Joint Transportation Research Program

JTRP

FHWA/IN/JTRP-99/1

Final Report

RECONCILED PLATOON ACCOMMODATIONS AT TRAFFIC SIGNALS

Jay Wasson
Montasir Abbas
Darcy Bullock
Avery Rhodes
Chong Kang Zhu

December 1999

Indiana Department of Transportation

Purdue University

Final Report

FHWA/IN/JTRP-99/1

RECONCILED PLATOON ACCOMMODATIONS AT TRAFFIC SIGNALS

By

Jay Wasson
ITS Engineer
Indiana Department of Transportation
(former Graduate Research Assistant)

Montasir Abbas
Graduate Research Assistant

Darcy Bullock
Associate Professor

Avery Rhodes
Undergraduate Research Assistant

Chong Kang Zhu
Graduate Research Assistant

School of Civil Engineering
Purdue University

Joint Transportation Research Program
Project No: C-36-17VV
File No: 8-4-48
SPR-2209

In Cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data represented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration and the Indiana Department of Transportation. The report does not constitute a standard, specification or regulation.

Purdue University
West Lafayette, Indiana 47907
December 1999

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-99/1		

4. Title and Subtitle	5. Report Date
Reconciled Platoon Accommodations at Traffic Signals	December 1999
	6. Performing Organization Code
7. Author(s) Jay Wasson, Montasir Abbas, Darcy Bullock, Avery Rhodes, and Chong Kang Zhu	8. Performing Organization Report No. FHWA/IN/JTRP-99/1
9. Performing Organization Name and Address Joint Transportation Research Program 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	10. Work Unit No.
	11. Contract or Grant No. SPR-2209
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

The use of microprocessor-based traffic signal controllers introduced in the 1960s has allowed for the development of many new strategies to make traffic signal systems more responsive to traffic conditions. Many efforts have focused on the development of real-time, adaptive control strategies. While some of these strategies have been shown to improve intersection performance, there are several factors that have limited their deployment. Some of these include substantial capital cost, complicated calibration procedures, and the reluctance of practicing engineers to deploy strategies radically different from those currently in use. Therefore, lower cost strategies that are compatible with existing infrastructure continue to be explored. This research effort is considered to be in this category. Isolated signalized intersections, which are operated by actuated type controllers, often do not allocate green time in an optimal manner when compared to the temporal distribution of arriving traffic. Current detection schemes are typically used to provide localized detection near the intersection. At isolated intersections, which do not have coordinated timing plans for allowing progression of platoons, timing decisions are based on the binary status of localized detectors. Therefore, when platoons are forced to stop to allow the passage of a few vehicles from a minor phase, excessive stops and delays are created at the intersection. The proposed strategy uses a detection device located several thousand feet upstream from the intersection from which information is processed to identify platoons. When these platoons are detected, the controller is manipulated using low-priority preemption to allow for the platoon to progress through the intersection unimpeded. This research presents a study in which the platoon accommodation strategy was shown to reduce both the percentage of stops and delays for vehicles in the platoon without significantly impacting any of the minor approaches. This system is designed to be a retrofit to existing control equipment.

Since the findings were based upon the simulated traffic, an extensive evaluation was conducted comparing field-observed platooning data with data obtained from CORSIM and the Robertson platoon distribution model. To compare field data with simulation and model data, a new procedure that looked at the percentage of vehicles arriving during a specified window was developed. Those quantitative numbers were summarized in easy to visualize charts. Platoon distribution charts were developed for 1) observed field data, 2) modeled CORSIM data, and 3) theoretical models. These charts, contained in the Appendix of the report, provide a rational procedure for estimating the upper bound on the arrival type used in the Highway Capacity calculations for signalized intersection and arterials (Chapters 9 and 11). In general, the observed field platooning characteristics were similar to the simulation model, but not exact. The CORSIM simulation model tended to have more overall platoon dispersion, which would likely provide slightly conservative estimates on benefits.

17. Key Words	18. Distribution Statement
Platoon, traffic signal controller, vehicle detection, algorithm, priority.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	217	

Form DOT F 1700.7 (8-69)

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

http://www.archive.org/details/reconciledplatoo00wass

TABLE OF CONTENTS

LIST OF FIGURES

Appendix Figures

LIST OF TABLES

APPENDIX TABLES

IMPLEMENTATION REPORT

Traffic signals are one of the few "active control" elements the Indiana Department of Transportation has available for regulating the flow of traffic. The department owns and maintains several thousand traffic signals through out the state and is constantly looking at how to improve their operating efficiency. This study was initiated by the Indiana ITS Program Engineer to determine if naturally occurring platoon of traffic could be identified and a traffic controller manipulated to accommodate the progression of that platoon through a traffic signal. Because of safety and public relation issues associated with debugging new control algorithms, it was not feasible to develop the platoon accommodation algorithm under live traffic conditions. Instead, a laboratory evaluation environment was proposed to develop and evaluate the algorithm. As a result of this research, we have developed several recommendations for implementing this research.

The first part of this study used the microscopic simulation program CORSIM connected to an actuated controller via a Controller Interface Device (CID) to simulate field conditions. A programmable logic controller (PLC) was introduced into the simulation and algorithms were developed for the PLC to recognize platoons. Once a platoon was recognized, a low priority transit preemption was introduced to facilitate the progression of that platoon through the system. Quantitative evaluation of the proposed algorithm on a case study intersection showed a reduction in stops and delays for the approach using the algorithm while not significantly impacting any of the other minor approaches. Since a "field hardened" PLC was used, this procedure could be directly implement on any intersection that could provide the appropriate detectors and low priority transit priority procedures.

The PLC technology used in this project to process detector inputs and implement logic necessary for triggering the low-priority preemption has direct and immediate application for a wide variety of low cost Intelligent Transportation System (ITS) initiatives. For example, the former graduate student on this project, adapted the PLC concept and wireless communication architecture to a warning sign indicating an interstate ramp was backing up on Exit 4 (SR 131) on I-65 Northbound. Early indications are that this has reduced accidents at that location. There are several other similar low cost ITS initiatives currently under considerations that could use this technology.

Although the focus of this research was the development of procedures for accommodating platoons, this project used, for the first time in Indiana, hardware-in-the-loop simulation procedures. These hardware-in-the-loop simulation procedures proved invaluable for evaluating novel (and more efficient) control schemes without subjecting motorists to the occasional "glitches" experienced when developing a new system. Further work is underway in another JTRP project to package the technology so these procedures can be used by districts to evaluate performance of arterial traffic signal control equipment. In conjunction with that JTRP study (which builds on this study), the hardware in the loop evaluation procedure was been used to retime a complicated diamond interchange down in Indianapolis at I-465 and SR 37 reducing annual delay over 32,000 veh-hours.

Finally, as a byproduct of evaluating the CORSIM platoon modeling characteristics, platoon distribution charts were developed for 1) observed field data, 2) modeled CORSIM data, and 3) theoretical models. These charts contained in the Appendix of the report provide a rational procedure for estimating the upper bound on the arrival type used in the Highway Capacity calculations for signalized intersection and arterials (Chapters 9 and 11).

CHAPTER 1 INTRODUCTION

Over the past several years, the traffic engineering profession including public, private and academic sectors have devoted many resources to advancing the state of traffic signal control algorithms. Many advancements have been made since the deployment of first generation electromechanical and vacuum tube type controllers. The advent of microprocessor based solid state controllers allow for even more features to be incorporated into these devices due to the increased available processing power.

Today a traffic signal may exist as a single isolated controller or may be part of a multi-signal traffic control system. These traffic control systems are comprised of interacting components such as signals, detectors, and a communications backbone that are arranged in a manner which effectively and efficiently coordinate traffic flow along a corridor or throughout a network [Homburger et al., 1992]. There currently are several different types of these components that result in widely varying deployment architectures.

The goals associated with deploying traffic signals have not significantly changed over the years. Traffic engineers' primary focus is to provide the control component of a road network that will allow for the safe and efficient movement of people and goods. Traffic engineers are continually refining the control strategies in an effort to better achieve these goals. The increases in motor vehicle use without proportional increases in infrastructure motivate the development of these strategies to an even greater extent.

The level of sophistication of traffic control strategies has advanced beyond the exclusive use of time-of-day programs and local detection, such as inductive loops. Today, new signal research is devoted to real-time traffic adaptive control. These systems not only operate based on local detector demand but also make control decisions based on predicted future demand. In order to make these decisions, it becomes necessary to predict the future demand. Engineers have been looking at the need for prediction since the early 1970s when the urban traffic control system (UTCS) was under development [Tarnoff, 1975]. Prediction becomes important in signal control if vehicle progression is to be maintained.

In arterial and network systems, traffic is thought of as moving groups known as platoons. Typically, signals that are located at the boundary of the system group vehicles together during the red phase and then discharge this platoon under green. Systems in which adjacent signal spacing is relatively small (less than 0.5 miles) allow for progression of the platoon by coordinating adjacent signals based on an offset from some known time reference. As the spacing between adjacent signals increases, the ability to provide progression using traditional methods becomes more difficult due to platoon dispersion and traffic sources and sinks. Therefore, when the spacing between intersections becomes large, the traffic signals are usually operated as an isolated intersection.

Traffic signal control systems at isolated intersections are typically actuated systems that use inductive loop detectors for local detection. The controller operates based on the active timing plan and the local demand near the intersection (usually within 500' of the stop bar). In this configuration, the control system is limited to a horizon of a few seconds for which control decisions can be made based on perceived demand. This limitation is believed to reduce the operational efficiency of the intersection when certain traffic patterns exist. Platoons of vehicles can exist on approaches to isolated intersections. However, unlike the traffic control systems that coordinate their cycles to traffic flow, isolated intersections do not provide for smooth platoon progression. This lack of responsiveness leads to increased vehicle delay and vehicle stops.

Although many adaptive algorithms have been developed to improve the operation of isolated intersections, few of these have undergone wide scale deployment. Possible reasons for this include excessive cost, difficulty in calibration, and the reluctance of the part of practicing engineers to implement strategies radically different from those in use. Because of this fact, this research proposes a cost-effective platoon accommodation procedure that uses existing signal system components to provide some of the benefits as those of adaptive control.

This document describes the development of a system within the constraints outlined above. Chapter 2 presents a review of the current state of the practice of traffic control algorithm development. Chapter 3 presents a new method for accommodating platoons at isolated rural intersections. This new strategy is evaluated in Chapter 4 using hardware-in-the-loop simulation. Chapter 5 presents a brief discussion on the expected benefits and costs associated with the deployment of this strategy. Chapter 6 evaluates platoon dispersion using filed data, simulation, and analytical models. Suggestions for further work is presented in Chapter 7

CHAPTER 2 CURRENT STATE OF ADAPTIVE TRAFFIC CONTROL ALGORITHMS

Modern traffic signals have evolved through several stages since the birth of the concept. The first operating traffic signals are considered to be manually operated semaphores, which were introduced in London in 1868. American James Hoge invented the first automated electric traffic signal in 1913. This device, which seems to be the origin of the standard three-color scheme used today, was first deployed in Cleveland, Ohio, in 1914. After their initial inception, the use of traffic signals spread rapidly during the late 1910's and early 1920's. The first interconnected signals were used in Salt Lake City, Utah, in 1917. A concept of a progressive signal system was first proposed in 1922. This lead to the installation of actuated signal systems in 1928 at New Haven, East Norwalk and Baltimore [Hamburger et al., 1992].

