4) (5,6)
	85th Percentile	(1,2) (3,4,5)	(3,4) (5,6)	(2,3,4) (5,6)	(2,3,4) (5,6)
70 (45)	Mean	(3,4,5) (5,6)	(2,3,4) (2,6)	(3,4,6)	(3,4) (4,5,6)
	85th Percentile	(2,3) (4,5)	(2,4,5,6)	(3,4,5)	(1,2) (4,5)
90 (55)	Mean	(2,3,4) (3,5)	(2,3,4) (3,5)	(2,3) (4,5,6)	(2,3,1) (4,5,6)
	85th Percentile	(2,3) (5,6)	(2,3) (5,6)	(2,3) (5,6)	(1,4) (2,3,5,6)

*1 ,2, 3, 4, 5, 6 correspond to detector layouts with first detector at 0 m (0'), 12 m (40'), 18 m (60'), 24 m (80'), 30 m (100'), or 36 m (120')

The numbers corresponding to detector layouts that have no significant difference in delays are shown in each cell. For most of the detector layouts, layouts with the first detector at the stop bar were significantly different from others for high volume levels. For any approach volumes, the detector layouts with a detector placed between 12 m (40 ft) and 18 m (60 ft) produced similar delays. Similarly, there was no significant difference in delays produced by detector placements with innermost detectors varying between 24 m (80 ft) and 36 m (120 ft) from the stop bar.

All detector layouts with detectors closer to the stop bar or at the stop bar have resulted in higher delays as they extend the green unnecessarily, even after the vehicle has travelled into the intersection. In order to avoid wastage of green time, thereby reducing delays, any stop line detector or detectors close to the stop bar have to be turned off after the minimum green time. As this could not be achieved with the TEXAS Model, a test run was performed for the detector layout determined based on the mean speeds of 90 km/h (55 mph), namely detectors at 0 m (0 ft), 57 m (186 ft), and 113 m (371 ft).

4.6 SPECIAL DETECTOR COMPARISON STUDIES

The stop line detectors on all through lanes and on approaches were made inactive, and runs were made with the same signal timing as the original layout for different approach volumes. The series "DET0" in Figure 10 shows the outcome of this run. The delays substantially decreased for lower approach volumes and increased for higher approach volumes, but were still on the higher side. This was because, though the stop line detectors were inactive (or excluded in this case) due to zero seconds as the minimum green, the phases were gapping out most of the time.

Instead of varying the stop line detector location between 0 m (0 ft) to 36 m (120 ft), it was intended to test the effect of shifting the whole detector system under the speed distribution. The difference was calculated in the outermost detector location (dilemma zone distance) for detector layouts obtained based on 50th percentile and 85th percentile speeds and with the first detector located at 24 m (80 ft) from the stop bar. This difference was then added to the location of each detector. For example, the difference in the location of the outer most detector was estimated as 35 m (114 ft). This was added to the detector layout (24 m (80 ft), 69 m (225 ft), and 113 m (370 ft)) to get a new detector layout with detectors at 59 m (194 ft), 103 m (339 ft), and 147.5 m (484 ft) from the stop bar.

This new detector layout was coded in to the SIMDATA file of the TEXAS Model, and runs were made for different approach volumes. The overall average delay was noted in each case and was plotted. The series INI0 in Figure 10 is the result of these runs. The initial interval of 12 seconds and the extension interval similar to that of the original layout were retained. Figure 10 demonstrates that at approach volumes less than 400 vph, INI0 layout resulted in highest delays, but at higher approach volumes the delays were lower. As the detector layouts were "moved" to the right beneath the speed distribution, lower delays resulted with the same signal timing parameters.

The effect of a single detector intended to provide dilemma zone protection for the vehicles travelling at 85th percentile speeds and for 50th percentile speeds was also studied. This was done by placing a single detector at 123 m (404 ft) (dilemma zone estimated for mean speeds of 90 km/h (55 mph)) and at 147.5 m (484 ft) (dilemma zone estimated based on 97 km/h (60.5 mph)), respectively. Figure 23 illustrates the effect these placements have for approach speeds of 90 km/h (55 mph). The initial interval in both cases was kept constant at 15 seconds, and extension intervals were 5 seconds and 4 seconds, respectively, to account for the difference in speeds. The detector located at the beginning of the dilemma zone estimated for 85th percentile speeds resulted in lower delay. With a detector placed at the dilemma zone for 85th percentile speeds, a higher percentage of vehicles travelling under the speed distribution could pass through the intersection with adequate extension, thereby resulting in lower delays. Whereas, in the case of a detector located at 122 m (404 ft) (which is the dilemma zone for 50th percentile speeds), protection is provided for only 50 percent of the vehicles travelling under the speed distribution. A large percentage of traffic travelling at speeds greater than the mean speed for which the detector was located would have had to stop due to insufficient green time, thereby resulting in higher delays.

The difference in overall average mean delays for a particular design speed and approach volume were then computed based on detector layouts estimated using the 50th and 85th percentile speeds. It was intended to test two particular features: 1) the effect of design speed on delay for various detector layouts estimated based on mean and 85th percentile speeds, and 2) the effect of "speed criterion," namely 50th percentile or 85th percentile speed of delay, for a particular approach speed and volume.

A paired two-tailed t-test with a significance level, α, equal to 0.05 was performed to test the above mentioned criteria. The null hypothesis assumed that the there was no difference in delays produced by a pair of detector layouts. In order to determine the effect of design speed on delays (produced by different detector layouts), the delays produced by different detector layouts estimated using mean speeds were compared for a pair of speeds. For example, in order to compare the delays produced by detector layouts for design speeds of 90 km/h (55 mph) and 70 km/h (45 mph), the delays for detector layouts estimated using the mean speeds for 90 km/h (55 mph) were compared to that of the delays estimated using the mean speeds of 70 km/h (45 mph). The same procedure was repeated for 90 km/h (55 mph) and 55 km/h (35 mph) speeds and for 70 km/h (45 mph) and 55 km/h (35 mph) speeds. The above mentioned procedure was employed to compare the delays produced by detector layouts determined using 85th percentile speeds.

At approach volumes less than 500 vph, there was no significant difference in delays for the detector layouts serving different approach speeds. For approach volumes greater than 500 vph, however, the null hypothesis was rejected, i.e, at low volumes, irrespective of the detector layout, there was no effect from design speed on the delays. However, at higher volumes, as speeds increased the delays increased. This trend was noticed both in the case of detector layouts determined using mean as well as 85th percentile speeds. Also, at higher approach volumes, the detector layouts estimated based on 85th percentile speed for all three design speeds resulted in higher delay.

For criterion 2, i.e., to determine the effect of 50th and 85th percentile speed on delay, a one-tailed t-test with 0.05 significance level was performed. For approach speeds of 90 km/h (55 mph) and approach volumes less than 500 vph, the detector layouts with the first detector varying between 0 m (0 ft) to 18 m (60 ft) based on mean speeds resulted in higher delays. Whereas for approach volumes greater than 500 vph, there was no significant difference in delays produced by detector layouts determined using the mean speed and 85th percentile speed.

For detector layouts with the first detector between 24 m (80 ft) to 36 m (120 ft), the 85th percentile speed detector layouts resulted in higher delays for both ranges of volumes.

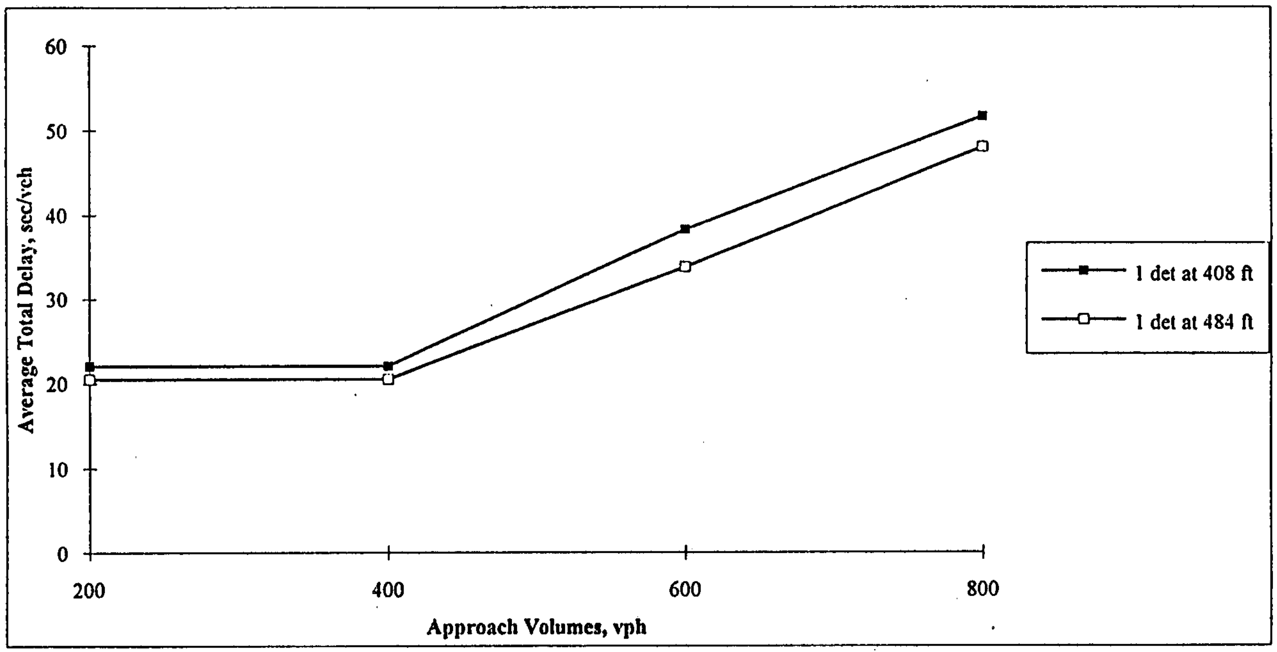


Figure 23. Difference in Delays for One Detector Located at Dilemma Zone

For approach speeds of 70 km/h (45 mph), there was no significant difference in delays for the 50th and 85th percentile layouts for volumes less than 500 vph. However, at approach volumes greater than 500 vph, the 85th percentile speeds resulted in higher delays. For approach speeds of 55 km/h (35 mph), the null hypothesis that the delays produced by the 50th and 85th percentile speed layouts was rejected.

Also, since the detector layouts were estimated by varying the location of the stop line detector, it was necessary to estimate the percentile of the speed distribution for which they provide protection at different extension intervals. Table 8 illustrates the speeds for which they provide protection; i.e., they extend the green time without the phase gapping out for vehicles. From Table 8, it can be seen that with a particular extension interval and with detectors located at x ft or x' m from the stop bar, all vehicles travelling above the speeds shown in column 3 can safely pass through the intersection.