The 1960's had a very important effect on the advancement of traffic engineering technology through the introduction of computer-based traffic signal control systems [Gartner et al., 1995]. Through the use of computers, traffic engineers have made significant advances in the development of optimization and control logic. Today, there are various microprocessor based vendor products available for designing, operating, and monitoring traffic signal installations. The constant advancement of the computer industry has resulted in the availability of improved processors, which are capable of performing more operations in a smaller amount of time. The fundamental objective of traffic engineers is to develop control strategies that use available processing power to safely and efficiently move traffic.

- A properly designed traffic control system can help to reduce traffic delay, fuel consumption, driver discomfort, and air and noise pollution by efficiently using the capacity of existing streets [Linkenheld et al., 1992]. The positive effects of signal installation can be any or all of the following [Homburger et al., 1992]:
- provision for the orderly movement of traffic,
- reduction in the frequency of certain types of accidents (i.e., right angle and pedestrian),
- an increase in the traffic handling capacity of the intersection,
- means of interrupting heavy traffic to allow other traffic, both vehicular and pedestrian, to enter or cross a traffic stream,

- continual movement of traffic at a desired speed along a given route by coordination,
- economical benefits over manual control at intersections where alternate assignment of right-of-way is required, and promotion of driver confidence by assigning right-of-way.

While the points indicated above illustrate the potential positive effects that traffic signals can have, it is important to note that the deployment of these traffic signal systems can also lead to less than desirable results. Some of the possible negative effects from the installation of traffic signals are as follows [Homburger et al., 1992]:

- increase in the total intersection delay and fuel consumption, especially during off-peak periods,
- probable increase in certain types of accidents (e.g. rear-end collisions),
- unnecessary delay when improperly located which results in disrespect for this type of control, and
- cause excessive delay when improperly timed which increases driver irritation.

Two of the four mentioned possible negative impacts traffic signals can have are attributed to the improper setting and location of the installation. Therefore, it is important to indicate that traffic signals, when properly configured, can provide significant improvements to the road network. However, it is equally as important to remember that even properly configured signals do have the potential to provide some negative results.

The optimal setting of traffic signal control systems has been on the minds of traffic engineering practitioners since their initial development. This is especially true since the 1960's when computer-based controllers allowed for more complex strategies to be implemented. Although many of today's control strategies are quite complex in nature, they focus on the manipulation of only a few configuration parameters. A particular controller many have tens or hundreds of possible parameter settings, but there are only four that are considered to have the most impact on system performance [Stewart et al., 1998]. These four variables are cycle length, split, phase sequencing, and offset. Cycle length is the time required for one complete sequence of signal phases. Split is the percentage of a cycle length allocated to each of the various phases. Phase sequencing is the order in which the phases of a cycle occur. Offset is the time relationship in seconds between a defined interval portion of the coordinated phase green and a system reference point [Gordon et al., 1996].

There are primarily three broad types of signal control. These are pre-time control, actuated control, and traffic responsive or adaptive control [Stewart et al., 1998]. In pre-timed control, one of several possible predetermined signal timing plans, which were calculated off-line using historical traffic data, is selected. These plans are implemented by time-of-day, direct operator selection, or matching current volumes and occupancies with those stored with an associated timing plan [Gartner et al, 1995]. The selected plan has a fixed cycle length, slit and offset. Actuated control is similar to pre-time control in that the various parameters in the timing plan are determined in advance using historical traffic data. However, actuated control uses detectors, such as inductive loop detectors placed on the approach legs of intersections, to determine if a particular phase should start early or end late [Stewart et al., 1998]. These two strategies are also referred to as off-line operation. Adaptive or traffic responsive control strategies have no preset plans, which are computed in advance. Instead only upper and lower bounds on cycle time, green split, and offset are provided to the controller. Adaptive control logics are capable of running in either actuated or non-actuated modes.

Currently in the United States, pre-timed and actuated control are much more used than adaptive control. The current practice is to use non-actuated control plans if the arrival pattern is predictable, such as when networks are heavily congested and intersections are closely spaced. Actuated control is used when arrival patterns are less predictable, such as during light traffic flows, and when intersections are spaced farther apart [Kell and Fullerton, 1991].

Continued growth in travel demand without similar growth in new infrastructure has forced the traffic engineer to design traffic control strategies, that provide a higher level of performance without reducing safety and comfort [Head et al., 1992]. There are two primary limitations of pre-timed control strategies that have helped to motivate the development of adaptive control algorithms. The first limitation is the inability of pre-timed controllers to react to unexpected deviations from historical trends, such as diversions resulting from incidents or day-to-day random variations of the magnitude and temporal distribution of the demand peaks. The second limitation is that even for predicted traffic conditions there are a finite number of time-of-day plans that can be handled by current controllers. During periods of build-up or decay of the demand peak, the selected time-of-day plan may still not be optimal. Developers of adaptive control strategies hope to capitalize on these inefficiencies inherent in off-line control to improve intersection performance through the use of more comprehensive algorithms [Stewart et al, 1998].

In the 1970's the Federal Highway Administration (FHWA) sponsored a project that was directed toward developing and testing a variety of advanced network control concepts and strategies. This project became known as the Urban Traffic Control System (UTCS) project. This project, which lasted nearly a decade, focused on control strategies that were broken into three groups referred to as generations.

First generation control (1-GC) consists of pre-stored signal timing plans that are calculated off-line, based on historical traffic data. This generation of control, which is essentially the same as the pre-timed control strategy discussed earlier, selects a particular timing plan by time-of-day, by direct operator selection or by matching the current traffic conditions with those stored in a library. The frequency of updating in the later mode of selection is 15 minutes. A modification of the last plan selection method mentioned above is spin-off of 1-GC control. It consists of the system automatically selecting a timing plan when conditions warrant its implementation. This strategy became known as 1.5 generation control (1.5-GC) [Gartner et al., 1995; McShane and Roess, 1990].

Second generation control (2-GC) consisted of an on-line strategy that computes and implements in real-time timing plans based on surveillance data and predicted values. Plans are optimized once every five minutes. However, to avoid transition disturbances from one implemented plan to the next, a timing plan is updated no more than once per 10 minute period [Gartner et al.,1995; McShane and Roess, 1990].

Third generation control (3-GC) is a strategy which uses on-line optimization to update the cycle lengths, splits, and offsets in real time. The sampling periods for these updates are short with a duration of 60-120 seconds [McShane and Roess, 1990]. 3-GC is similar to 2-GC except that the period after which timing plans are revised is shortened, and cycle length is allowed to vary among the signals, as well as the same signal, during the control period [Gartner et al., 1995].

The results of the UTCS experiments are mixed. It was found that the strategies used for 1-GC and 2-GC control worked. However, 3-GC control did not perform as intended [Stephanedes et al., 1981]. 1-GC control strategies that were implemented, typically used fixed-time plans and sometimes allowed plan selection through the time-of-day option. The 1.5-GC and 2-GC systems that were implemented allowed on-line selection of timing plans responding to time-of-day or detected traffic conditions and, in some cases, timing plans were generated online Using smoothed traffic flows [Head et al, 1992]. After the fact, a closer examination of the UTCS 3-GC control revealed that the goals were not met for this particular generation. This was not because their rationale, which was that traffic responsive control should provide benefits over fixed time control, was wrong, but because the models and procedures failed to deliver the desired results [Gartner et al., 1995].

Adaptive Control

In the traffic engineering community, there has been a general consensus that increasing responsiveness contributes to improved traffic performance. Therefore, the concept is that on-line traffic control strategies should be capable of providing better results than strategies in which off-line methods are used. Due to the inadequacies of 3-GC control in the UTCS experiments of the 1970's, it became obvious in the early 1980's that new strategies needed to be developed for adaptive control [Gartner et al., 1995].

Adaptive control relies on very short-term advance vehicle arrival information in an attempt to achieve real-time optimization of signal operations. To estimate flow conditions, it is necessary to place detectors several hundred feet upstream on the approach legs of an intersection in order to provide advanced vehicle arrival information. Using detectors in this manner does provide advanced information, however, the time frame in which controller has to respond before the vehicles arrive at the intersection is usually limited to less than 120 seconds. To overcome the limitations of this small timeline of advanced information, some strategies have been developed which predict vehicle arrival data to supplement the detector data. The downside of this approach is that it tends to introduce errors in the information used to formulate the timing plans. The differences between the estimated and actual flows can be caused by several factors including lane changes, variations in speed, traffic sources/sinks, and more [Lin, 1988].

Adaptive control has limitations due to its need to rely on estimated flow conditions, which always differ from the actual conditions. It is important to note that in some cases the discrepancies can offset the benefits of having an elaborate control logic [Lin, 1988]. The effectiveness of the control system response is entirely dependent on the quality of the prediction model [Gartner, 1995]. Therefore, the implementation of an adaptive optimization logic in signal control does not always result in improved signal operations [Lin, 1988]. When traffic is highly peaked, or where the average traffic volume is high, the best results can often be achieved through the use of a simple time-of-day strategy [Stewart et al., 1998].

Responsive methods can provide substantial benefits compared with non-responsive methods, but if they are not properly applied, they are likely to degrade performance [Gartner et al., 1995]. Regardless of the level of sophistication of an adaptive control methodology, optimal signal operations can never be achieved in a real life situation. In light of the drawback of the discrepancies between the estimated and actual flow characteristics, it is worth investigating whether strenuous decision-making processes can be replaced by simple decision rules for adaptive control. Often the term optimization is used casually to represent a process of searching for a better course of action. This search for a better course of action can be based on a very elaborate procedure or on a simple, relatively straightforward procedure [Lin, 1988].

Significant advances towards the development of an effective demand responsive traffic control system were achieved during the 1980's through the introduction of two control strategies. These two strategies were Split, Cycle, Offset Optimization Technique (SCOOT) in the United Kingdom [Hurt et al., 1981] and by Sydney Control Algorithm for Traffic Signals (SCATS) in Australia [Lowrie, 1992]. SCATS is considered to be a variant of the UTCS 1.5-GC traffic response variant. SCOOT is considered by most to be a UTCS-3-GC, although some authors put it into the 2-GC category [Gartner et al., 1995].

SCATS consists of a hierarchical two-layer control strategy. The local level, which is at the bottom of the hierarchy, consists of sets of intersections grouped together at the discretion of a traffic engineer. These subsystems make independent decisions regarding timing parameters involving cycle, offset and phase lengths, which are based on the degree of saturation in the subsystem. As the timing parameters of adjacent subsystems become equal or nearly equal, a regional computer in the next higher level of the hierarchy "marries" the systems into one contiguous system. Similarly, the regional computer relinquishes control of the subsystems when their desired control parameters become different. In this strategy, the timing plans are incrementally adjusted to varying traffic conditions [Head et al., 1992].

SCOOT is a more successful implementation of 3-GC type control than the strategies developed under the UTCS experiment. At the heart of the SCOOT system is a variant of the TRANSYT optimization model that runs in the background called the SCOOT Kernel. Since 3-GC control is an on-line strategy, the suggested timing parameters generated by the SCOOT Kernel are immediately communicated to the controller. The controller then uses these suggestions in combination with observed changing traffic demands to make incremental adjustments to the cycle lengths, phase lengths, and offsets for the current and next cycles [Head et al., 1992].

The key factor of SCATS and SCOOT is that they do generate their timing plans on-line [Gartner et al, 1995]. SCOOT and SCATS view the control problem in a "macro" setting in which the signal control parameters are optimized on a macroscopic traffic flow model [Sen and Head, 1997]. There are, however, authors who feel that these systems do have some drawbacks. The argument is that these systems are not proactive and, therefore, cannot adequately accommodate significant fluctuations in traffic flows. A proactive system would be one which attempts to predict future demand on the network and to accommodate this demand as it evolves [Head et al., 1992]. The proliferation of computer technology and the deployment of traffic management systems have led to the focus on the development of decentralized real-time control systems which would provide this proactive functionality [Sen and Head, 1997].

Optimized Policies for Adaptive Control (OPAC)

In 1983, Gartner introduced the concept of a new adaptive control strategy called Optimized Policies for Adaptive Control (OPAC). Gartner was the first to document the need for shifting away from models that optimize cycle time, splits and offsets. His model involved the determination of when to switch between successive phases based on actual arrival data at the intersection. It was felt that this model would be more relevant for real-time traffic control [Sen and Head, 1997].

Gartner stated that predictions had problems due to their deficiency in providing good temporally distributed results. He felt that using actual flow data instead of using average volumes, which had been the state of practice at the time, could mitigate this problem. The method proposed for obtaining actual flow data was to place detectors on the approach links upstream from the intersection and use the actual flow data from these detectors to make predictions of vehicle arrivals at the intersection [Gartner, 1981]. Therefore, OPAC allows for proactive control based on predicted traffic flows [Head, 1992].

OPAC has gone through several different development efforts. There have been several versions of the algorithm with varying levels of complexity that have been evaluated. The earliest version was designed for an isolated two phase signal. The most recent version is for controlling a system of several intersections with 8-Phase controllers.

OPAC was originally designed using dynamic programming (DP) to optimize the signal control problem after it was divided into multiple stages. DP is a mathematical optimization technique used in configuring multi-stage decision processes. The decision control problem is broken into subproblems, which are individually optimized. This approach leads to a more efficient computational process than attempting to optimize the problem in one simultaneous effort [Gartner, 1983].

In the first version called OPAC-1, DP is applied based on the assumption that traffic arrivals are known for a finite amount of time, referred to as the horizon. This horizon is divided into several stages, each having a uniform time interval. Each stage has three inputs including the input state, vehicle arrival data, and decision input. Each stage also has two outputs including economic return (cost) and output state. The input and output states of a particular stage include the state of the signal (red or green) and the lengths of the queues on all approaches at the beginning and ending of the stage, respectively. The vehicle arrival data is obtained from the upstream detectors. The decision variable indicates whether the current phase is to be terminated or extended. The return cost output is the performance index for the intersection measured in total delay time. The DP optimizes the setting to minimize this value [Gartner, 1983].

DP optimization is accomplished by beginning with the last time interval and moving forward to the first. Once the DP reaches the beginning stage, it has determined the optimal phase switching points in the planning horizon. In order for the DP approach to function, it was mentioned that the arrival data was known for the entire planning horizon. In practice, this horizon may be several cycles in length. The surveillance system needed to provide this information would need to be very elaborate and most likely very costly. Additionally, this DP framework requires “extensive computational effort.” Since the program is optimized in a backwards time sequence, it becomes impossible to implement the DP on-line in real-time, because the time required to compute the optimal settings precludes the opportunity of updating the input data or correcting the already established control decisions on which preceding stages are based [Gartner, 1983].

The limitations indicated above led Gartner to develop a simplified optimization procedure that could be implemented in real-time on-line, but would have the results comparable in quality to those obtained using DP. This concept led to the development of OPAC-2. Like OPAC-1, this strategy consists of breaking the future planning horizon into stages with each having a common length in the range of 50-100 seconds. Each stage is further subdivided into smaller time intervals. These intervals are then sequentially optimized in a forward direction. The optimization logic computes a performance index value for each approach in terms of vehicle delay. Using an optimal sequential constraint search (OSCO), total delay is calculated for all possible phase switching options, under the constraint that each stage has to have at least one, but no more than three, phase switches. The switching option, which produces the lowest total delay values, determines the optimal solution. In comparison with the OPAC-1 results, OPAC-2 was found to derive solutions with performance indexes within 10% of those generated with DP [Gartner, 1983].

Although OPAC-2 seemed to provide results which were capable of being derived in a timely enough manner to be implemented in real-time, this procedure still has a significant drawback. As was the case with OPAC-1, OPAC-2 relies on vehicle arrival information for the entire planning stage. Remembering that a planning stage is 50-100 seconds in length, indicates that arrival data is needed for a period greater than that which can be provided using current detection schemes. To overcome this limitation, Gartner used a rolling horizon approach that had been used for years by operations research analysts in production inventory control [Gartner, 1983].

The rolling horizon approach to OPAC became known as ROPAC. The current stage, which was the time period being optimized, was divided into k intervals for which arrival information was needed. Using arrival data from upstream detectors, it is possible to know the first r intervals at the beginning or "head" of the stage. The remaining intervals (k-r) are known as the tail of the stage. The arrival data for these intervals in the tail are obtained from a model. The stage is optimized for all intervals but is only implemented for the first r intervals at the head of the stage. Once these stages have been implemented, the projection horizon is advanced by r intervals creating a new stage to be optimized. A graphical representation of this process can be seen in Figure 1 [Gartner, 1983].

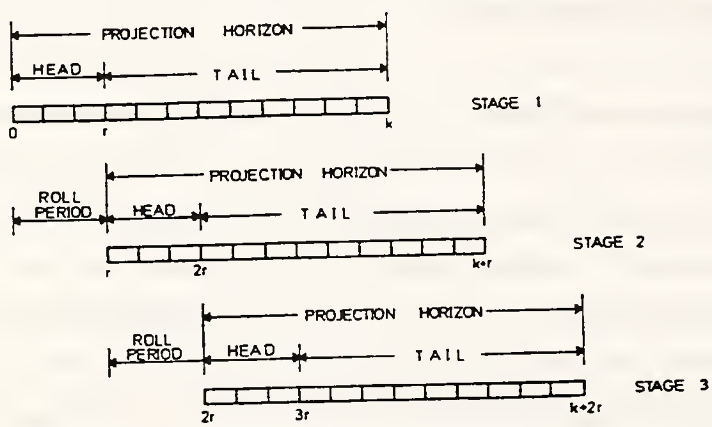


Figure 1 Rolling Horizon Approach in ROPAC [Gartner, 1983]

There have been two types of models used for predicting the tail portion of the stage in the ROPAC approach. The first model consists of a variable tail, where the arrivals are projected. The second model consists of a fixed tail, where the tail consists of a fixed flow that is equal to the average flow rate of the first r intervals. The variable tail model was used only for testing the rolling horizon approach in comparison to previous experiments. The fixed tail model, the one which was selected for ROPAC, is more practical to implement [Gartner, 1983]. ROPAC was converted to an on-line algorithm that can be implemented in real-time called OPAC-RT version 1.0. This version, which was developed for a simple two-phase fully actuated isolated intersection, was found to improve the performance based on delay and percent stops. In situations where the traffic flow was light, it was found that OPAC operated with nearly the same efficiency as that of actuated control. As the volumes increased, however, the performance of OPAC-RT version 1.0 improved over that of actuated control [Gartner et al, 1991].

OPAC-RT version 2.0 was the next strategy that was implemented and consisted of the control of an eight-phase intersection. In this version of OPAC, only the through phases are controlled by the system. The minor phases, which are primarily the left turn phases, are considered by OPAC to be part of the green time allocated to the corresponding approach's through phase. Termination of these minor phases is determined by the gap/out or max/out functionality of the actuated controller. The results from the deployment and evaluation of this version of OPAC showed both a reduction in total delay and percent stops [Gartner et al., 1991].

The latest version of the OPAC algorithm is version 3.0. This version has several enhancements based on the knowledge from previous development and evaluation efforts. These added features included optimization of all eight phases, the ability to skip phases, and an advanced algorithm for providing coordination for adjacent signals. Therefore, OPAC-RT is now able to address signal systems for a corridor rather than for just an isolated signal. This strategy has been deployed and the results showed promise for future implementation. The OPAC-RT version 3.0 showed its best performance during oversaturated conditions and changing demand conditions for an arterial. Additionally, version 3.0 was evaluated for an isolated intersection under light traffic conditions and was found to reduce delay without any significant impact on percent stops [Andrews et al., 1997].

Real-Time, Hierarchial, Optimized, Distributed and Effective System (RHODES)

In 1992, Head et al. presented an adaptive control strategy entitled RHODES. This algorithm consists of a distributed hierarchical framework that operates in real-time. The basic premise of RHODES is to respond to the natural stochastic variation in traffic flow. It is felt that using the knowledge of this variation and proactively responding to it will create opportunities, which even if small in magnitude, will cumulatively provide a substantial total improvement in intersection or corridor performance.

The formulation of RHODES is based around the decomposition of the traffic control problem. Additionally, RHODES is developed to proactively respond to the variations in traffic flow through the use of predictive models [Head et al., 1998]. After the introduction of

OPAC, adaptive control strategies began to incorporate dynamic programming in their framework [Gartner et al., 1983]. The motivation behind the development of RHODES is similar to that of OPAC. It formulates a strategy that will operate under a variety of traffic conditions and will make phase switching decisions based on vehicle arrival data for an intersection. However, unlike OPAC, RHODES is entirely based on dynamic programming [Sen and Head, 1997].

Through the use of dynamic programming RHODES is an efficient and general procedure. RHODES allows for phase sequencing to be optimized in addition to the various timing parameters (cycle, split, offset, etc). This allows for more flexibility in making control decisions, thereby, allowing this adaptive control strategy to have a greater potential impact on intersection performance. RHODES has the ability to use a variety of performance measures including delays, queues and stops [Sen and Head, 1997].

As was indicated earlier, the design of RHODES is based on the separation of the traffic control problem into sub-problems. These sub-problems involve making decisions on various aspects of the control problem, which are defined over different time and distance horizons. These sub-problems or levels from the top down include: network loading problem, network flow control problem and intersection control problem. The relationship of these levels in the hierarchy is depicted in Figure 2.

Level One control at the top of the hierarchy is the network loading problem. This level provides the estimates of the link loads as well as the prediction of the trends in the change of loads from real-time data [Head et al., 1992]. These two elements result in providing insight for the general travel demand over long periods of time such as one hour. RHODES proactively uses this information to predict future platoon sizes near the boundaries of the system [Head et al, 1998].

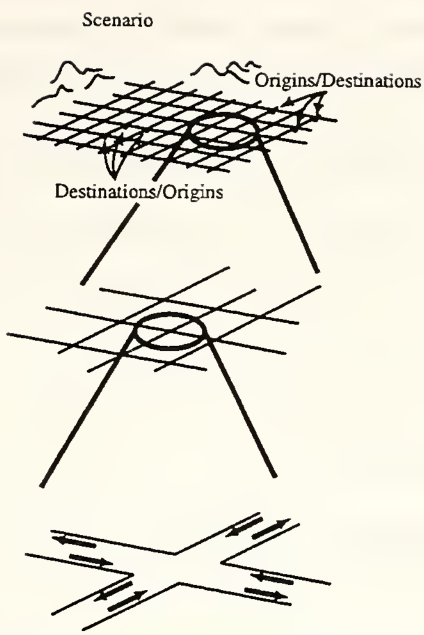


Figure 2 Hierarchy Framework of RHODES [Head et al, 1992].