Table 8. Calculation of Speed Coverage Provided by the First Detector

First Detector Location m (ft)	Extension Interval	Speed km/h (mph)
0 (0)	1	0 (0)
12 (40)	1	43.8 (27.2)
18 (60)	1	65.6 (40.8)
24 (80)	1	87.6 (54.4)
30 (100)	1	109.5 (68.02)
36 (120)	1	131.4 (81.63)
0 (0)	1.5	0 (0)
12 (40)	1.5	29 (18)
18 (60)	1.5	43.8 (27.2)
24 (80)	1.5	58.4 (36.28)
30 (100)	1.5	73 (45.35)
36 (120)	1.5	87.6 (54.42)
0 (0)	2	0 (0)
12 (40)	2	22 (13.6)
18 (60)	2	33 (20.4)
24 (80)	2	43.8 (27.2)
30 (100)	2	54.8 (34.08)
36 (120)	2	65.7 (40.81)
0 (0)	2.5	0(0)
12 (40)	2.5	17.4 (10.08)
18 (60)	2.5	26 (16.2)
24 (80)	2.5	35 (21.7)
30 (100)	2.5	43.8 (27.2)
36 (120)	2.5	52.56 (32.65)

5.0 FINDINGS AND RECOMMENDATIONS

This final chapter contains the major findings and recommendations of this study, which was conducted to optimize detector placements for high speed approaches of an isolated intersection.

Due to the limitations in the TEXAS Model, the current TxDOT detector layouts could not be simulated as originally proposed. Limitations in the number of detectors, lack of special detector functions like extended call and delayed call, the "memory function" and rounded extension intervals resulted in modifications to the original study. New detector layouts were developed using the dilemma zone criteria for mean speed and 85th percentile speed for each design speed of 90 km/h (55 mph), 70 km/h (45 mph), and 55 km/h (35 mph).

5.1 FINDINGS

The following are the findings of this research:

1. For all detector layouts, the graphs showing the relationship between overall average total delay and approach volumes, delay increased with an increase in approach volumes. For low volumes of 500 vph (<200 vphpl), detectors closer to the stop bar resulted in lower delay, while at approach volumes greater than 500 vph (>200 vphpl), detector layouts away from the stop bar (first detector between 24 m (80 ft) and 36 m (120 ft)) resulted in lower delays.

2. For all detector layouts, the cycle lengths increased as approach volumes increased, and the detector layout resulting in higher cycle lengths for a particular approach volume and speed resulted in higher delays and vice versa.

3. The extent of space covered by the detectors may result in greater or lower delay. Any detector placement technique should be centered on the normal speed distribution. When high speeds exist on approaches, a trade off analysis of detector placement is essential to take both the dilemma zone problem and vehicular delays into account.

4. Regression analysis performed on delays and cycle lengths obtained for different detector layouts showed that a linear relationship exists between them. For a fully actuated signal control operation at an isolated intersection, irrespective of approach speed and speed criterion, delay per vehicle can be predicted for a known cycle length using the equation $d = 0.3524C + 0.0028$.

5. A statistical analysis using Duncan's new multiple range test showed that detector layouts closer to the stop bar (with the first detector placed between 0 m (0 ft) to

18 m (60 ft)) had no significant difference in delays within the group, while the detector layouts placed between 24 m (80 ft) to 36 m (120 ft) from the stop bar had no significant difference in delays within this group.

6. Results of the special detector studies provided insight into the following. Any actuated phase for multiple loop detection can terminate because of two possible reasons: a) the absence of arrival of vehicles, and b) the speed of the vehicle arrival is slower than the gap timing between a pair of detectors. At low approach volumes, locating a detector for 50th or 85th percentile (speed distribution) will not significantly affect delay or phase length because the phase will not terminate due to insufficient gap timing; rather, it will terminate because no vehicles arrived. Also, the speed distribution will produce only a small difference in delays irrespective of the detector layout.

7. At high volumes, however, vehicles will hold the green irrespective of the detector design. The extent of space covered by the detectors now plays a dominant role. The simulation results clearly indicate that as approach volumes increased, the difference in delays for detector layouts estimated based on 50th and 85th percentile speeds also increased, with the 85th percentile detector layouts resulting in higher delay. The detection area was larger for the 85th percentile detector layouts than for the median speed detector layouts for all approach speeds.

8. A paired t-test performed to test the effect of design speed on delay produced by both the 50th and 85th percentile speed-based detector layouts showed that at low approach volumes there was no significant difference in delays; whereas, at high approach volumes, delay increased with increase in approach speed.

9. Table 9 identifies the detector layouts that resulted in lower delays for a particular approach volume and speed. Detector layouts estimated for 85th percentile speeds resulting in lower delays are also shown. Though at lower volumes the detector layout consisting of the first detector at the stop bar resulted in lower delay, detector layouts with the first detector at 12 meters (40 ft) were considered in order to provide minimum green. The location of the detector from the stop bar is rounded to the nearest whole number.

5.2 RECOMMENDATIONS

5.2.1 Practical Engineering Recommendations

When multiple loop detector layouts are used on high-volume high speed approaches, any detector located at or close to the stop bar must be disabled after the initial dispersion of queue following the onset of green, if delay is to be minimized.

Table 9. Optimal Detector Layouts, by Approach Volume and Speed

Speed km/h (mph)	Detector Location from the Stop Bar, m (ft)			
	Mean		85th percentile	
	Volume ≤ 200 Vphpl	Volume ≥ 200 Vphpl	Volume ≤200Vphpl	Volume ≥ 200 Vphpl
90 (55)	12, 70, 125 m (40, 225, 410 ft)	30, 75, 120 m (100, 250, 400 ft)	0, 75, 150 m (0, 250, 500 ft)	30, 90, 95 m (100, 300, 500 ft)
70 (45)	0, 45, 95 m (0, 150, 300 ft)	30, 55, 85 m (100, 200, 300 ft)	0, 50, 105 m (0, 175, 350 ft)	30, 75, 120 m (100, 250, 400 ft)
55 (35)	12, 35, 55 m (40, 115, 190 ft)	24, 45, 70 m (80, 155, 230 ft)	15, 45, 75 m (50, 150, 250 ft)	30, 55, 80 m (100, 200, 300 ft)

5.2.2 TEXAS Model Recommendations

1. Though the TEXAS Model output consisted of the number of max-outs and gap-outs, the exact time at which a gap-out occurred or the cause for the gap-out occurring cannot be determined. Hence, it would be desirable to include these features in future model enhancements thereby simulating more accurately real life situations.

2. The scan interval in the NEMA Controller of the TEXAS Model should be 0.1 seconds. With this capability, the signal timing parameters can be input to one-tenth of a second as set in the controller unit.

3. The number of detectors permitted in the TEXAS Model (with NEMA controller functions) should be increased to at least 25.

4. The TEXAS Model (NEMA Controller) should be modified to allow presence mode of operation with phase memory detection "off."

REFERENCES

1. P. S. Parsonson, "Signalization of High-Speed, Isolated Intersections," *Transportation Research Record 681*, pp. 34-40, Transportation Research Board, Washington, D.C., 1978.

2. William R. McShane and Roger P. Roess, *Traffic Engineering*, pp. 380-508, Prentice Hall, Englewood Cliffs, New Jersey, 1990.

3. D. L. Woods, *Texas Traffic Signal Detector Manual*, FHWA/TX/1163-1, pp. 2-6, Texas Transportation Institute, College Station, Texas, July 1992.

4. *CVEN 625 Class notes*, Texas A&M University, Summer 1993.

5. J. H. Kell and I. J. Fullerton, *Manual of Traffic Signal Design*, pp. 79-160, Prentice Hall, Englewood Cliffs, N. J., 1982.

6. C. S. Wu, R. B. Machemehl, and C. E. Lee, *Detector Configuration and Location at Signalized Intersections*, Research Report 259-1F, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, March 1983.

7. H. Sackman, B. Mohanan, P. S. Parsonson, and A. F. Trevino, *Vehicle Detector Placement for High-Speed, Isolated Traffic-Actuated Intersection Control Volume 2*, FHWA-RD-77-32, pp. 1-87, U.S. Department of Transportation, May 1977.

8. J. A. Bonneson and P. T. McCoy, *Manual of Traffic Detector Design*, Civil Engineering Department, University of Nebraska-Lincoln, Lincoln, Nebraska, April 1994.

9. L. M. Rodgers, "Detector Placement - A Misunderstood Subject," *Traffic Engineering Journal*, Volume 43, pp. 42-44, Institute of Traffic Engineers, Washington, D.C., April 1973.

10. P. D. Cribbins and C. A. Meyer, "Choosing Detectors and Placing Them Right," *Journal of Traffic Engineering*, Volume 45, pp. 15-18, Institute of Traffic Engineers, Washington, D. C., January 1975.

11. H. Beirele, "A Method of Detector Placement," *IMSA Signal Magazine*, Volume 10, Number 3, pp 9-15, Signal Publishing Company, Houston, Texas, May/June 1974.

12. A. G. R. Bullen, "Effects of Actuated Signal Settings and Detector Placement on Vehicle Delay," *Transportation Research Record 1244*, pp 32-39, Transportation Research Board, National Research Council, Washington, D.C., 1989.

13. F. B. Lin, "Optimal Timing Settings and Detector Lengths of Presence Mode Full-Actuated Control," *Transportation Research Record 1010*, pp. 37-45, Transportation Research Board, National Research Council, Washington, D.C., 1985.

14. P. J. Tarnoff and P. S. Parsonson, "Selecting Traffic Control At Individual Intersections," NCHRP Report 233, pp. 12-20, Transportation Research Board, National Research Council, Washington, D.C., June 1981.

15. C. E. Lee, R. B. Machemehl, T. W. Rioux, and R. F. Inman. *Texas Model For Intersection Traffic Version 3.0 Documentation (Updated Version For 3.20),* Center For Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, November 1993.

16. *Loop Detector Placement for Traffic Signals*. State Department of Highways and Public Transportation, Austin, Texas, 1983.

17. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1988, pp. 40-3.

18. R. Lyman Ott, *An Introduction to Statistical Methods and Data Analysis*, pp. 825-828, Duxbury Press, Belmont, California, 1993.