The middle level, Level Two, consists of the network flow problem. This level involves making high-level signal timing decisions to optimize the overall flow of vehicles in the network [Head et al., 1992]. The decisions in this level are made every 200-300 seconds. This level is broken into two parts. The first part involves the prediction of platoons in the network and is known as the platoon prediction logic. These predictions are made using the information in Level One in addition to actual detector data. The second part of this level involves the network optimization logic, and its purpose is to optimize the signal timings in the network to allow for the most efficient movement of these platoons. RHODES uses a model called REALBAND created by Dell 'Olmo and Mirchandani to perform this task [Dell' Olmo and Mirchandani, 1995]. The results from this network optimization logic are used as constraints for the decision made in the next level [Head et al., 1998].

The lowest level of the control strategy is that of the intersection control problem. This level is responsible for making the final second-by-second decisions regarding traffic signal operation. As is the case in the previous level, this level is divided into two parts. One of these is the Link Flow Prediction Logic. This logic uses data from upstream detectors, such as those near the stop bar of an upstream intersection, as well as the target timings of the upstream signal to estimate vehicle arrivals at the intersection being optimized. Figure 3 shows four time space diagrams depicting the possible vehicle trajectories from d_i to d_A based on the status of the signal at B and the traffic detected at d_i. The predictions made by this logic increase the horizon of information used for making control decisions from a few seconds, as is the case for actuated control, to well over 30 seconds. The second part of this lowest level is the Intersection Control Logic. In 1997, Sen and Head developed a model called Controlled Optimization of Phases (COP) to solve the problem of finding optimal phase sequences and their associated duration. COP uses the information from the network flow problem, in addition to the results from link prediction logic, to make the determination as to whether the current phase should be terminated or

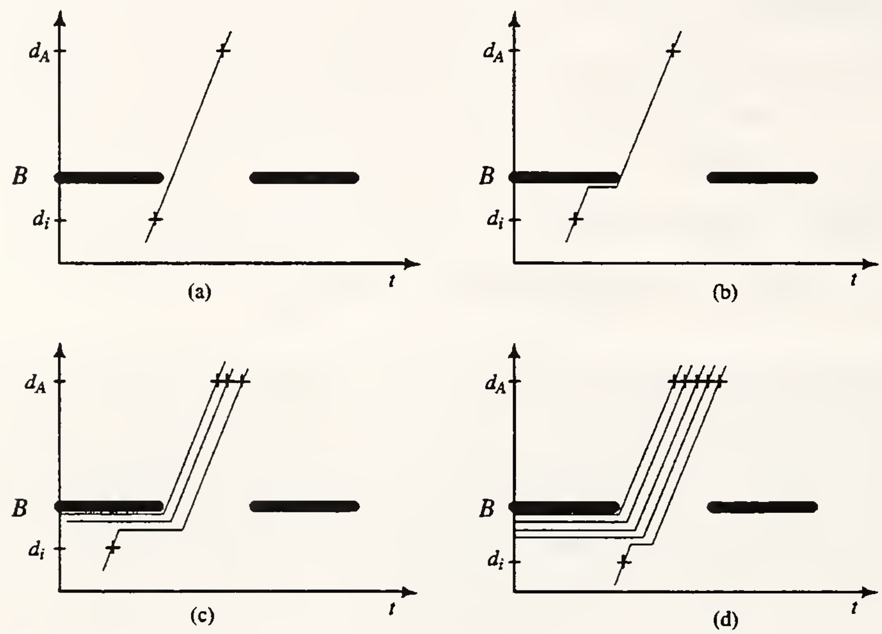


Figure 3 RHODES Link Prediction Logic [Head et al., 1998]

extended. Additionally, COP generates target phase timings which are used by adjacent intersections in their link prediction logic [Head et al., 1998].

Rhodes is currently being evaluated in a laboratory environment using simulation but is scheduled for limited field deployment in Arizona in the Fall of 1998. In the simulations of the arterial systems and diamond interchange that have been modeled, RHODES resulted in decreasing traffic delay [Head et al, 1998]. Further evaluations of this model under a variety of traffic conditions are needed, however, the current knowledge regarding the strategy's performance appears promising.

The preceding discussion has introduced a variety of strategies for providing more efficient signal control. It has been found that each of these methods perform different under certain types of conditions. When the traffic network is lightly to moderately loaded, it may be more appropriate to control traffic as freely as possible. In this strategy the focus is to accommodate individual vehicles, thereby, reducing stops. When the traffic network is heavily loaded, it may be more desirable to control traffic for improved network performance. In the situation timing decisions are based on accommodating network flows and not individual vehicles [Head et al., 1992].

Therefore, different algorithms will be needed for different situations. In some cases the use of upstream detectors will be sufficient to provide the desired level of performance. In other cases, more complex prediction algorithms may be required [Head, 1995]. Therefore, a major contribution of the new technologies will be to enable identification of traffic characteristics in a network and select the most appropriate strategy for the existing conditions [Gartner et al., 1995].

In November 1991 the Federal Highway Administration (FHWA) issued a solicitation for the envelopment and evaluation of a real-time, traffic adaptive signal control system referred to as RT-TRACS [FHWA, 1991]. RT-TRACS is designed to be capable of adapting to specific traffic conditions as they occur by selecting the appropriate optimal control strategy from a library of real-time control strategies. It is felt that providing a menu of possible strategies will provide improved performance over the use of one particular strategy [Gartner et al., 1995].

While the concept of RT-TRACS may provide improved performance, it comes at a significant price. The architecture of RT-TRACS currently being tested uses a 2070-Type controller. The concept behind these units are that the controller and software are broken into two distinct elements that are purchased separately [Gordon et al., 1996]. These units cost approximately $3,500 each without any software. Since the software used for RT-TRACS type algorithms, such as OPAC and RHODES, for the most part are still under development, it becomes expensive to implement this type of software because system integration costs are substantial in setting the system. It is not unreasonable to expect that the deployment of an RT-TRACS type algorithm at a single intersection to cost at least $10,000.

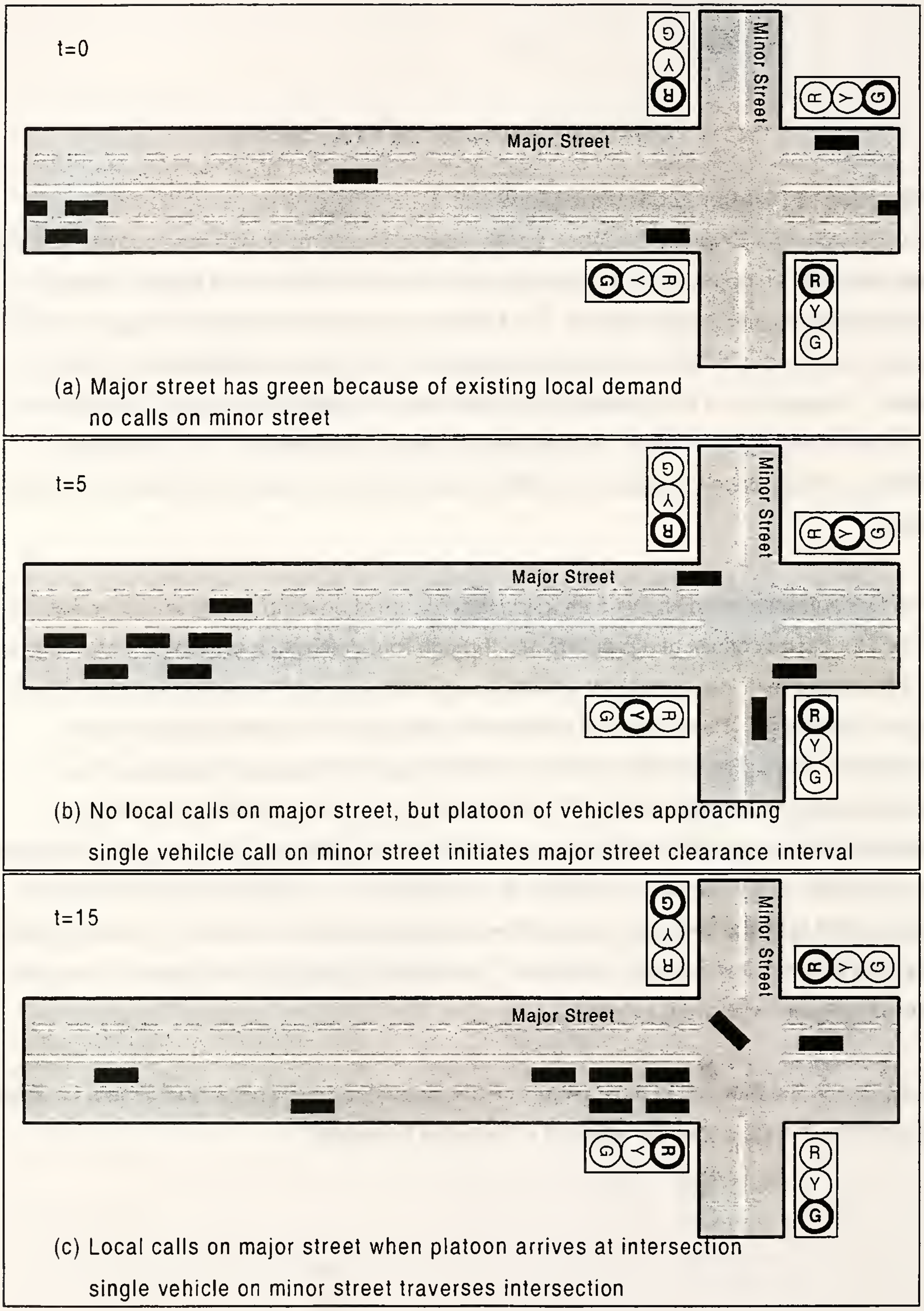
CHAPTER 3 PROBLEM STATEMENT

Objective of Platoon Accommodations

Dan Shamo, ITS Program Engineer, for the Indiana Department of Transportation (INDOT) has identified an opportunity in improving the operational efficiency of isolated signalized intersections by detecting platoons. It is felt that current control strategies may not allocate green time in an optimal manner when compared to the temporal distribution of arriving traffic. An example of this inefficiency is described and depicted in Figure 4. As can be seen in Figure 4, the actuated traffic signal controller using local detection did not provide for optimal control, since the platoon of vehicles was stopped for the one vehicle on the side street.

The example illustrated shows a situation that occurs often at rural isolated intersections. These locations consist of a predominate through route, usually a state or US highway, that is intersected by a low to medium volume road, which has met the warrants for a traffic signal installation. These types of installations consist of either semi-actuated or fully actuated control. For actuated control, inductive loop detectors are installed on the approach legs of the intersection. The locations of these loop detectors at isolated intersections are typically within a range of 500 feet from the stop bar. In cases where the running speed on a particular approach is 55 miles per hour (MPH) and the detector set back is 500 feet, the vehicles' arrival at the intersection stop bar is within 6.5 seconds after the time in which it was initially detected. Therefore, the controller only has a 6.5-second horizon to plan for arriving vehicles.

Considering the fact that in most situations the clearance time (yellow and all red) is at least 5 seconds, it is clear that the ability of a controller to respond



(a) Major street has green because of existing local demand
no calls on minor street

(b) No local calls on major street, but platoon of vehicles approaching
single vehilcle call on minor street initiates major street clearance interval

(c) Local calls on major street when platoon arrives at intersection
single vehicle on minor street traverses intersection

Figure 4 Example of current control inefficiency quickly to arriving traffic is significantly limited by the upstream detector placement. Current controllers are further limited because of their inability to quantify the level of demand detected on the various approaches. For example, an actuated controller cannot distinguish between a single call on a minor road from several calls on a major road. If flows are high on the major road and low on the minor road, the actuated controller has the potential to cause excessive delay to the major street. This delay occurs because it assigns the same priority to the single vehicle on the minor street as it assigns to the many vehicles on the major street [Gartner et al., 1991].

The fact that current control strategies for isolated intersections have significant limitations on their ability to adapt to arriving traffic is known. Due to the example above and other inefficiencies, which have been observed, there have been several attempts to develop a control methodology that will improve the operational efficiency of these intersections. Some of the strategies include:

- Modernized Optimized Vehicle Actuation Strategy [Vincent and Young, 1986],
- Optimization Policies for Adaptive Control (OPAC) [Gartner, 1983],
- Traffic Optimization Logic [Bang, 1996],
- Stepwise Adjustment of Signal Timing Logic [Lin et al., 1987],
- Split, Cycle and Offset Optimization Technique (SCOOT) [Lowrie, 1992],
- Knowledge Based Expert System Logic [Linkeheld et al., 1992], and others.

There have been a great deal of resources devoted to the development of these strategies. Adaptive control has the potential to provide improved control at isolated intersections [Lin, 1988], but there has yet to be one strategy which has shown significant potential for wide scale deployment. The reasons for this could be due to excessive cost, calibration difficulty, or the reluctance on the part of practicing traffic engineers to deploy strategies radically different from those currently in use.

The focus of this research effort was to develop a control methodology that will improve the operation of isolated signalized intersections in Indiana by addressing the inefficiency described and illustrated in Figure 4. The basic concept of the research is that groups of vehicles traveling together, referred to as platoons, on the major route should be given preferential treatment by the signal. It is desired that this preferential treatment will result in the platoon being able to traverse the intersection unimpeded by a red signal indication. In other words, this control strategy is developed for platoon accommodation at isolated intersections. Possible benefits of this system are a reduction in percent stops, reduction in environmental emissions, and reduction in total delay.

The development of this platoon accommodation strategy is done under some constraints. Perhaps the most important constraint that greatly impacts its chance of being deployed is that this system is to be an economically viable solution. Secondly, this strategy should use existing equipment to the maximum extent possible. The reason for this is to help keep costs low, but perhaps even more importantly, to keep with the same familiar equipment currently in use. The deployment of a radically different strategy could hinder deployment and maintenance efforts. Other constraints are that any additional equipment used must be rugged enough to operate under the harsh Indiana environment. The integrity of existing safety features must be maintained, and a straight forward set of guidelines can be created to assist the traffic engineer and technicians in deploying and maintaining the system.
To simplify the description of the developed system the problem will be addressed in three parts. These parts are as follows:

- What is a platoon and how can it be detected?
- If a platoon is known to exist, how can the controller be manipulated to accommodate it?
- How can the above be accomplished within the existing framework that exists at these locations?

The remainder of this chapter will focus on the answers to these three and related questions.

Platoon Identification

As was indicated earlier, a platoon is nothing more that a group of closely spaced vehicles traveling together along a roadway segment. In 1998, Head et al. described a platoon in terms of detector data as “a flow density above a pre-specified level for some length of time.” The two key points in the definition are density and length of time. Density is defined as the number of vehicles in a specified length of roadway. Measurement of actual density along a roadway segment in real-time would require an enormous amount of detection equipment and would be cost prohibitive. Flow density differs from density in that it is calculated as a spot observation using data from a traffic detection device. In addition to the flow density being above some prescribed threshold, it must exceed this threshold for some period of time for a platoon to exist.

Based on the definition above, it became necessary to develop a platoon detection algorithm that uses standard detection outputs as inputs for the model. Although there are several detection technologies available today, inductive loop detectors are by far the most common. A typical traffic signal controller (see Figure 5) uses the outputs from loop detectors to monitor traffic on the approaches to the intersection.

Loop detectors use an amplifier connected to a loop of wire placed in the roadway. The amplifier sends an electric current through the wire loop resulting in the formation of an electric field in the vicinity of the loop. When a vehicle or any other large metal object enters the magnetic field of the loop, it changes the inductance in the loop circuit. The amplifier observes this change in inductance and therefore knows that a vehicle is present in the location of the loop.

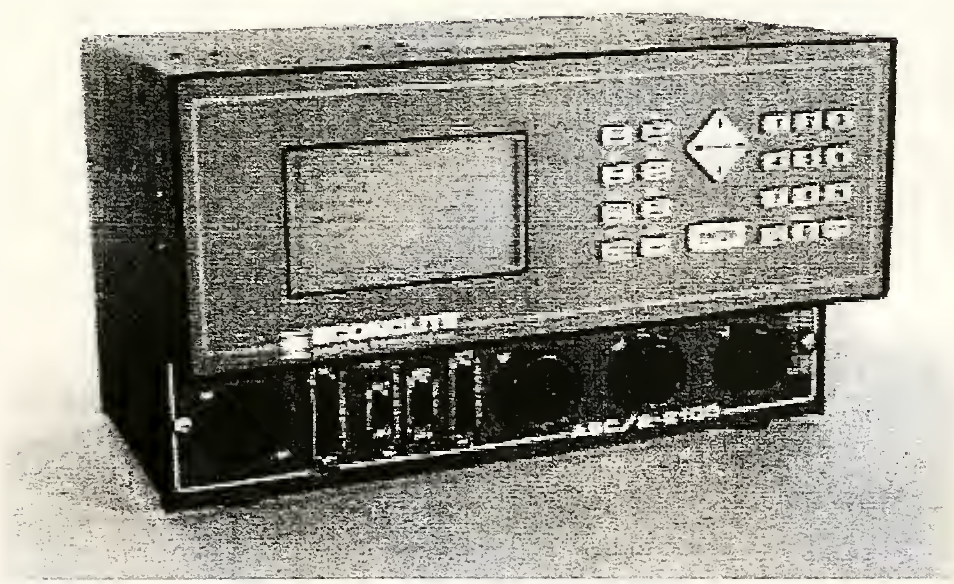


Figure 5 Typical NEMA Solid State Controller [Econolite, 1998]

The amplifier communicates the status of the loop on another circuit to the traffic signal controller. This circuit operates on 24-volts DC as do all the inputs and outputs to a traffic signal controller. When there are no vehicles present, the amplifier allows the 24-volt current to pass all the way through to the controller. Once the amplifier detects a vehicle by the change in inductance, it shunts the 24-volt circuit to ground. Therefore, if the controller observes 0-volts on a channel connected to a loop detector, it knows that there is a vehicle present on the loop, and if it observes 24-volts in the channel, it knows that there are no vehicles present. Figure 6 depicts the two states of a loop detector system. It is important to note that the loop detectors can operate in one of two modes. In presence mode, loop detector amplifier grounds the 24-volt circuit until the vehicle leaves the magnetic field. Pulse mode consists of the 24-volt circuit being grounded for approximately 110 milliseconds regardless of how long a vehicle remains in the magnetic field [NEMA, 1992].

Based on the above discussion, it is important to note that the controller operates based on the combination of various binary inputs and the values in the controller's active timing plan. These binary inputs consist of 24-volt DC circuits, which have a logic state indicated by either 0 or 24-volts. Many of the advanced detection technologies have the ability to emulate the loop by providing a 24-volt DC circuit as an available output option. Because of these facts, it is important that the developed control strategy operates with this established standard.

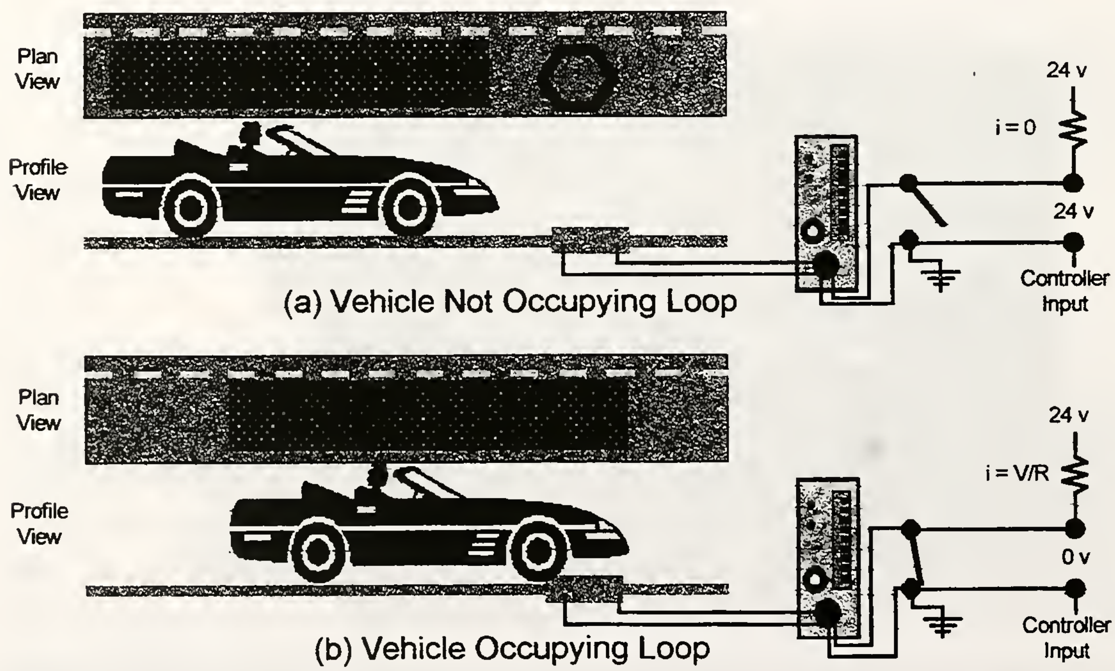


Figure 6 Loop Detector Outputs Based on Vehicle Location

Current controllers used in Indiana and other parts of the United States do not have the ability to detect platoons from binary information obtained from detection devices. The controllers can only distinguish as to whether a vehicle is currently present on a detector. As was mentioned at the beginning of chapter, actuated controllers do not provide different priority for a single call or several calls. Therefore, we need to add some additional logic to the current equipment to allow for the controller to favor the platoon, which is to be serviced. To perform this function, it is necessary to process the binary detector data to identify platoons in the traffic stream.