7.0 APPENDIX A

TEXAS MODEL INPUT FILES

Table A-1. Sample GDVDATA File of TEXAS Model, for 600 Vph, 90 km/h (55 mph)

```
         1         2         3         4         5
12345678901234567890123456789012345678901234567890123456789012345
60055.DET, 600VPH, 55MPH

IS TITLE TEXT OK ?
Y

PARAMETER-OPTION DATA:
F(1) - TOTAL NUMBER OF LEGS.  <3 TO 6> [4]
F(2) - TOTAL (STARTUP+SIMULATION) TIME IN MINUTES.  <1 TO 65> [20]
F(3) - MINIMUM HEADWAY IN SECONDS.  <1.0 TO 3.0> [1.0]
F(4) - NUMBER OF VEHICLE CLASSES.  <12> [12]
F(5) - NUMBER OF DRIVER CLASSES.  <3> [3]
F(6) - PERCENT OF LEFT TURNING VEHICLES TO ENTER IN MEDIAN LANE.<50 TO 100>[80]
F(7) - PERCENT OF RIGHT TURNING VEHICLES TO ENTER IN CURB LANE. <50 TO 100>[80]
F(8) - CREATE A GEOMETRY PLOT DATA FILE ? <"YES" OR "NO"> ["YES"]
F(9) - SIZE OF GEOMETRY PLOT (INCHES). <4.0 TO 34.0> [7.50]
EDIT EXAMPLE: "F(6)=75" CHANGES FIELD 6 TO "75", OTHER FIELDS REMAIN UNCHANGED
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE
  DATA FIELDS:       4   65  2.0   12    3   80   80 YES  7.50
FIELD NUMBERS:    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/ \.7/ \8/ \.9./

IS PARAMETER-OPTION DATA OK ?
 Y

ARE CURB RETURN RADII OK ?
Y

LEG 1 GEOMETRY DATA:
F(1) - LEG ANGLE.  POSITIVE IS CLOCKWISE FROM NORTH = 0 (ZERO) DEGREES.
       <0 TO 359, IN INCREASING ORDER>  [0]
F(2) - LENGTH OF INBOUND LANES.  <400 TO 1000>  [800]
F(3) - LENGTH OF OUTBOUND LANES.  [250]  (SUGGEST 250 FOR LOW TRAFFIC VOLUME,
       400 FOR HIGH VOLUME. FOR EMISSIONS, MUST BE SAME AS INBOUND LANE LENGTH)
F(4) - NUMBER OF INBOUND LANES.  <0 TO 6>  [2]
F(5) - NUMBER OF OUTBOUND LANES.  <0 TO 6>  [2]
F(6) - SPEED LIMIT ON INBOUND LANES IN MPH.  <10 TO 80>  [30]
F(7) - SPEED LIMIT ON OUTBOUND LANES IN MPH.  <10 TO 80>  [30]
F(8) - LEG CENTERLINE OFFSET FROM INTERSECTION CENTER. POSITIVE IS TO THE RIGHT
       WHEN FACING IN DIRECTION OF INBOUND TRAFFIC.  <-200 TO 200>  [0]
F(9) - MEDIAN WIDTH. WILL BE CENTERED ON INTERSECTION CENTERLINE. <0 TO 100>[0]
F(10) - LIMITING ANGLE FOR STRAIGHT MOVEMENT.  <0 TO 45 DEGREES>  [20]
F(11) - LIMITING ANGLE FOR U-TURN.  <0 TO 45 DEGREES>  [10]
  DATA FIELDS:       0  800  800    3    2   55   55  -12   16  20  10
FIELD NUMBERS:    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/ \.7/ \.8/ \.9/ \10 \11


IS LEG 1 GEOMETRY DATA OK ?
Y

F(1) - WIDTH OF LANE.  <8 TO 15>  [12]
F(2) - MOVEMENT CODE. ANY OF"U"(U-TURN),"L"(LEFT),"S"(STRAIGHT) AND "R"(RIGHT).
F(3) - LENGTH OF USABLE LANE FROM LANE TERMINAL.  [0, FOR OPEN LANE]
F(4) - LENGTH OF USABLE LANE FROM OUTER END.  [0, FOR OPEN LANE]
F(5) - OFFSET OF LANE TERMINAL.  POS. IS TOWARD INTERSECTION. <-350 TO 100> [0]
F(6) - PERCENT OF INBOUND TRAFFIC TO ENTER IN THIS LANE.
       <0 TO 100, SUM FOR LEG=100, 0 FOR OUTBOUND OR LANE WITH F(4) NOT= 0>
EDIT EXAMPLE: "LANE(3,1)=8" CHANGES FIELD 1 OF LANE 3 TO "8", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL INFORMATION
```

Table A-1 (Continued)

```
LANE DATA FOR LEG 1:
 1  (INBOUND 1)       12 L     250    0    0    0
 2  (INBOUND 2)       12 S       0    0    0   50
 3  (INBOUND 3)       12 SR      0    0    0   50
 4  (OUTBOUND 1)      12 LS      0    0    0    0
 5  (OUTBOUND 2)      12 SR      0    0    0    0
                    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/
IS LANE DATA FOR LEG 1 OK ?
Y


INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 1:
F(1) - NAME FOR INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION:
       "CONSTAN", "ERLANG", "GAMMA", "LOGNRML", "NEGEXP","SNEGEXP" OR "UNIFORM"
       MAY BE ABBREVIATED TO THE FIRST CHARACTER.
F(2) - TOTAL HOURLY VOLUME ON LEG, VPH. <0 TO 4000> [200 PER INBOUND LANE]
F(3) - PARAMETER FOR HEADWAY FREQUENCY DISTRIBUTION:
         CONSTANT - NONE.
         ERLANG - INTEGER VALUE (ROUNDED) FOR MEAN**2/VARIANCE.<GREATER THAN 1>
         GAMMA - MEAN**2/VARIANCE. <GREATER THAN 1>
         LOGNORMAL - STANDARD DEVIATION.
         NEGATIVE EXPONENTIAL - NONE.
         SHIFTED NEGATIVE EXPONENTIAL - MINIMUM HEADWAY IN SECONDS. <LESS THAN
                                        OR EQUAL MEAN HEADWAY>
         UNIFORM - STANDARD DEVIATION
F(4),F(5)- MEAN,85 PERCENTILE SPEED OF ENTERING VEHICLES, MPH.<10 TO 80>[29,31]
F(6) - TRAFFIC MIX DATA TO FOLLOW ? <"YES" OR "NO">  ["NO"]
F(7) - SEED FOR RANDOM NUMBERS (0 FOR AUTO. SELECTION).  <0 TO 99999> [0]
EDIT EXAMPLE: "F(4)=29,32" CHANGES FIELD 4 TO "29" AND FIELD 5 TO "32"
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE
  DATA FIELDS:    SNEGEXP   600    1.00  55.0  60.5 NO      0
FIELD NUMBERS:    \..1../ \.2./ \..3./ \.4./ \.5./ \6/ \.7./

IS INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 1 OK
Y


OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 1:
EACH FIELD - PERCENT OF VEHICLES FROM LEG 1 TO LEAVE THE INTERSECTION VIA THE
             SPECIFIED (BY FIELD NUMBER) LEG.  <0 TO 100 AND SUM = 100>
EDIT EXAMPLE: "F(2)=3*20" CHANGES FIELDS 2 THRU 4 TO "20", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE

  DATA FIELDS:      0  10  80  10
FIELD NUMBERS:    \1/ \2/ \3/ \4/

LEG 2 GEOMETRY DATA:
F(1) - LEG ANGLE.  POSITIVE IS CLOCKWISE FROM NORTH = 0 (ZERO) DEGREES.
       <0 TO 359, IN INCREASING ORDER>  [90]
F(2) - LENGTH OF INBOUND LANES.  <400 TO 1000>  [800]
F(3) - LENGTH OF OUTBOUND LANES.  [250]  (SUGGEST 250 FOR LOW TRAFFIC VOLUME,
       400 FOR HIGH VOLUME. FOR EMISSIONS, MUST BE SAME AS INBOUND LANE LENGTH)
F(4) - NUMBER OF INBOUND LANES.  <0 TO 6>  [2]
F(5) - NUMBER OF OUTBOUND LANES.  <0 TO 6>  [2]
F(6) - SPEED LIMIT ON INBOUND LANES IN MPH.  <10 TO 80>  [30]
F(7) - SPEED LIMIT ON OUTBOUND LANES IN MPH.  <10 TO 80>  [30]
F(8) - LEG CENTERLINE OFFSET FROM INTERSECTION CENTER. POSITIVE IS TO THE RIGHT
       WHEN FACING IN DIRECTION OF INBOUND TRAFFIC.  <-200 TO 200>  [0]
F(9) - MEDIAN WIDTH. WILL BE CENTERED ON INTERSECTION CENTERLINE. <0 TO 100>[0]
F(10) - LIMITING ANGLE FOR STRAIGHT MOVEMENT.  <0 TO 45 DEGREES>  [20]
F(11) - LIMITING ANGLE FOR U-TURN.  <0 TO 45 DEGREES>  [10]
  DATA FIELDS:      90  800  800    3    2   55   55  -12   16  20  10
FIELD NUMBERS:    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/ \.7/ \.8/ \.9/ \10 \11

IS LEG 2 GEOMETRY DATA OK ?
```

Table A-1 (Continued)

```
F(5) - NUMBER OF OUTBOUND LANES.  <0 TO 6>  [2]
F(6) - SPEED LIMIT ON INBOUND LANES IN MPH.  <10 TO 80>  [30]
F(7) - SPEED LIMIT ON OUTBOUND LANES IN MPH.  <10 TO 80>  [30]
F(8) - LEG CENTERLINE OFFSET FROM INTERSECTION CENTER. POSITIVE IS TO THE RIGHT
       WHEN FACING IN DIRECTION OF INBOUND TRAFFIC.  <-200 TO 200>  [0]
F(9) - MEDIAN WIDTH. WILL BE CENTERED ON INTERSECTION CENTERLINE. <0 TO 100>[0]
F(10) - LIMITING ANGLE FOR STRAIGHT MOVEMENT.  <0 TO 45 DEGREES>  [20]
F(11) - LIMITING ANGLE FOR U-TURN.  <0 TO 45 DEGREES>  [10]
  DATA FIELDS:     180  800  800    3    2   55   55    0   16  20  10
FIELD NUMBERS:    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/ \.7/ \.8/ \.9/ \10 \11

IS LEG 3 GEOMETRY DATA OK ?
Y

F(1) - WIDTH OF LANE.  <8 TO 15>  [12]
F(2) - MOVEMENT CODE. ANY OF"U"(U-TURN),"L"(LEFT),"S"(STRAIGHT) AND "R"(RIGHT).
F(3) - LENGTH OF USABLE LANE FROM LANE TERMINAL.  [0, FOR OPEN LANE]
F(4) - LENGTH OF USABLE LANE FROM OUTER END.  [0, FOR OPEN LANE]
F(5) - OFFSET OF LANE TERMINAL.  POS. IS TOWARD INTERSECTION. <-350 TO 100> [0]
F(6) - PERCENT OF INBOUND TRAFFIC TO ENTER IN THIS LANE.
       <0 TO 100, SUM FOR LEG=100, 0 FOR OUTBOUND OR LANE WITH F(4) NOT= 0>
EDIT EXAMPLE: "LANE(3,1)=8" CHANGES FIELD 1 OF LANE 3 TO "8", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL INFORMATION

LANE DATA FOR LEG 3:
 1  (INBOUND 1)      12 L     250    0    0    0
 2  (INBOUND 2)      12 S       0    0    0   50
 3  (INBOUND 3)      12 SR      0    0    0   50
 4  (OUTBOUND 1)     12 LS      0    0    0    0
 5  (OUTBOUND 2)     12 SR      0    0    0    0
                   \.1/ \.2/ \.3/ \.4/ \.5/ \.6/
IS LANE DATA FOR LEG 3 OK ?
Y

INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 3:
F(1) - NAME FOR INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION:
       "CONSTAN", "ERLANG", "GAMMA", "LOGNRML", "NEGEXP","SNEGEXP" OR "UNIFORM"
       MAY BE ABBREVIATED TO THE FIRST CHARACTER.
F(2) - TOTAL HOURLY VOLUME ON LEG, VPH. <0 TO 4000> [200 PER INBOUND LANE]
F(3) - PARAMETER FOR HEADWAY FREQUENCY DISTRIBUTION:
         CONSTANT - NONE.
         ERLANG - INTEGER VALUE (ROUNDED) FOR MEAN**2/VARIANCE.<GREATER THAN 1>
         GAMMA - MEAN**2/VARIANCE. <GREATER THAN 1>
         LOGNORMAL - STANDARD DEVIATION.
         NEGATIVE EXPONENTIAL - NONE.
         SHIFTED NEGATIVE EXPONENTIAL - MINIMUM HEADWAY IN SECONDS. <LESS THAN
                                        OR EQUAL MEAN HEADWAY>
         UNIFORM - STANDARD DEVIATION
F(4),F(5)- MEAN,85 PERCENTILE SPEED OF ENTERING VEHICLES, MPH.<10 TO 80>[29,31]
F(6) - TRAFFIC MIX DATA TO FOLLOW ? <"YES" OR "NO">  ["NO"]
F(7) - SEED FOR RANDOM NUMBERS (0 FOR AUTO. SELECTION).  <0 TO 99999> [0]
EDIT EXAMPLE: "F(4)=29,32" CHANGES FIELD 4 TO "29" AND FIELD 5 TO "32"
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE
  DATA FIELDS:   SNEGEXP   600   1.00  55.0  60.5 NO      0
FIELD NUMBERS:   \..1../ \.2./ \..3./ \.4./ \.5./ \6/ \.7./

IS INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 3 OK ?
Y

OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 3:
EACH FIELD - PERCENT OF VEHICLES FROM LEG 3 TO LEAVE THE INTERSECTION VIA THE
             SPECIFIED (BY FIELD NUMBER) LEG.  <0 TO 100 AND SUM = 100>
EDIT EXAMPLE: "F(2)=3*20" CHANGES FIELDS 2 THRU 4 TO "20", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE

  DATA FIELDS:    80  10   0  10
```