Loop detectors and other detection devices, which can emulate loop detector outputs, operate by making spot observations at a particular location. It is therefore desired that a platoon, which occupies a length of roadway, be detected by spot observations. If a detector is operated in pulse mode, it is possible to record the arrival of each vehicle as a specified point in time (t_i). Once the arrival times of consecutive vehicles are known, the vehicle headways (h_i), which is the time between successive arrivals, can be easily calculated. If this process is repeated for n consecutive vehicles, n-1 headway values can be calculated. If these n-1 headway values are then averaged, it is possible to estimate the average density for the n vehicles if an average speed for the n vehicles is assumed.

Equation 3-1(a) shows the equation used in basic traffic theory that relates three characteristics found in any traffic flow problem. Equation 3-1(a) can be rearranged to solve for density as shown in Equation 3-1(b).

$$q = \overline{u_s} k \qquad \text{Equation 3-1(a)}$$

$$k = \frac{q}{\overline{u_s}} \qquad \text{Equation 3-1(b)}$$

Where q = Vehicle Flow Rate (vehicles/hour)

$\overline{u_s}$ = Space Mean Speed (miles/hour)

k = Vehicle Density (vehicles/mile)

In this case vehicle density is defined as vehicle flow rate divided by the space mean speed of the vehicles within a specified length of roadway. This equation becomes difficult to apply in the practice because of the difficulty in measuring space mean speed.

Space mean speed is the average speed of all vehicles within a specified length of roadway at a single point in time. Because loop detectors and other traffic detection devices make spot observations over a period of time, it becomes necessary to approximate space mean speed by time mean speed as shown in Equation 3-2.

$$k \approx \frac{q}{\overline{u_t}} \qquad \text{Equation 3-2}$$

where q = Vehicle Flow Rate (vehicles/hour)

$\overline{u_t}$ = Time Mean Speed (miles/hour)

k = Vehicle Density (vehicles/mile)

This density value in Equation 3-2 can be represented as a measurement of the relative spacing of vehicles along a roadway segment. If a platoon can be defined as n vehicles in a specified length of roadway, it becomes possible to compare this value to that of the calculated average density and therefore determine the existence of a platoon. Flow rate can be defined in terms of average headway as shown in Equation 3-3.

$$q = \frac{3600}{\overline{h}} \qquad \text{Equation 3-3}$$

where q = Vehicle Flow Rate (vehicles/mile)

$\overline{h}$ = Average Headway (Seconds/Vehicle)

This relationship can be substituted into Equation 3-2 as shown in Equation 3-4.

$$d \approx \frac{3600}{\overline{h} \times \overline{u_t}} \qquad \text{Equation 3-4}$$

where d = Average Density (vehicles/mile)

$\overline{h}$ = Average Headway (seconds/vehicle)

$\overline{u_t}$ = Average Speed (miles/hour)

The time mean speed is assumed fixed. Therefore from Equation 3-4 density is inversely proportional to the average headway of the n vehicles. Therefore, it is possible to use the average headway alone as a measure of the relative spacing of n vehicles. Furthermore when n, which is the minimum number of vehicles needed for the existence of a platoon, is known, the average headway is directly related to the sum of the n-1 headway values for the n vehicles considered. This value is referred to as the cumulative headway value (H). Since the cumulative headway value for the n vehicles is equal to the headway between the first and n[th] vehicle, a platoon can be defined as the passage of n vehicles past a specific point in a specified period of time, referred to as the critical time (T). In other words, a platoon exists if the cumulative headway value for n vehicles is less than the critical time. This decision rule is shown in Figure 7.

While the above definition of a platoon is fairly simple to understand and calculate, it is important to note that there was a major assumption made in the process. This assumption was that an average time mean speed was selected for all the vehicles instead of using space mean speed. The potential impacts of this assumption will be discussed later in this chapter.

If $H = \sum_{i=0}^{n-1} h_i \geq T$, then a platoon does not exist.

Where n = the minimum number of vehicles in a platoon

h_i = the headway value between vehicle n_i and n_{i+1}

H = the cumulative headway value for the n vehicles

T = the critical time for which platoon existence is determined

Figure 7 Decision Rule for the Existence of a Platoon

The establishment of a methodology to identify platoons using spot observed data led to the development of a process that would, perform this task in real-time using real detector outputs. Current NEMA signal controllers do not provide any means of executing this task, therefore, additional equipment would need to be selected. This device would need to be able to process discrete detector outputs to identify platoons and then trigger the control process involved in the accommodation of this platoon at the intersection.

The device that has been selected and developed to be the platoon detector is known as a programmable logic controller (PLC). A PLC, shown in Figure 8, consists of an assembly of solid state digital logic elements designed to make logical decisions and provide outputs based on these decisions. A PLC operates on sequential instructions programmed in relay ladder logic. A PLC can perform logic functions previously executed by a series of electromechanical relays wired together. However, the PLC offers several advantages over the traditional relay type of control. Some of these advantages include:

- logic configurations which can be easily changed without having to rewire individual elements,
- solid-state reliability,
- lower power consumption, and
- ease of expansion.

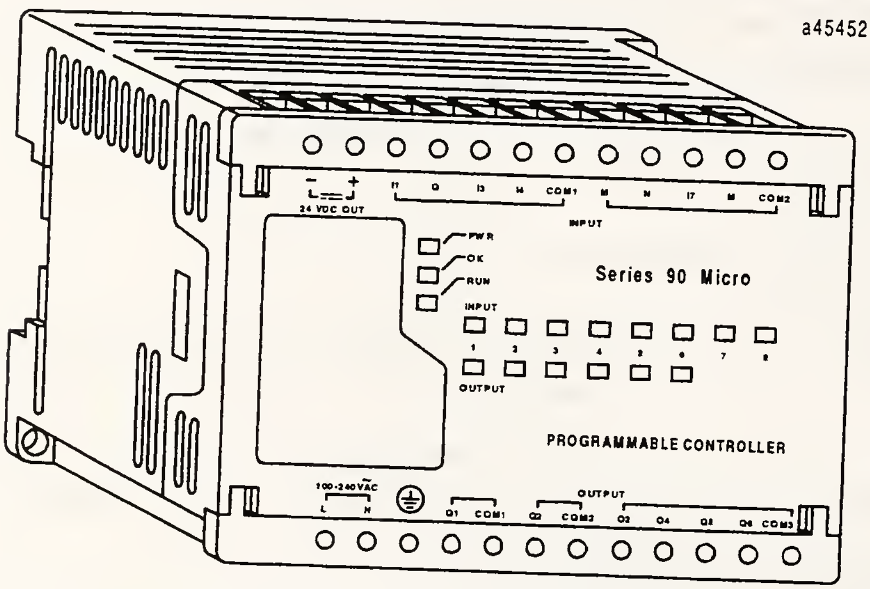


Figure 8 Programmable Logic Controller [GE Fanac, 1997]

A PLC consists of three parts. The central processor unit (CPU) contains the micro-processor that controls the logic gate circuits, converter, timers, and other functions. The I/O modules consist of the interface between the PLC and connected equipment. The final part of the PLC is the programming device, which is external to the PLC, and connects to the PLC's serial port. The programming device can be a personal computer or similar device which facilitates the development of the logic programs used by the CPU [Petruzella, 1989]. Figure 9 shows the configuration of a PLC connected to a personal computer for programming.

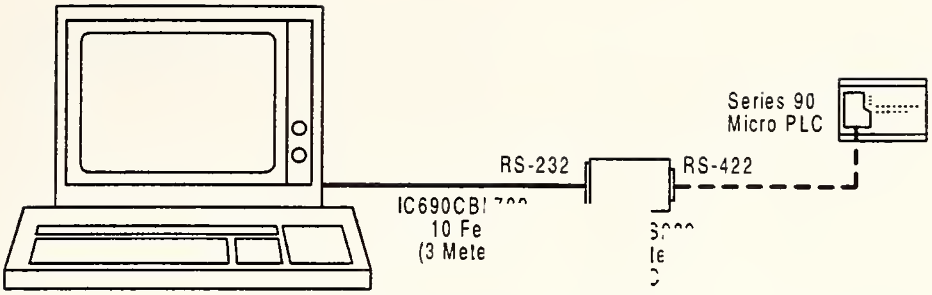


Figure 9 PLC Connected to a Computer Via the Serial Port [GE Fanac, 1997]

PLC units, which are used extensively in industrial applications, are made by several different manufactures and are designed to operate in a wide range of temperatures and humidity. They are manufactured in a variety of sizes to allow for increased flexibility in development and expansion of control systems.

For this application a Micro Series 90™ PLC manufactured by GE Fanac was selected. This model, shown in Figure 8 and Figure 9, operated on 110 volts AC and consisted of 8 input modules, 6 output modules, and a serial communications port. The I/O modules were rated for 24-volts DC. The PLC was purchased as part of a toolbox, which included the serial cable, MS-DOS based programming software and all relevant manuals. The cost of the complete package was approximately $270.

As was indicated earlier, the PLC has a CPU, which must be programmed before it can operate. A PLC uses relay ladder logic as the language from which operational programs are created. Based on the binary status of the input modules, the PLC executes the programmed sequential instructions including timers, counters, and mathematical functions to control the binary states of the output modules. Ladder logic is broken down into individual lines of instructions referred to as rungs.

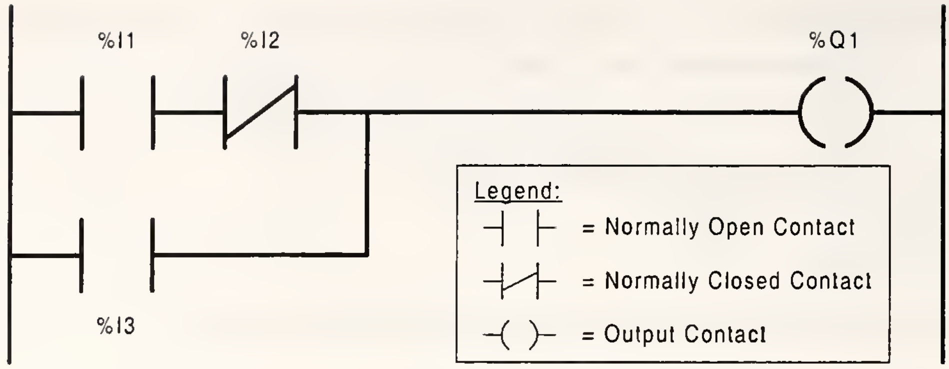


Figure 10 Example of a Ladder Logic Program

An example of a ladder logic program is shown in Figure 10. In this example, there are three input contacts and one output contract. This program consists of one rung. Reading ladder logic is much like reading a text document. One progresses through the code by beginning on the top rung and working from left to right. Once the end or right most portion of a rung as been reached, the next rung below is executed beginning on the left. In this example, output contact %Q1 can be energized (turned on) by one of two ways. The first is when input %I1 is on and input %I2 is turned off. This might seem illogical that %I2 must be off for %Q1 to be on, but %I2 is a normally closed contact. Normally closed contacts default to having their relay closed when not receiving current. Therefore, to energize %Q1 through %I1, %I2 must not receive external power though the input module. The second possible way in which output %Q1 can be energized is through %I3 being turned on. In this example these three input contacts work together to determine the binary state of output %Q1. Table 1 shows the state of %Q1 based on the status of the three input contacts.

The logic for the first version of the platoon detection algorithm only uses one input contact and one output contact. However, the logic consists of several rungs containing timers, counters, mathematical functions, and temporary memory allocations. The full program is presented as Figure A-1 in the appendix. The program is essentially broken down into three parts, which will be discussed individually.