Table A-1 (Continued)

```
Y

F(1) - WIDTH OF LANE.  <8 TO 15>  [12]
F(2) - MOVEMENT CODE. ANY OF"U"(U-TURN),"L"(LEFT),"S"(STRAIGHT) AND "R"(RIGHT).
F(3) - LENGTH OF USABLE LANE FROM LANE TERMINAL.  [0, FOR OPEN LANE]
F(4) - LENGTH OF USABLE LANE FROM OUTER END.  [0, FOR OPEN LANE]
F(5) - OFFSET OF LANE TERMINAL.  POS. IS TOWARD INTERSECTION. <-350 TO 100> [0]
F(6) - PERCENT OF INBOUND TRAFFIC TO ENTER IN THIS LANE.
       <0 TO 100, SUM FOR LEG=100, 0 FOR OUTBOUND OR LANE WITH F(4) NOT= 0>
EDIT EXAMPLE: "LANE(3,1)=8" CHANGES FIELD 1 OF LANE 3 TO "8", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL INFORMATION

LANE DATA FOR LEG 2:
 1  (INBOUND 1)       12 L     250    0    0    0
 2  (INBOUND 2)       12 S       0    0    0   50
 3  (INBOUND 3)       12 SR      0    0    0   50
 4  (OUTBOUND 1)      12 LS      0    0    0    0
 5  (OUTBOUND 2)      12 SR      0    0    0    0
                     \.1/ \.2/ \.3/ \.4/ \.5/ \.6/
IS LANE DATA FOR LEG 2 OK ?
Y

INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 2:
F(1) - NAME FOR INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION:
       "CONSTAN", "ERLANG", "GAMMA", "LOGNRML", "NEGEXP","SNEGEXP" OR "UNIFORM"
       MAY BE ABBREVIATED TO THE FIRST CHARACTER.
F(2) - TOTAL HOURLY VOLUME ON LEG, VPH. <0 TO 4000> [200 PER INBOUND LANE]
F(3) - PARAMETER FOR HEADWAY FREQUENCY DISTRIBUTION:
         CONSTANT - NONE.
         ERLANG - INTEGER VALUE (ROUNDED) FOR MEAN**2/VARIANCE.<GREATER THAN 1>
         GAMMA - MEAN**2/VARIANCE. <GREATER THAN 1>
         LOGNORMAL - STANDARD DEVIATION.
         NEGATIVE EXPONENTIAL - NONE.
         SHIFTED NEGATIVE EXPONENTIAL - MINIMUM HEADWAY IN SECONDS. <LESS THAN
                                        OR EQUAL MEAN HEADWAY>
         UNIFORM - STANDARD DEVIATION
F(4),F(5)- MEAN,85 PERCENTILE SPEED OF ENTERING VEHICLES, MPH.<10 TO 80>[29,31]
F(6) - TRAFFIC MIX DATA TO FOLLOW ? <"YES" OR "NO">  ["NO"]
F(7) - SEED FOR RANDOM NUMBERS (0 FOR AUTO. SELECTION).  <0 TO 99999> [0]
EDIT EXAMPLE: "F(4)=29,32" CHANGES FIELD 4 TO "29" AND FIELD 5 TO "32"
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE
  DATA FIELDS:    SNEGEXP   600    1.00  55.0  60.5 NO      0
FIELD NUMBERS:    \..1../ \.2./ \..3./ \.4./ \.5./ \6/ \.7./

IS INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 2 OK ?
Y

OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 2:
EACH FIELD - PERCENT OF VEHICLES FROM LEG 2 TO LEAVE THE INTERSECTION VIA THE
             SPECIFIED (BY FIELD NUMBER) LEG.  <0 TO 100 AND SUM = 100>
EDIT EXAMPLE: "F(2)=3*20" CHANGES FIELDS 2 THRU 4 TO "20", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE

  DATA FIELDS:    10   0  10  80
FIELD NUMBERS:   \1/ \2/ \3/ \4/

IS OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 2 OK ?
Y

LEG 3 GEOMETRY DATA:
F(1) - LEG ANGLE.  POSITIVE IS CLOCKWISE FROM NORTH = 0 (ZERO) DEGREES.
       <0 TO 359, IN INCREASING ORDER>  [180]
F(2) - LENGTH OF INBOUND LANES.  <400 TO 1000>  [800]
F(3) - LENGTH OF OUTBOUND LANES.  [250]  (SUGGEST 250 FOR LOW TRAFFIC VOLUME,
       400 FOR HIGH VOLUME. FOR EMISSIONS, MUST BE SAME AS INBOUND LANE LENGTH)
F(4) - NUMBER OF INBOUND LANES.  <0 TO 6>  [2]
```

Table A-1 (Continued)

```
FIELD NUMBERS:   \1/ \2/ \3/ \4/

IS OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 3 OK ?
Y

LEG 4 GEOMETRY DATA:
F(1) - LEG ANGLE.  POSITIVE IS CLOCKWISE FROM NORTH = 0 (ZERO) DEGREES.
       <0 TO 359, IN INCREASING ORDER>  [270]
F(2) - LENGTH OF INBOUND LANES.  <400 TO 1000>  [800]
F(3) - LENGTH OF OUTBOUND LANES.  [250]  (SUGGEST 250 FOR LOW TRAFFIC VOLUME,
       400 FOR HIGH VOLUME. FOR EMISSIONS, MUST BE SAME AS INBOUND LANE LENGTH)
F(4) - NUMBER OF INBOUND LANES.  <0 TO 6>  [2]
F(5) - NUMBER OF OUTBOUND LANES.  <0 TO 6>  [2]
F(6) - SPEED LIMIT ON INBOUND LANES IN MPH.  <10 TO 80>  [30]
F(7) - SPEED LIMIT ON OUTBOUND LANES IN MPH.  <10 TO 80>  [30]
F(8) - LEG CENTERLINE OFFSET FROM INTERSECTION CENTER. POSITIVE IS TO THE RIGHT
       WHEN FACING IN DIRECTION OF INBOUND TRAFFIC.  <-200 TO 200>  [0]
F(9) - MEDIAN WIDTH. WILL BE CENTERED ON INTERSECTION CENTERLINE. <0 TO 100>[0]
F(10) - LIMITING ANGLE FOR STRAIGHT MOVEMENT.  <0 TO 45 DEGREES>  [20]
F(11) - LIMITING ANGLE FOR U-TURN.  <0 TO 45 DEGREES>  [10]
  DATA FIELDS:     270  800  800    3    2   55   55    0   16   20   10
FIELD NUMBERS:    \.1/ \.2/ \.3/ \.4/ \.5/ \.6/ \.7/ \.8/ \.9/ \10 \11

IS LEG 4 GEOMETRY DATA OK ?
Y

F(1) - WIDTH OF LANE.  <8 TO 15>  [12]
F(2) - MOVEMENT CODE. ANY OF"U"(U-TURN),"L"(LEFT),"S"(STRAIGHT) AND "R"(RIGHT).
F(3) - LENGTH OF USABLE LANE FROM LANE TERMINAL.  [0, FOR OPEN LANE]
F(4) - LENGTH OF USABLE LANE FROM OUTER END.  [0, FOR OPEN LANE]
F(5) - OFFSET OF LANE TERMINAL.  POS. IS TOWARD INTERSECTION. <-350 TO 100> [0]
F(6) - PERCENT OF INBOUND TRAFFIC TO ENTER IN THIS LANE.
       <0 TO 100, SUM FOR LEG=100, 0 FOR OUTBOUND OR LANE WITH F(4) NOT= 0>
EDIT EXAMPLE: "LANE(3,1)=8" CHANGES FIELD 1 OF LANE 3 TO "8", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL INFORMATION

LANE DATA FOR LEG 4:
 1  (INBOUND 1)      12 L     250    0    0    0
 2  (INBOUND 2)      12 S       0    0    0   50
 3  (INBOUND 3)      12 SR      0    0    0   50
 4  (OUTBOUND 1)     12 LS      0    0    0    0
 5  (OUTBOUND 2)     12 SR      0    0    0    0
                   \.1/ \.2/ \.3/ \.4/ \.5/ \.6/
IS LANE DATA FOR LEG 4 OK ?
Y

INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 4:
F(1) - NAME FOR INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION:
       "CONSTAN", "ERLANG", "GAMMA", "LOGNRML", "NEGEXP","SNEGEXP" OR "UNIFORM"
       MAY BE ABBREVIATED TO THE FIRST CHARACTER.
F(2) - TOTAL HOURLY VOLUME ON LEG, VPH. <0 TO 4000> [200 PER INBOUND LANE]
F(3) - PARAMETER FOR HEADWAY FREQUENCY DISTRIBUTION:
         CONSTANT - NONE.
         ERLANG - INTEGER VALUE (ROUNDED) FOR MEAN**2/VARIANCE.<GREATER THAN 1>
         GAMMA - MEAN**2/VARIANCE. <GREATER THAN 1>
         LOGNORMAL - STANDARD DEVIATION.
         NEGATIVE EXPONENTIAL - NONE.
         SHIFTED NEGATIVE EXPONENTIAL - MINIMUM HEADWAY IN SECONDS. <LESS THAN
                                        OR EQUAL MEAN HEADWAY>
         UNIFORM - STANDARD DEVIATION
F(4),F(5)- MEAN,85 PERCENTILE SPEED OF ENTERING VEHICLES, MPH.<10 TO 80>[29,31]
F(6) - TRAFFIC MIX DATA TO FOLLOW ? <"YES" OR "NO">  ["NO"]
F(7) - SEED FOR RANDOM NUMBERS (0 FOR AUTO. SELECTION).  <0 TO 99999> [0]
EDIT EXAMPLE: "F(4)=29,32" CHANGES FIELD 4 TO "29" AND FIELD 5 TO "32"
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE
  DATA FIELDS:    SNEGEXP   600    1.00   55.0   60.5 NO      0
```

Table A-1 (Continued)

```
FIELD NUMBERS:    \..1../ \.2./ \..3./ \.4./ \.5./ \6/ \.7./

IS INBOUND TRAFFIC HEADWAY FREQUENCY DISTRIBUTION DATA FOR LEG 4 OK ?
Y

OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 4:
EACH FIELD - PERCENT OF VEHICLES FROM LEG 4 TO LEAVE THE INTERSECTION VIA THE
             SPECIFIED (BY FIELD NUMBER) LEG.  <0 TO 100 AND SUM = 100>
EDIT EXAMPLE: "F(2)=3*20" CHANGES FIELDS 2 THRU 4 TO "20", OTHERS UNCHANGED
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE

  DATA FIELDS:    10  80  10   0
FIELD NUMBERS:   \1/ \2/ \3/ \4/

IS OUTBOUND TRAFFIC DESTINATION DATA FOR LEG 4 OK ?
Y
```

Table A-2. Sample SIMDATA File of TEXAS Model, 90 km/h (55 mph)

```
         1         2         3         4         5
12345678901234567890123456789012345678901234567890123456789012345
5531S.DET, 3 DET AT 0,113,226 FT

IS TITLE TEXT OK ?
Y

SIMULATION PARAMETER-OPTION DATA:
F(1) - START-UP TIME IN MINUTES. (STATISTICS NOT GATHERED)  <2.0 TO 5.0> [5.0]
F(2) - SIMULATION TIME IN MINUTES.  <10.0 TO 60.0> [FROM G&D-V REF. FILE]
F(3) - TIME INCREMENT FOR SIMULATION, "DT". (SUGGEST 1.0 FOR SIGNAL,
       0.5 FOR NON-SIGNAL)  <0.50 TO 1.00> [0.50]
F(4) - TYPE OF INTERSECTION CONTROL: <"U", "Y", "ST", "A", "P", "SE", "F", "N">
       "U" - UNCONTROLLED.                    "Y" - YIELD.
       "ST" - STOP, LESS THAN ALL WAY.        "A" - ALL-WAY STOP.
       "P" - PRETIMED SIGNAL.                 "SE" - SEMI-ACTUATED SIGNAL.
       "F" - FULL-ACTUATED SIGNAL.            "N" - NEMA ACTUATED SIGNAL.
F(5) - STATISTICAL SUMMARY BY TURNING MOVEMENT ?  <"YES" OR "NO"> ["YES"]
F(6) - STATISTICAL SUMMARY BY INBOUND APPROACH ?  <"YES" OR "NO"> ["YES"]
F(7) - COMPRESSED OUTPUT OF STATISTICS ?  <"YES" OR "NO"> ["NO"]
F(8) - VEHICLE POSITION (DISPLAY/POLLUTION) DATA ?  <"YES", "NO", "POL">["YES"]
F(9) - VEHICLE POSITION DATA ENDING TIME IN MINUTES.  <0.0 TO 70.0> [5.0]
F(10) - PRINTED OUTPUT USES 132 COLUMNS ("NO" USES 80) ? <"YES" OR "NO">["YES"]
F(11) - LEFT TURNING VEHICLES PULL INTO INTERSECTION ?  <"YES" OR "NO"> ["NO"]
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE.

DATA: 5.00 60.00 0.50 NEMA 8   NO  YES NO  YES 10.0 YES NO
 FLD: \.1/ \.2./ \.3/ \...4../ \5/ \6/ \7/ \8/ \.9/ \10 \11

IS SIMULATION PARAMETER-OPTION DATA OK ?
Y

SIMULATION PARAMETER-OPTION DATA 2:
F(1) - SPEED BELOW WHICH A SPECIAL DELAY STATISTIC IS COLLECTED. <0 TO 40> [10]
F(2) - MAXIMUM CLEAR DISTANCE FOR BEING IN A QUEUE.  <4 TO 40> [30]
F(3) - CAR FOLLOWING EQUATION PARAMETER LAMBDA.  <2.300 TO 4.000> [2.800]
F(4) - CAR FOLLOWING PARAMETER MU.  <0.600 TO 1.000> [0.800]
F(5) - CAR FOLLOWING PARAMETER ALPHA.  <0 TO 10000> [ 4000]
F(6) - TIME FOR LEAD ZONE USED IN CONFLICT CHECKING.  <0.50 TO 3.00> [0.80]
F(7) - TIME FOR LAG ZONE USED IN CONFLICT CHECKING.  <0.50 TO 3.00> [0.80]
KEYIN "HELP" FOR ADDITIONAL ASSISTANCE.

DATA: 10  30 2.800 0.800  4000 0.80 0.80
 FLD: \1 \2/ \.3./ \.4./ \.5./ \.6/ \.7/

IS SIMULATION PARAMETER-OPTION DATA 2 OK ?
Y

LANE CONTROL DATA:
EACH FIELD - TYPE OF CONTROL FOR THE INDICATED INBOUND LANE:
 "BL" - BLOCKED LANE. LANE ENDS BEFORE THE INTERSECTION.
 "UN" - UNCONTROLLED. <ONLY IF INTER. CONTROL = "NONE", "YIELD" OR "STOP">
 "YI" - YIELD SIGN. <NOT IF INTERSECTION CONTROL = "NONE">
 "ST" - STOP SIGN. <ONLY IF INTERSECTION CONTROL = "STOP" OR "ALL-WAY">
 "SI" - SIGNAL WITHOUT LEFT OR RIGHT TURN ON RED. <SIGNALIZED INTER. ONLY>
 "LT" - SIGNAL WITH LEFT TURN ON RED. <SIGNALIZED INTERSECTION ONLY>
 "RT" - SIGNAL WITH RIGHT TURN ON RED. <SIGNALIZED INTERSECTION ONLY>
 LEG: /---1--\ /---2--\ /---3--\ /---4--\
LANE:  1  2  3  1  2  3  1  2  3  1  2  3
DATA: SI SI RT SI SI RT SI SI RT SI SI RT
 FLD: \1 \2 \3 \4 \5 \6 \7 \8 \9 10 11 12

IS LANE CONTROL DATA OK ?
Y
```

Table A-2 (Continued)

```
THIS IS A SINGLE RING CONTROLLER.

NEMA ACTUATED CONTROLLER SIGNAL TIMING DATA:
F(1) - INITIAL INTERVAL.  <"DT" TO 99.0> [3.0]
F(2) - VEHICLE INTERVAL. <"DT" TO 99.0> [2.0]
F(3) - YELLOW-CHANGE INTERVAL.  <1.0 TO 9.0> [3.0]
F(4) - ALL RED-CLEARANCE INTERVAL.  <0.0 TO 9.0> [0.5]
F(5) - MAXIMUM EXTENSION. <0 TO 99>  [30]
F(6) - DUAL ENTRY PHASE. (0 = SINGLE ENTRY PERMITTED)  <0 TO 8> [0]
F(7) - PROVISION FOR STORING DEMAND ? <"YES" OR "NO"> [YES]
F(8) - ENABLE MAXIMUM RECALL ? <"YES" OR "NO"> [NO]
F(9) - ENABLE MINIMUM RECALL ? <"YES" OR "NO"> [NO]
F(10) - PLACE CALL ON MAX-OUT ? <"YES" OR "NO"> [YES]
F(11) - USE VOLUME DENSITY OPTIONS ?  <"YES" OR "NO"> [NO]
** DATA IN FIELDS 1 THRU 4 WILL BE AUTOMATICALLY ROUNDED TO THE NEAREST "DT".

P(1):  7.0  0.5 5.0 1.0 30  0 YES NO  NO  YES NO
 (2):  0.0  2.5 5.0 1.0 60  0 YES NO  NO  YES NO
 (3):  7.0  0.5 5.0 1.0 30  0 YES NO  NO  YES NO
 (4):  0.0  2.5 5.0 1.0 60  0 YES NO  NO  YES NO
 FLD: \.1/ \.2/ \3/ \4/ \5 \6 \7/ \8/ \9/ \10 \11

IS NEMA ACTUATED CONTROLLER SIGNAL TIMING DATA OK ?
Y

OVERLAP DEFINITIONS:
EACH FIELD - ONE OF THE PHASES THAT DEFINES THE OVERLAP.
             (USE FIELD (1) = 0 TO DEACTIVATE THE OVERLAP)

P(A):  0 (INACTIVE)
 (B):  0 (INACTIVE)
 (C):  0 (INACTIVE)
 (D):  0 (INACTIVE)
 FLD: \1 \2 \3

ARE OVERLAP DEFINITIONS OK ?
Y

EACH FIELD -GREEN SIGNAL INDICATION FOR THE CONTROLLER PHASE AND LANE:
"C" - CIRCULAR GREEN. ALL PERMITTED MOVEMENTS MAY MOVE.
"L", "S", "R" - LEFT, STRAIGHT, RIGHT GREEN ARROW.  PROTECTED MOVEMENTS.
*** ANY TWO OF THE ABOVE MAY BE USED TOGETHER, EXCEPT "LS" OR "LR".
"UN" - UNSIGNALIZED, SIGN CONTROL OR BLOCKED LANE, PER LANE CONTROL DATA.
BLANK - IMPLIED RED.
*** "LC" IS LANE CONTROL DATA.   "MC" IS MOVEMENT CODE FROM GEOMETRY REF. DATA.

 LEG: /---1--\ /---2--\ /---3--\ /---4--\
LANE:  1  2  3  1  2  3  1  2  3  1  2  3
  MC: L  S  SR L  S  SR L  S  SR L  S  SR
  LC: SI SI RT SI SI RT SI SI RT SI SI RT
P(1): L                 L
 (2):    C  C              C  C
 (3):          L                 L
 (4):             C  C              C  C
      ------------- OVERLAPS -------------
 (A):
 (B):
 (C):
 (D):
 FLD: \1 \2 \3 \4 \5 \6 \7 \8 \9 10 11 12

IS GREEN INTERVAL SEQUENCE DATA FOR TIMED PHASES AND OVERLAPS OK ?
Y

                             LANE: 1 2 3 1 2 3 1 2 3 1 2 3
D(1): 1 1 1     0  40 PR           X
 (2): 1 2 2     0   6 PR             X X
 (3): 1 2 2  -246   6 PR             X X
 (4): 1 2 2  -492   6 PR             X X
```

Table A-2 (Continued)

```
 (5): 1 2 2  -320   6 IN <INACTIVE. DON'T INCLUDE IN CONNECTION LIST.
 (6): 2 1 1     0  40 PR            X
 (7): 2 2 2     0   6 PR              X X
 (8): 2 2 2  -246   6 PR              X X
 (9): 2 2 2  -492   6 PR              X X
(10): 2 2 2  -320   6 IN <INACTIVE. DON'T INCLUDE IN CONNECTION LIST.
(11): 3 1 1     0  40 PR                   X
(12): 3 2 2     0   6 PR                     X X
(13): 3 2 2  -246   6 PR                     X X
(14): 3 2 2  -492   6 PR                     X X
(15): 3 2 2  -320   6 IN <INACTIVE. DON'T INCLUDE IN CONNECTION LIST.
(16): 4 1 1     0  40 PR                          X
(17): 4 2 2     0   6 PR                            X X
(18): 4 2 2  -246   6 PR                            X X
(19): 4 2 2  -492   6 PR                            X X
(20): 4 2 2  -320   6 IN <INACTIVE. DON'T INCLUDE IN CONNECTION LIST.
 FLD: 1 2 3 \.4./ \5/ \6

IS DATA FOR DETECTORS OK ?
Y

DETECTOR CONNECTION DATA:
EACH FIELD - THE NUMBER OF A DETECTOR CONNECTED TO THE CONTROLLER PHASE.
             (USE "0" TO INDICATE THAT NO DETECTOR IS CONNECTED)
             <SMALLER OF THE NUMBER OF DETECTORS (20) OR 6>

P(1):  1 11
 (2):  2  3  4 12 13 14
 (3):  6 16
 (4):  7  8  9 17 18 19
 FLD: \1 \2 \3 \4 \5 \6

IS DETECTOR CONNECTION DATA OK ?
Y
```