Table 1 States of Output Module based on Status of Input Modules for Example Ladder Logic Program

%I1	%I2	%I3	%Q1
On	On	Off	Off
Off	Off	Off	Off
Off	On	Off	Off
On	Off	On	On
On	On	On	On
On	Off	Off	On
Off	Off	On	On

The first part involves the calculation of the headway values. In this segment of the logic, the PLC, using a normally open input contact, measures the amount of time which elapses between subsequent actuations received from a traffic detection device that emulates the output of a loop detector operating in pulse mode. Recall that the protocol for a loop detector consists of binary logic in which the output current is 24-volts DC in the absence of any vehicles and 0-volts when a vehicle has been detected. Headways are calculated using a timer connected to the PLC's input module. This timer accumulates the time when it receives power and resets to zero when power flow stops. Therefore, the headway between any two sequential vehicles is equal to the timer's value immediately prior to its being reset.

The second portion of the program logic involves the decision making step which determines if a platoon exists. This task begins by calculating the cumulative headway value between n vehicles, where n equals the minimum number of vehicles needed to form a platoon. For these n vehicles there are n-1 individual headway values, which represent the relative spacing of successive vehicles. Therefore, the cumulative headway value for these n vehicles is equal to the sum of the n-1 headway values as indicated by Equation 3-5. The PLC performs this task using a shift register.

$$H = \sum_{i=0}^{n-1} h_i \qquad \text{Equation 3-5}$$

Where n = the minimum number of vehicles in a platoon

h_i = the headway value between vehicle n_i and n_{i+1}

H = the cumulative headway value for the n vehicles

The shift register is a specific memory location in which data is temporarily stored and relocated according to a selected pattern [Simpson, 1994]. The type of shift register used by this particular program is known as a first-in-first-out (FIFO) register. Conceptually this FIFO register can be thought of as a sequence of slots for available data. New data is inserted at the bottom of the stack, but before it can enter the stack, the existing values must move or shift upward in the stack to open the bottom slot. The shifting action of the register causes the highest value in the stack to be removed. Figure 11 shows this process for a register with a length of five slots. This is the process by which the PLC stores individual headway values. The cumulative headway is calculated using the PLC's addition function each time a new headway value is added to the register.

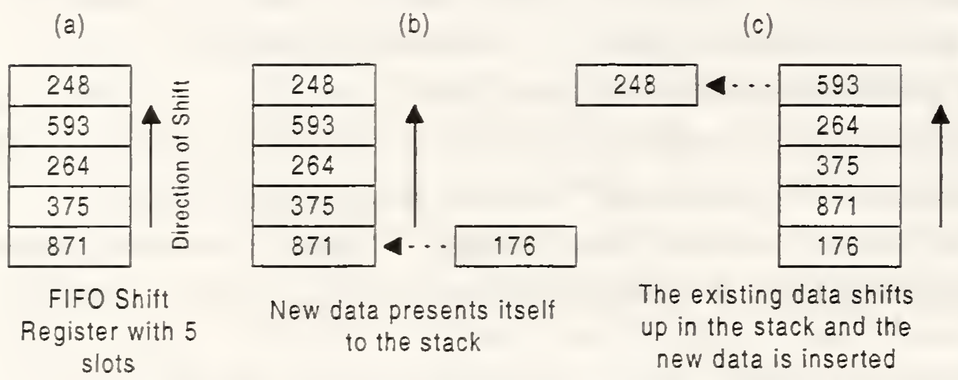


Figure 11 Example of a FIFO Shift Register in Operation

Once the program logic calculates the cumulative headway value, the third and final stage of the program begins. Using the "less than" logical function of the PLC, a comparison is made between the calculated cumulative headway value and that of a predetermined critical value stored in a different memory location. In this case, if the calculated headway value is less than the critical value, it is determined that a platoon exists. Once the platoon's existence is known, the PLC begins the process of manipulating the traffic signal controller to accommodate the platoon at the intersection. This manipulation process will be discussed in the next section. Figure 12 shows the sequential logic of the entire platoon detection process.

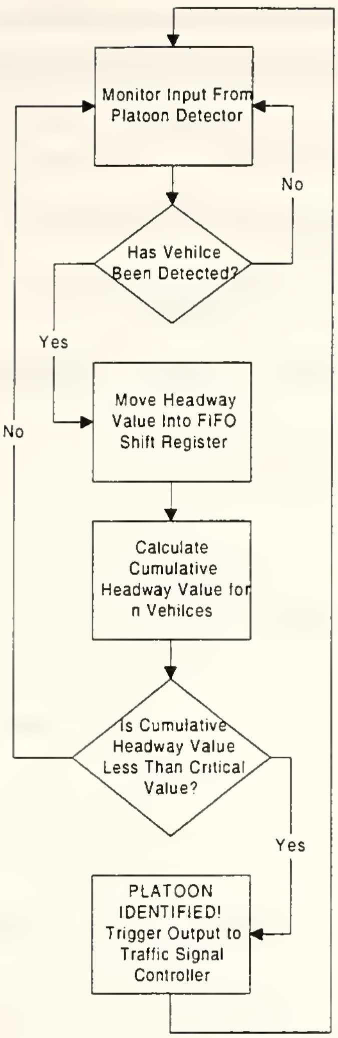


Figure 12 Sequential Logic of Platoon Detection Process

Platoon Accommodation

The PLC provides for a method by which platoons of vehicles can be identified in a stream of traffic based on spot observations. If the location of these spot observations is up stream from a signalized intersection, the PLC is providing advanced information regarding the future demand at the intersection for the instrumented approach. In situations where the approach has predominate turning movements which are known, such as the through movement of a major highway intersected by a minor road, it becomes logical to manipulate the controller to accommodate the platoon in making this movement.

Accommodating a platoon is nothing more than ensuring that a green signal exists for the predominate movement prior to the platoon's arrival at the intersection. In other words, this green signal should be displayed no later than the point in time when the vehicles in the platoon would normally begin to slow down if a red or amber signal were displayed. As was indicated at the beginning of this chapter, actuated controlled intersections that are located along high-speed roadways provide information from their local detectors, which allow for a limited planning horizon. Since a platoon occupies a certain length of roadway and its existence cannot be determined until the last vehicle passes the location at which the spot observations are made, existing detector configurations at actuated controllers cannot provide the information to the PLC for platoon detection. Allowance for the necessary time for the controller to transition into the desired state is necessary, so the need of detecting the arriving platoon in advance of its arrival at traditional local detectors is evident.

The accommodation of a platoon involves the identification of the platoon and then predicting the time of its arrival at the intersection. As was discussed in the previous section, the identification of the platoon is based on the assumption that all vehicles in the platoon have a common speed. This assumed speed should therefore be used to predict the time necessary for the platoon to traverse the distance form the location of the spot observations to the intersection. Because of this assumption and other exogenous factors, there is a trade off between the distance from the intersection to the location of the spot observation and the accuracy of the prediction. It is true that the farther the location of the information source is away from the intersection, the longer the potential planning horizon the controller has with which to work to accommodate the platoon. However, the farther the location of the source of information is from the intersection, the greater the chance of the temporal distribution of the vehicles in the platoon to change during the planning horizon. This change or distortion of the temporal distribution can result in platoon dispersion and subsequently nullify the existence of the platoon downstream at the intersection. Therefore, the location of the platoon detector becomes an important parameter in the prediction of a platoon's arrival at an intersection.

Once the platoon detector is configured to make accurate predictions regarding the arrival of platoons at an intersection, the process of manipulating the controller into allowing a green window to open-up for any detected platoon is initiated. There are three methods of manipulating the controller, which were considered for this platoon accommodation strategy. The three methods considered are:

- application of phase holds and force offs to step the controller into the desired phase,
- generating and removing calls on local detector inputs to the controller, and
- low-level preemption.

Each of these methods and their potential use in this application will be discussed. The traditional application of force off and hold inputs for a traffic signal control are for keeping a signal, which is part of a system, in coordination with adjacent signals. Force offs are points in a cycle in which specific phases must be terminated regardless of the traffic demand for that phase. Holds do not have a defined location within a cycle, however they too are used to keep adjacent signals in coordination. Holds are sometimes used to sync the base reference point for a cycle when transitions occur in coordinated timing plans. For accommodating platoons, the hold input would be used in cases where the current phase needed to be extended to ensure the platoon receives the green signal. The force off inputs would be used to terminate conflicting phases in order to cycle the controller into the desired phase for accommodating the platoon at the desired time.

The second possible method of manipulating the controller involves the generation and removal of calls on the detector inputs. The idea behind this concept is that when a platoon is detected the controller can be coerced into a particular phase through a combination of generating detector calls on the platoon's approach and removing calls for conflicting phases. In this method the controller runs in actuated mode without the knowledge that local detectors are detecting imaginary vehicles and actual vehicles are being ignored in order for a phase to become green before the platoon arrives at the local detectors. The final method is that of preemption. Traditionally, this involves the preemption of the normal cycling of traffic signals for one of the following reasons [Gordon et al., 1996]:

- right-of-way is given to phase(s) not conflicting with movements over the track when a signalized intersection is adjacent to a rail crossing,
- right-of-way assignment to emergency vehicles, such as fire trucks and ambulances, and
- right-of-way provision to transit vehicles, usually buses.

While the application and transition procedure situations in which preemption is used may differ, the purpose remains the same. Preemption involves the specification of which phase or phases are allowed to be services during some specified period of time. The preemption period begins based on the change in state of a binary input of the controller. The triggering mechanism for this input is usually associated with the activation of the crossing gates for a railroad preemptor or with the detection of an optical or radio signal transmitted from the vehicle in the case of emergency and vehicle transit preemption.

A hierarchy or priority level is usually established for a preemption strategy in locations where multiple types of preemption are enabled. This hierarchy allows the controller to determine the desired coarse of action in cases where multiple preemption calls are received. Typically railroad preemption is given the highest priority because of the necessity of clearing potentially trapped vehicles from the path of an oncoming train. Railroad preemptors are followed in level of priority by emergency vehicles and finally transit vehicles. Emergency vehicle preemption is usually limited to fire fighting equipment because of its lack of maneuverability at congested intersections, however, ambulances are sometimes provided with the equipment to facilitate preemption. Bus preemption is at the lowest level of the hierarchy, since unlike the other two, it does not greatly impact the safety of drivers at the intersection or persons for whom emergency services were dispatched, but rather improves the movement of a particular transportation mode.

In addition to determining which preemption call is serviced in the case of multiple calls, priority has an impact on the aggressiveness of the actions taken by the controller to reach the desired state. In the case of railroad preemption, the preemptor quickly begins its track clearance phase by terminating any conflicting movements regardless of their location in the timing sequence. Once the track clearance interval is completed, the controller begins somewhat normal operation for the specified hold phases. The hold interval remains in effect until the train has cleared the crossing or a maximum time has been reached. Emergency vehicle preemption is also executed in a fairly aggressive manner, however, unlike railroad preemption it only consists of a hold interval for a specific phase or set of phases. The overall time of an emergency vehicle preemption sequence is usually much less than that of railroad preemption. The lowest level of preemption is that of bus preemption. The capabilities of this type of preemptor are limited in comparison to the previous two. However, it does provide a mechanism for which a specified phase or complementing phases can be serviced during a particular time interval.