8.0 APPENDIX B

TEXAS MODEL OUTPUT FILES

VOLUM	DET LOC	OVERALL AVERAGE TOTAL DELAY,SECONDS/VEHICLE						
		NUM	MINIMUM	MEAN	MAXIMUM	VAR	STD. DEV	ST.DEV/MEAN
200	0,186,371 ft	3	16.8	17	17.2	0	0.2	0.01
400	0,186,371 ft	3	16.8	17	17.2	0	0.2	0.01
600	0,186,371 ft	7	38.6	42.2	44.6	3.6	1.9	0.045
800	0,186,371 ft	3	50.7	51.3	52	0.4	0.6	0.012
200	40,226,412 ft	3	17.8	18	18.2	0	0.2	0.01
400	40,226,412 ft	3	17.8	18	18.2	0	0.2	0.01
600	40,226,412 ft	4	38.4	39.2	39.9	0.6	0.8	0.019
800	40,226,412 ft	4	51	52.1	53.5	1.2	1.1	0.021
200	60,246,432 ft	4	18.3	18.7	19.4	0.3	0.5	0.029
400	60,246,432 ft	4	18.3	18.7	19.4	0.3	0.5	0.029
600	60,246,432 ft	3	38.9	39.7	40.2	0.5	0.7	0.018
800	60,246,432 ft	3	50.4	50.9	51.2	0.2	0.4	0.008
200	80,225,370 ft	7	16.7	18.1	19.5	0.8	0.9	0.05
400	80,225,370 ft	7	16.7	18.1	19.5	0.8	0.9	0.05
600	80,225,370 ft	3	32.8	33.3	33.8	0.3	0.5	0.016
800	80,225,370 ft	5	44.6	47	48.3	2.3	1.5	0.032
200	100,245,390 ft	3	19.4	19.6	20	0.1	0.3	0.015
400	100,245,390 ft	3	19.4	19.6	20	0.1	0.3	0.015
600	100,245,390 ft	3	34.4	34.7	35.1	0.1	0.3	0.01
800	100,245,390 ft	3	46.8	47.6	48.3	0.6	0.8	0.017
200	120,265,410 ft	3	20.3	20.6	20.8	0.1	0.3	0.013
400	120,265,410 ft	3	20.3	20.6	20.8	0.1	0.3	0.013
600	120,265,410 ft	3	34.1	34.4	35.1	0.3	0.6	0.016
800	120,265,410 ft	3	47.1	47.5	48	0.2	0.4	0.009

Table B-1. Overall Average Total Delay for Different Detector Layouts, 90 km/h (55 mph) Mean Speed

VOLUM	DET LOC	OVERALL AVERAGE TOTAL DELAY, SECONDS						
		NUM	MINIMU	MEAN	MAXIMU	VAR	STD. DEV	ST.DEV/MEAN
200	0,156,312 ft	8	13.7	15.0	15.9	0.7	0.9	0.058
400	0,156,312 ft	3	28.6	29.0	29.3	0.1	0.4	0.013
600	0,156,312 ft	5	37.6	39.3	40.6	1.9	1.4	0.035
800	0,156,312 ft	6	45.9	49.1	51.4	3.5	1.9	0.038
200	40,163,286 ft	4	15.9	16.2	16.9	0.2	0.5	0.030
400	40,163,286 ft	5	22.0	23.1	24.0	0.7	0.8	0.036
600	40,163,286 ft	3	32.2	32.8	33.3	0.3	0.5	0.017
800	40,163,286 ft	3	44.5	45.4	45.8	0.6	0.7	0.016
200	60,183.206 ft	4	16.4	17.0	17.5	0.2	0.5	0.029
400	60,183.206 ft	4	21.9	22.5	23.3	0.3	0.6	0.026
600	60,183.206 ft	3	28.7	29.4	29.9	0.3	0.6	0.020
800	60,183.206 ft	4	39.7	40.4	41.2	0.5	0.7	0.018
200	80,170,260 ft	6	15.8	17.0	17.8	0.4	0.7	0.039
400	80,170,260 ft	6	20.8	22.5	23.6	1.1	1.0	0.046
600	80,170,260 ft	3	29.2	29.4	29.5	0.0	0.1	0.005
800	80,170,260 ft	4	37.8	38.9	39.8	0.7	0.8	0.021
200	100,190,280 ft	4	17.2	17.9	18.5	0.3	0.5	0.030
400	100,190,280 ft	4	17.2	17.9	18.5	0.3	0.5	0.030
600	100,190,280 ft	5	22.4	23.2	24.2	0.5	0.7	0.031
800	100,190,280 ft	3	37.7	37.9	38.3	0.1	0.3	0.007
200	120,210,300 ft	3	18.1	18.4	18.8	0.1	0.4	0.019
400	120,210,300 ft	5	22.9	23.8	24.6	0.5	0.7	0.030
600	120,210,300 ft	3	29.1	29.5	29.9	0.1	0.4	0.013
800	120,210,300 ft	3	37.2	37.7	38.2	0.3	0.5	0.014

Table B-2. Overall Average Delay for Different Detector Layouts, 70 km/h (45 mph) Mean Speed

VOLUME	DET LOC	OVERALL AVERAGE TOTAL DELAY, SECONDS						
		NUM	MINIMUM	MEAN	MAXIMUM	VAR	STD. DEV	ST.DEV/MEAN
200	0,101,202 ft	5	14.4	15.1	16.0	0.3	0.6	0.039
400	0,101,202 ft	4	26.3	26.9	27.5	0.3	0.5	0.019
600	0,101,202 ft	3	33.5	33.7	34.0	0.1	0.2	0.007
800	0,101,202 ft	5	42.6	44.9	46.8	2.7	1.7	0.037
200	40,115,190 ft	4	14.6	14.9	15.2	0.1	0.3	0.018
400	40,115,190 ft	6	20.3	21.5	22.2	0.7	0.9	0.040
600	40,115,190 ft	3	28.7	29.2	29.8	0.3	0.5	0.019
800	40,115,190 ft	3	38.0	38.7	39.3	0.4	0.7	0.017
200	60,135,210 ft	4	15.1	15.6	16.0	0.1	0.4	0.023
400	60,135,210 ft	4	15.1	15.6	16.0	0.1	0.4	0.023
600	60,135,210 ft	3	28.5	29.1	29.3	0.2	0.5	0.016
800	60,135,210 ft	4	37.8	39.0	39.9	1.0	1.0	0.026
200	80,155,230 ft	7	15.0	16.0	16.9	0.5	0.7	0.044
400	80,155,230 ft	7	15.0	16.0	16.9	0.5	0.7	0.044
600	80,155,230 ft	4	27.1	28.2	29.1	0.7	0.8	0.030
800	80,155,230 ft	3	37.3	37.9	38.3	0.3	0.5	0.014
200	100,175,250 ft	5	16.2	17.1	17.7	0.4	0.6	0.037
400	100,175,250 ft	3	22.8	23.1	23.6	0.2	0.4	0.019
600	100,175,250 ft	3	28.0	28.4	28.9	0.2	0.5	0.016
800	100,175,250 ft	3	37.4	38.0	38.4	0.2	0.5	0.013
200	120,195,290 ft	4	17.7	18.3	18.7	0.3	0.5	0.027
400	120,195,290 ft	6	21.6	23.1	24.6	1.1	1.1	0.045
600	120,195,290 ft	4	28.1	29.0	29.8	0.6	0.7	0.026
800	120,195,290 ft	3	36.8	37.1	37.6	0.2	0.4	0.012

Table B-3. Overall Average Total Delay for Different Detector Layouts, 55 km/h (35 mph) Mean Speed

VOLUME	DETLOC	PHASE1			PHASE2			PHASE3			PHASE4			CYCLE LENGTH
		Max	Gap	% GREE	Max	Gap	% GREE	Max	Gap	% GREE	Max	Gap	% GREEN	SECONDS
200	0,186,371 ft	0	32	12.5	0	108	37.2	0	28	10.9	0	109	39.3	33.03
400	0,186,371 ft	0	32	12.5	0	108	37.2	0	28	10.9	0	109	39.3	33.03
600	0,186,371 ft	0	29	9.8	3	28	39.2	0	29	9.5	3	28	41.5	116.13
800	0,186,371 ft	0	24	9.3	9	15	40.4	0	24	9.4	10	14	40.9	150.00
200	40,226,412 ft	0	30	9.7	0	75	40.3	0	28	9	0	75	41	48.00
400	40,226,412 ft	0	30	9.7	0	75	40.3	0	28	9	0	75	41	48.00
600	40,226,412 ft	0	31	10.1	2	29	38.8	0	31	9.9	4	28	41.2	112.50
800	40,226,412 ft	0	22	9.3	17	6	42.9	0	23	9.2	11	11	39.6	156.52
200	60,246,432 ft	0	25	7.8	0	66	41.2	0	30	9.1	0	66	41.9	54.55
400	60,246,432 ft	0	25	7.8	0	66	41.2	0	30	9.1	0	66	41.9	54.55
600	60,246,432 ft	0	29	9.7	3	26	41.4	0	27	8.8	6	23	40	124.14
800	60,246,432 ft	0	23	9.2	12	11	40	0	23	9.4	13	10	40.6	156.52
200	80,225,370 ft	0	26	8	0	68	41	0	28	8.6	0	69	42.4	52.17
400	80,225,370 ft	0	26	8	0	68	41	0	28	8.6	0	69	42.4	52.17
600	80,225,370 ft	0	38	12.2	0	42	38.6	0	38	12.2	0	42	37	85.71
800	80,225,370 ft	0	27	10.8	6	21	39.8	0	26	10.3	3	24	39.11	133.33
200	100,245,390 ft	0	29	8.6	0	60	40.7	0	26	7.7	0	61	43	59.02
400	100,245,390 ft	0	29	8.6	0	60	40.7	0	26	7.7	0	61	43	59.02
600	100,245,390 ft	0	37	11.9	2	37	39.5	0	32	10.5	0	39	38.01	92.31
800	100,245,390 ft	0	26	9.3	7	19	39.6	0	26	9.7	9	17	41.4	138.46
200	120,265,410 ft	0	29	8.5	0	58	41.4	0	25	7.3	0	57	42.8	62.07
400	120,265,410 ft	0	29	8.5	0	58	41.4	0	25	7.3	0	57	42.8	62.07
600	120,265,410 ft	0	28	12.2	1	38	40.8	0	31	10.2	0	39	36.8	92.31
800	120,265,410 ft	0	27	10	4	23	37.8	0	27	10	5	22	42	133.33

Table B-4. Cycle Lengths for Different Detector Layouts, 90 km/h (55 mph) Mean Speed

		PHASE 1			PHASE 2			PHASE 3			PHASE 4			CYCLE LENGTH
VOLUME	DET LOC	MAX	GAP	GREE	MAX	GAP	% GREEN	MAX	GAP	GREE	MAX	GAP	% GREEN	SECONDS
200	0,156,312 ft	0	26	9.8	0	117	37.11	0	35	13.3	0	115	39.8	30.77
400	0,156,312 ft	0	42	13.6	0	68	36.70	0	37	12.0	0	69	37.7	52.17
600	0,156,312 ft	0	31	10.0	3	31	40.00	0	34	10.1	4	30	39.9	105.88
800	0,156,312 ft	1	22	9.0	14	10	42.00	0	24	9.6	12	11	39.3	150.00
200	40,163,286 ft	0	29	9.1	0	81	41.80	0	31	9.9	0	82	39.2	43.90
400	40,163,286 ft	0	42	13.0	0	61	38.01	0	40	12.4	0	61	36.7	59.02
600	40,163,286 ft	0	36	11.4	0	39	39.90	0	37	11.3	0	40	37.4	90.00
800	40,163,286 ft	0	26	9.0	9	17	42.60	0	26	9.7	6	20	38.7	138.46
200	60,183.206 ft	0	31	9.5	0	75	40.60	0	34	10.5	0	75	39.2	48.00
400	60,183.206 ft	0	41	12.9	0	64	37.00	0	40	12.6	0	64	37.5	56.25
600	60,183.206 ft	0	43	13.6	0	48	35.60	0	41	12.5	0	48	38.2	75.00
800	60,183.206 ft	0	33	11.3	0	34	39.90	0	33	11.3	0	33	37.5	105.88
200	80,170,260 ft	0	28	8.5	0	72	41.50	0	26	7.8	0	74	42.1	48.65
400	80,170,260 ft	0	43	13.7	0	59	37.30	0	42	13.3	0	60	35.8	60.00
600	80,170,260 ft	0	47	15.0	0	52	36.80	0	45	14.4	0	51	33.8	69.23
800	80,170,260 ft	0	37	12.7	1	35	39.10	0	34	11.9	0	37	36.5	97.30
200	100,190,280 ft	0	27	7.9	0	66	42.71	0	29	8.4	0	65	41.0	54.55
400	100,190,280 ft	0	42	12.7	0	55	36.90	0	40	12.2	0	55	38.1	65.45
600	100,190,280 ft	0	43	13.3	0	48	36.90	0	42	13.4	0	47	36.4	75.00
800	100,190,280 ft	0	36	12.3	0	37	37.20	0	35	11.9	1	36	38.6	97.30
200	120,210,300 ft	0	30	8.6	0	60	41.40	0	25	7.3	0	62	42.8	58.06
400	120,210,300 ft	0	39	11.5	0	52	39.50	0	38	11.3	0	52	37.7	69.23
600	120,210,300 ft	0	42	13.1	0	46	37.30	0	40	12.5	0	47	37.2	76.60
800	120,210,300 ft	0	35	11.2	1	36	39.50	0	36	12.3	0	37	36.9	97.30

Table B-5. Cycle Lengths for Different Detector Layouts, 70 km/h (45 mph) Mean Speed

VOLUME	DETLOC	PHASE1			PHASE 2			PHASE 3			PHASE 4			CYCLE LENGTH
		MAX	GAP	GREE	MA	GAP	GREE	MAX	GAP	% GREE	MAX	GAP	GREE	Seconds
200	0,101,202 ft	0	30	12.1	0	130	37.2	0	30	12.4	0	127	38.3	27.69
400	0,101,202 ft	0	45	15.5	0	80	36.1	0	43	14.8	0	81	33.7	45.00
600	0,101,202 ft	0	38	11.7	1	42	36	0	39	12.3	1	42	40	83.72
800	0,101,202 ft	0	26	10.2	3	23	40	0	27	10.3	3	23	39.5	138.46
200	40,115,190 ft	0	29	9.5	0	84	39.8	0	31	10.1	0	87	40.6	41.38
400	40,115,190 ft	0	44	14.8	0	70	35.6	0	46	15.1	0	69	34.5	51.43
600	40,115,190 ft	0	45	14.5	0	48	36.6	0	41	12.7	0	48	36.2	75.00
800	40,115,190 ft	0	35	11.6	0	36	39.3	0	35	11.7	8	34	37.4	100.00
200	60,135,210 ft	0	29	9	0	78	40.3	0	33	10.4	1	78	40.3	46.15
400	60,135,210 ft	0	29	9	0	78	40.3	0	33	10.4	0	78	40.3	46.15
600	60,135,210 ft	0	46	14.5	0	50	35.4	0	42	13.5	0	49	36.6	72.00
800	60,135,210 ft	0	31	11.5	0	31	36.2	0	32	11.2	3	29	41.1	116.13
200	80,155,230 ft	0	27	8.1	0	71	40.6	0	27	8.1	0	72	43.1	50.00
400	80,155,230 ft	0	27	8.1	0	71	40.6	0	27	8.1	0	72	43.1	50.00
600	80,155,230 ft	0	43	13.6	0	50	36.7	0	44	14	0	49	35.6	72.00
800	80,155,230 ft	0	33	11.1	0	36	39.8	0	36	12.1	0	36	37	100.00
200	00,175,250 f	0	30	8.7	0	66	41.4	0	25	7.3	0	66	42.6	54.55
400	00,175,250 f	0	30	8.7	0	65	41.4	0	25	7.3	0	66	42.3	54.55
600	00,175,250 f	0	40	13	0	47	38.4	0	41	12.7	0	47	37.9	76.60
800	00,175,250 f	0	36	11.2	1	34	38.8	0	34	11.7	0	36	38.3	100.00
200	20,195,290 f	0	28	8.1	0	61	42	0	30	8.6	0	60	41.2	59.02
400	20,195,290 f	0	35	10.7	0	53	38	0	42	12.4	0	53	38.9	67.92
600	20,195,290 f	0	43	13.1	0	49	37.5	0	42	13.1	0	44	36.3	73.47
800	20,195,290 f	0	35	11.6	0	37	30.3	0	35	12	0	37	36.4	97.30

Table B-6. Cycle Lengths for Different Detector Layouts, 55 km/h (35 mph) Mean Speed

		OVERALL AVERAGE TOTAL DELAY, SECONDS						
VOLUME	DETLOC	NUM	INIMU	MEAN	MAXIMU	VAR	TD. DEV	ST.DEV/MEAN
200	0,246,493 FT	5	15.3	16.3	16.6	0.3	0.6	0.034
400	0,246,493 FT	5	15.3	16.3	16.6	0.3	0.6	0.034
600	0,246,493 FT	3	42.1	42.5	43.2	0.4	0.6	0.014
800	0,246,493 FT	4	52.5	53.4	54.7	0.9	0.9	0.017
200	40,242,444 FT	4	17	17.5	18	0.2	0.5	0.027
400	40,242,444 FT	4	17	17.5	18	0.2	0.5	0.027
600	40,242,444 FT	4	37.2	38.2	39.1	0.8	0.9	0.024
800	40,242,444 FT	3	50.8	51.3	52	0.4	0.6	0.013
200	60,282,484 FT	5	17.6	18.2	19.1	0.4	0.7	0.036
400	60,282,484 FT	5	17.6	18.2	19.1	0.4	0.7	0.036
600	60,282,484 FT	3	36.9	37.6	38.1	0.3	0.6	0.015
800	60,282,484 FT	3	50	50.7	51.3	0.4	0.7	0.013
200	80,282,484 FT	4	21.4	21.9	22.4	0.2	0.4	0.02
400	80,282,484 FT	4	21.4	21.9	22.4	0.2	0.4	0.02
600	80,282,484 FT	3	40.6	40.8	41	0	0.2	0.005
800	80,282,484 FT	3	51.4	52.1	53.2	0.9	0.9	0.018
200	100,302,504 F	3	20.1	20.4	20.7	0.1	0.3	0.017
400	100,302,504 F	3	20.1	20.4	20.7	0.1	0.3	0.017
600	100,302,504 F	4	36.6	37.4	38.4	0.8	0.9	0.024
800	100,302,504 F	4	49.1	49.8	50.8	0.8	0.9	0.018
200	120,322,524 F	4	20.5	20.9	21.8	0.4	0.6	0.029
400	120,322,524 F	4	20.5	20.9	21.8	0.4	0.6	0.029
600	120,322,524 F	3	37.3	37.9	38.4	0.3	0.5	0.014
800	120,322,524 F	5	48.7	50.6	53.1	2.6	1.6	0.032

Table B-7. Overall Average Total Delay for Different Detector Layouts, 90 km/h (55 mph) 85th Percentile Speed

		OVERALL AVERAGE TOTAL DELAY, SECONDS						
VOLUME	DETLOC	NUM	MINIMU	MEAN	MAXIMU	VAR	STD. DE	ST.DEV/MEAN
200	0,172,344 FT	3	14.4	14.6	14.8	0	0.2	0.014
400	0,172,344 FT	9	25.1	26.9	30	2.9	1.7	0.063
600	0,172,344 FT	3	37.1	37.8	38.3	0.4	0.6	0.016
800	0,172,344 FT	3	47.7	48.4	49.3	0.7	0.9	0.018
200	40,212,384 FT	5	15.7	16.2	16.9	0.3	0.6	0.035
400	40,212,384 FT	4	22.9	23.6	24.1	0.3	0.5	0.022
600	40,212,384 FT	3	34.9	35.3	35.8	0.2	0.5	0.013
800	40,212,384 FT	4	47	48.5	49.9	1.6	1.2	0.026
200	60,195,320 FT	4	15.8	16.3	16.8	0.2	0.5	0.03
400	60,195,320 FT	4	21.2	22.2	22.7	0.5	0.7	0.031
600	60,195,320 FT	4	30.7	31.8	32.5	0.6	0.8	0.025
800	60,195,320 FT	3	43.1	44.1	44.7	0.7	0.8	0.019
200	80,215,350 FT	5	16.7	17.3	18	0.3	0.5	0.031
400	80,215,350 FT	3	22.9	23.3	23.8	0.2	0.5	0.02
600	80,215,350 FT	5	29.4	30.9	32.1	1.3	1.2	0.038
800	80,215,350 FT	3	40.8	41.5	42	0.4	0.6	0.015
200	100,235,370 FT	3	17.8	17.8	17.8	0	0	0.002
400	100,235,370 FT	3	23.4	23.7	24.1	0.1	0.3	0.014
600	100,235,370 FT	4	29.8	30.8	31.7	0.9	1	0.031
800	100,235,370 FT	3	41.4	41.7	41.8	0.1	0.2	0.006
200	120,218,316 FT	4	17.9	18.3	19.1	0.3	0.5	0.03
400	120,218,316 FT	5	22.6	23.8	24.4	0.5	0.7	0.03
600	120,218,316 FT	3	28.4	28.7	29	0.1	0.3	0.01
800	120,218,316 FT	3	38.2	38.8	39.2	0.3	0.6	0.014

Table B-8. Overall Average Total Delay for Different Detector Layouts, 70 km/h (45 mph) 85th Percentile Speed

VOLUME	DET LOC	OVERALL AVERAGE TOTAL DELAY, SECONDS						
		NUM	INIMU	MEAN	MAXIMU	VAR	STD. DEV	ST.DEV/MEAN
200	0,113,226 FT	4	14.3	14.8	15.3	0.2	0.5	0.031
400	0,113,226 FT	4	14.3	14.8	15.3	0.2	0.5	0.031
600	0,113,226 FT	4	33	33.8	34.8	0.7	0.8	0.025
800	0,113,226 FT	3	41.6	42.5	43.1	0.6	0.8	0.019
200	40,153,226 FT	6	14.3	15	15.8	0.3	0.6	0.039
400	40,153,226 FT	3	21.1	21.6	21.9	0.2	0.4	0.019
600	40,153,226 FT	3	30.9	31.2	31.5	0.1	0.3	0.009
800	40,153,226 FT	4	43.2	44.6	45.7	1.3	1.2	0.026
200	60,144,228 FT	5	14.9	15.8	16.4	0.3	0.6	0.036
400	60,144,228 FT	5	14.9	15.8	16.4	0.3	0.6	0.036
600	60,144,228 FT	6	26.8	28.8	30.1	1.3	1.2	0.04
800	60,144,228 FT	3	38.1	38.6	39.4	0.5	0.7	0.018
200	80,164,248 FT	3	15.6	15.8	15.9	0	0.2	0.01
400	80,164,248 FT	3	15.6	15.8	15.9	0	0.2	0.01
600	80,164,248 FT	3	28.1	28.5	29	0.3	0.5	0.018
800	80,164,248 FT	3	36.7	37.1	37.7	0.3	0.5	0.015
200	100,184,268 F	3	16.3	16.5	16.6	0	0.1	0.008
400	100,184,268 F	3	16.3	16.5	16.6	0	0.1	0.008
600	100,184,268 F	4	27.6	28.5	29.1	0.5	0.7	0.025
800	100,184,268 F	3	36.6	36.9	37.2	0.1	0.3	0.008
200	120,174,228 F	5	17.3	18.1	18.6	0.4	0.6	0.033
400	120,174,228 F	4	22	22.7	23.5	0.4	0.6	0.026
600	120,174,228 F	4	27.4	28.4	29.4	0.7	0.8	0.029
800	120,174,228 F	3	35.4	35.8	36.3	0.2	0.5	0.013

Table B-9. Overall Average Total Delay for Different Detector Layouts, 55 km/h (35 mph) 85th Percentile Speed

VOLUME	DET LOC	PHASE1 MAX	PHASE1 GAP	PHASE1 %GREEN	PHASE2 MAX	PHASE2 GAP	PHASE2 %GREE	PHASE3 MAX	PHASE3 GAP	PHASE3 %GREEN	PHASE4 MAX	PHASE4 GAP	PHASE4 %GREE	CYCLE LENGTH SECONDS
200	0,246,493 FT	0	29	10.6	0	101	40	0	27	10	0	101	39.4	35.64
400	0,246,493 FT	0	29	10.6	0	101	40	0	27	10	0	101	39.4	35.64
600	0,246,493 FT	0	26	8.2	9	18	39.5	0	26	8.3	11	16	44	133.33
800	0,246,493 FT	0	23	9.5	15	7	41.3	0	21	8.9	16	7	40.3	156.52
200	40,242,444 FT	0	28	9	0	73	41.7	0	32	10.2	0	74	39.4	48.65
400	40,242,444 FT	0	28	9	0	73	41.6	0	32	10.2	0	74	39.4	48.65
600	40,242,444 FT	0	28	9.9	4	26	41.5	0	30	9.2	3	28	39.3	116.13
800	40,242,444 FT	0	23	9	13	10	41.5	0	23	9.4	10	13	40.1	156.52
200	60,282,484 FT	0	30	9.2	0	68	41.5	0	27	8.4	0	68	40.9	52.94
400	60,282,484 FT	0	30	9.2	0	68	40.7	0	27	8.4	0	68	40.9	52.94
600	60,282,484 FT	0	30	9.7	4	27	40.6	0	29	9	4	27	40.6	116.13
800	60,282,484 FT	0	24	9.4	12	11	37.6	0	23	8.9	13	11	41.01	150.00
200	80,282,484 FT	0	24	11.5	0	57	37.6	0	29	14	0	57	36.8	63.16
400	80,282,484 FT	0	24	11.5	0	57	37.6	0	29	14	0	57	36.8	63.16
600	80,282,484 FT	0	29	12.6	0	31	35.11	0	28	12.5	3	28	39.8	116.13
800	80,282,484 FT	0	23	10.5	11	12	39.3	0	23	10.8	11	12	39.4	156.52
200	100,302,504 FT	0	27	8	0	60	41	0	27	8	0	60	43	60.00
400	100,302,504 FT	0	27	8	0	60	41	0	27	8	0	60	43	60.00
600	100,302,504 FT	0	32	10.1	2	30	41.4	0	31	9.7	0	32	38.8	112.50
800	100,302,504 FT	0	24	9.5	8	15	38.4	0	23	9.8	13	11	42.3	150.00
200	120,322,524 FT	0	23	6.8	0	54	42.5	0	29	8.4	0	53	42.3	66.67
400	120,322,524 FT	0	23	10.7	0	54	42.5	0	29	8.4	0	53	42.3	66.67
600	120,322,524 FT	0	32	6.8	3	30	42.9	0	29	9.7	2	30	36.7	109.09
800	120,322,524 FT	0	24	10.1	11	13	41.2	0	23	9.3	9	15	39.4	150.00

Table B-10. Cycle Lengths for Different Detector Layouts, 90 km/h (55 mph) 85th Percentile Speed

VOLUME	DETLOC	PHASE1			PHASE2			PHASE3			PHASE4			CYCLE LENGTH
		MAX	GAP	% GREE	MAX	GAP	% GREE	MAX	GAP	% GREE	MAX	GAP	% GREE	SECONDS
200	0,172,344 FT	0	33	13.2	0	124	36.71	0	28	11.2	0	125	38.89	28.80
400	0,172,344 FT	0	44	14.3	0	65	37.5	0	45	14.2	0	65	34	55.38
600	0,172,344 FT	0	35	10.8	0	37	40.9	0	33	10.2	2	34	38.1	97.30
800	0,172,344 FT	0	24	9	12	12	42	0	23	8.2	10	14	40.8	150.00
200	40,212,384 FT	0	30	9.3	0	78	43.4	0	26	8	0	77	39.3	46.15
400	40,212,384 FT	0	37	11.1	1	54	41.2	0	38	11.5	0	54	36.2	65.45
600	40,212,384 FT	0	33	10.5	1	33	40.9	0	32	10	2	31	38.6	105.88
800	40,212,384 FT	0	24	9.4	11	12	39.8	0	23	9.2	11	13	41.6	150.00
200	60,195,320 FT	0	32	10	0	74	40.9	0	32	9.8	0	74	39.3	48.65
400	60,195,320 FT	0	43	13.1	0	60	35.7	0	40	12.4	0	60	38.8	60.00
600	60,195,320 FT	0	40	12.2	0	41	37.8	0	36	10.8	1	40	39.2	87.80
800	60,195,320 FT	0	27	9.7	7	19	39.9	0	26	9.4	5	22	41	133.33
200	80,215,350 FT	0	30	8.9	0	69	42.1	0	27	8	0	69	41	52.17
400	80,215,350 FT	0	39	12.9	0	57	38.8	0	37	11.6	0	57	36.7	63.16
600	80,215,350 FT	0	39	12.9	0	43	40.3	0	40	12.2	0	43	34.6	83.72
800	80,215,350 FT	0	30	10.3	2	28	39.5	0	30	10.5	1	29	39.7	120.00
200	100,235,370 FT	0	29	8.5	0	65	42.2	0	25	7.3	0	65	42	55.38
400	100,235,370 FT	0	37	11.2	0	52	39.4	0	32	10.1	0	53	39.3	67.92
600	100,235,370 FT	0	39	12	0	41	38.3	0	37	11.1	0	41	38.6	87.80
800	100,235,370 FT	0	28	9.7	2	28	39.8	0	30	10.6	4	25	39.9	120.00
200	120,218,316 FT	0	28	8.3	0	60	41	0	30	8.7	0	60	42	60.00
400	120,218,316 FT	0	40	11.7	0	51	38.01	0	41	12	0	51	38.29	70.59
600	120,218,316 FT	0	42	13.3	0	47	36.7	0	40	12.7	0	47	37.3	76.60
800	120,218,316 FT	0	37	12.4	0	37	37	0	36	12.7	0	38	37.9	94.74

Table B-11. Cycle Lengths for Different Detector Layouts, 70 km/h (45 mph) 85th Percentile Speed

		PHASE1			PHASE2			PHASE3			PHASE4			CYCLE LENGTH
VOLUME	DET LOC	MAX	GAP	% GREEN	MAX	GAP	% GREEN	MAX	GAP	% GREEN	MAX	GAP	% GREE	SECONDS
200	0,113,226 FT	0	31	12.5	0	123	35.31	0	36	14.5	0	125	37.7	28.80
400	0,113,226 FT	0	31	12.5	0	123	35.3	0	36	14.5	0	125	37.7	28.80
600	0,113,226 FT	0	42	13.1	0	44	37.4	0	42	12.8	1	43	36.8	81.82
800	0,113,226 FT	0	28	10	4	25	42.1	0	29	10.2	2	26	37.7	124.14
200	40,153,226 FT	0	26	8.6	0	85	39.3	0	25	7.9	0	86	44.2	41.86
400	40,153,226 FT	0	40	12.5	0	66	37.2	0	36	11.7	0	65	38.6	54.55
600	40,153,226 FT	0	36	11.2	0	40	38.9	0	36	11.1	0	41	38.8	87.80
800	40,153,226 FT	0	27	10.2	7	20	39.7	0	27	10	4	23	40.1	133.33
200	60,144,228 FT	0	31	9.7	0	79	41.2	0	28	8.8	0	81	40.3	44.44
400	60,144,228 FT	0	31	9.7	0	79	41.2	0	28	8.8	0	81	40.3	44.44
600	60,144,228 FT	0	42	13.3	0	51	38.01	0	43	14	0	51	34.7	70.59
800	60,144,228 FT	0	35	11.3	1	34	39.6	0	33	11	0	35	38.1	102.86
200	80,164,248 FT	0	29	8.8	0	73	42	0	26	7.9	0	74	41.3	48.65
400	80,164,248 FT	0	29	8.8	0	73	42	0	26	7.9	0	74	41.3	48.65
600	80,164,248 FT	0	45	14.3	0	50	35.7	0	44	13.8	0	50	36.2	72.00
800	80,164,248 FT	0	36	11.3	0	35	37.7	0	34	11.7	1	35	39.4	100.00
200	00,184,268 F	0	29	8.7	0	67	41.8	0	27	8	0	68	41.5	52.94
400	00,184,268 F	0	29	8.7	0	67	41.8	0	27	8	0	68	41.5	52.94
600	00,184,268 F	0	47	14.2	0	48	36.3	0	44	13.5	0	48	36.1	75.00
800	00,184,268 F	0	35	11.1	1	35	37.6	0	35	11.9	1	36	39.4	97.30
200	20,174,228 F	0	30	8.7	0	63	42.5	0	27	7.8	0	63	41	57.14
400	20,174,228 F	0	41	12.6	0	55	37.4	0	39	11.8	0	56	38.2	64.29
600	20,174,228 F	0	48	15.2	0	50	35.5	0	43	13.8	0	50	35.6	72.00
800	20,174,228 F	0	43	13.6	0	44	35.9	0	43	14.2	0	43	36.3	81.82

Table B-12. Cycle Lengths for Different Detector Layouts, 55 km/h (35 mph) 85th Percentile Speed