Of the three methods considered for manipulating the controller, it was determined that preemption would be used. This selection was based on the fact that this feature has been built into many of today's deployed controllers and it operates based on the manipulation of only one input pin to the controller. The other two options having been selected would have resulted in the need to develop a more complex platoon accommodation algorithm, which would have involved the manipulation of several of the controller's input pins. Additionally, the use of preemption was considered the safest alternative. This was especially true when compared to the first method proposed. The use of the hold and force off inputs to the controller, has the risk of becoming locked in an undesirable state such as an infinite hold on a particular phase.

It was determined that bus preemption would be the type of preemption used. This selection was based on the fact that the platoon accommodation algorithm was to manipulate the controller in the least intrusive manner possible. Due to the fact that bus preemption was the selected method for manipulating the controller, it is necessary to understand its operation. At this point it becomes important to note that bus preemption is somewhat of a proprietary issue for each of the different manufactured brands of traffic signal controllers available on the market. However, the difference between manufacturer's products is likely to be small. This research made use of the Advanced System Controller ASC/2-2100, Firmware Version 1.56, manufactured by Econolite Control Products, Inc. of Anaheim, California. Therefore, the operation of bus preemption discussed below is based on this particular model.

The configuration of bus preemption involves setting the values to parameters contained in a preemptor menu. The key parameters identified for this research included: minimum hold time, maximum time, reservice time, delay time, inhibit time, detector lock, and hold phase(s). These parameters and their interactions will be discussed in Table 2.

Table 2 Low Level Bus Preemption Parameters [Econolite, 1996].

Parameter	Description
Hold Phase	Identifies which compatible phase of phases (up to two) are to be serviced when a preemption call is received.
Delay Time	Fixed period of time which elapses between the initial receipt of a preemptor call and initiation of preemption.
Inhibit Time	Final portion of delay time in which phases not part of the preemption hold phase(s) are prevented form being serviced next.
Minimum Hold Time	Fixed amount of time in which the specified preemption phases must be held regardless of the current status of the preemption input.
Maximum Hold Time	Time in which preemption is terminated regardless of the presence of a call.
Reservice Time	Minimum period of time that is allowed to elapse between successive preemption sequences. The controller is automatically required when coming out of a preemption sequence to service any phase which has an active call before it can accept a new preemptor call regardless of the reservice time. Therefore, the reservice time consists of the time required to perform this function as well as any additional desired time before the preemptor can be reserviced.
Detector Lock	When activated requires that a called preemption sequence occurs even if the call is dropped during the delay time.

There are two periods in the preemption sequence, which necessitate further explanation. These two periods are at the point in which the preemptor becomes active and the point in which normal service is continued.

Once a preemption call is received the process of transitioning to the selected hold phase(s) begins when the delay time expires. (If the delay time is set to zero, this transition begins immediately.) Before the transition beings the controller can be thought of as being in one of two states. It is either in the desired phase or it is not. If the controller is in the desired phase, no transition is made and the minimum hold time is initiated. In the event that the controller is not in the desired phase, it becomes necessary to terminate the current phase and possibly skip subsequent phases to enable the desired phase. The responsiveness of the controller in making this necessary transition is limited. The limitation is that in order for an active phase to be terminated, it must have been active for the duration of the minimum green interval for that phase. In the case where a particular conflicting phase becomes active immediately prior to a preemptor becoming active, the entire minimum green time must be allowed to elapse. If the minimum green time is long, the process of beginning the transition of the preempted phase becomes delayed. To prevent this sluggish performance, an inhibit timer is used. As was indicated in Table 3-2, inhibit time is the final portion of the delay time in which conflicting phases are not allowed to begin service. If the inhibit time is greater than or equal to the longest minimum green time for all the phases normally serviced, the longest possible transition time is equal to the longest clearance interval for all the conflicting phases.

When the preemption sequence terminates the controller resumes normal operation in the phase that was held by the preemptor. Depending on the state of the controller when the preemptor became active, normal operation begins in one of two places in the timing sequence of this phase. If the preempted phase was active at the beginning of the preemption hold (end of delay time), and the minimum green time has elapsed, the controller begins at the end of the minimum green interval. In all other cases, the controller begins timing the phase at the beginning of the minimum green interval.

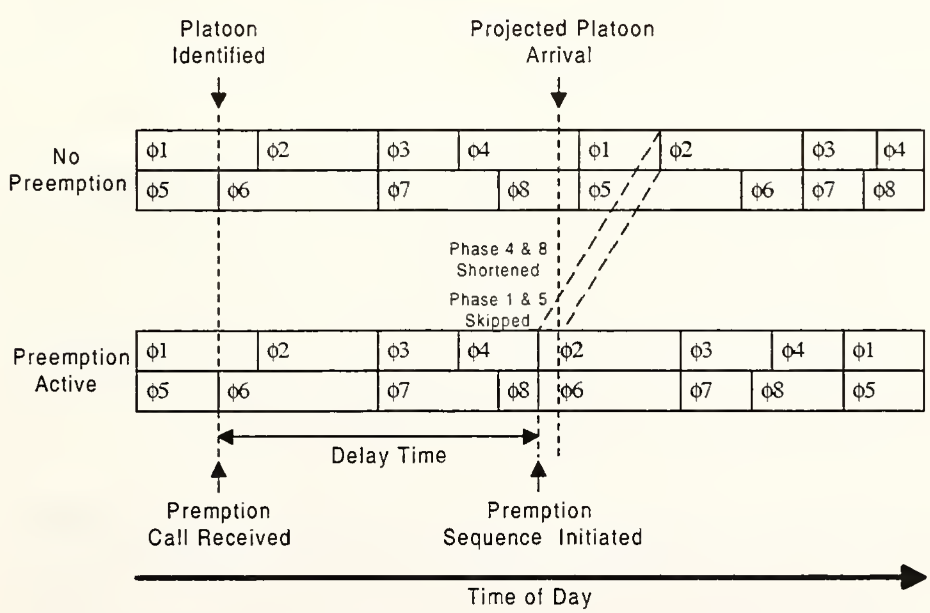


Figure 13 Example of Preemption Impact on 8- Phase Timing Plan

Figure 13 shows an example of preemption used in the context of accommodating platoons for a particular phase. This example illustrates a standard 8-phase timing plan in which a platoon is detected on the approach tied to phase 2. The top plan shows what would happen without preemption. It can be observed that for this case the platoon arrives at the intersection during a time in which another phase is being serviced and therefore would be required to stop. The bottom plan illustrates the effects of preemption when configured properly. It can be seen that the initiation of the preemption sequence resulted in both shortening phases 4 and 8 and not servicing phases 1 and 5. Note that the preempted phase becomes active before the platoon's arrival. This serves to clear any vehicles, which may be in the queue, and to prevent the platoon from slowing down as it nears the intersection because of a red indication.

The previous section discussed the use of a PLC to implement this platoon accommodation algorithm. The third portion of the sequential ladder logic programmed into the PLC involves the manipulation of the traffic signal controller. The fact that preemption is activated by a single binary input makes the interface between the PLC and the controller very simple. In the particular model of controller used in this research, the bus preemptors are activated by grounding one of the 24-volt preemptor input pins at a rate of 1 hertz per second [Econolite, 1996]. The PLC performs this task through the use of interval timers connected to the output module. The program logic is shown in Figure A-1 of the Appendix.

System Architecture

The first two questions posed at the beginning of this chapter have been addressed. A strategy based on the use of a programmable logic controller has been developed to identify platoons of vehicles in a traffic stream. Once a platoon has been identified, the same PLC manipulates the controller into a specified phase(s). With the individual elements of the strategy having been developed, it is necessary to establish the framework in which this system will operate. This will answer the third and final question posed.

Figure 14 and Figure 15 depicts two possible functional block diagrams for the system. Figure 14 has the PLC located in the traffic signal control cabinet where the other traffic control decisions are determined and implemented. This central processing approach requires that all data from the remote upstream traffic detector is sent through the communications system back to the PLC. Figure 15 consists of a distributed processing approach in which the PLC, which makes the decision as to whether a platoon exists, is located at the remote site with the traffic detection device. While both approaches have the potential to provide the same results, they each have their own positive and negative aspects.

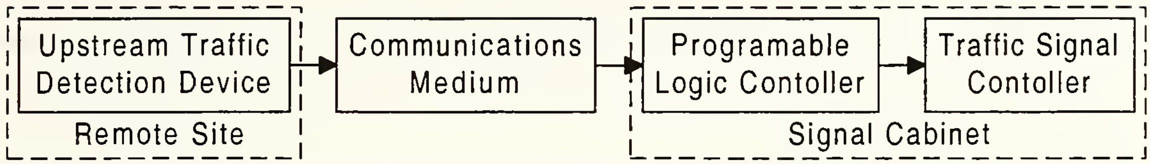


Figure 14 Functional Block Diagram for Central Processing Approach

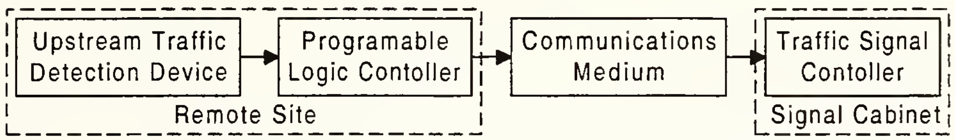


Figure 15 Functional Block Diagram for Distributed Processing Approach

The centralized approach has several positive advantages. First is that there is ample available power to run the unit since both 110-volts AC and 24-volts-DC are provided for the existing equipment located in the cabinet. Most existing cabinets have the necessary space in which to house the PLC. Additionally, the particular model of PLC used for this project has more input and output modules than are being used by the first generation platoon accommodation algorithm proposed. Therefore, the PLC has the ability of allowing the system to expand to incorporate platoon identification on multiple approaches to the intersection and the ability to implement more sophisticated algorithms (strategies which monitor the controller's status, etc) without any additional PLC devices. Furthermore, having most of the intelligence of the system in the cabinet makes installation and maintenance activities easier because cabinets are typically located well off of the roadway where personnel have the space necessary to safely perform their work. The primary disadvantage of the centralized approach is that extensive amounts of vehicle arrival data are sent through the communications system from the remote site to the signal cabinet in which the PLC resides. This extensive use of the communications system may greatly increase the power requirements of the remote site. This may become a critical issue if the remote site is to run on an alternative power source such as solar power.

The distributed processing approach has one primary benefit over that of a centralized approach. The distributed approach has the PLC located in the field with the traffic detection device. In this configuration, the PLC processes all of the detector outputs at the remote site and only makes use of the communications network when a platoon has been detected. This process greatly reduces the amount of information communicated through the system thereby reducing the communications power requirements at the remote site. It should be noted that the power required by the PLC is much less than that normally used in communications equipment such as radio transmitters. Therefore, the incorporation of the PLC with the equipment already located at the remote site does not necessitate the need for more power, but rather reduces the overall power demand at the remote site due to the significant reduction in communications requirements.

Chapter 5 will discuss the recommended architecture based on the cost and power consumption of all the various devices.

Equipment

The above discussion has outlined two approaches possible in which the strategy may be implemented. The four critical elements of both approaches that have been identified are:

- programmable logic controller (PLC),
- traffic detection device,
- communications link between the remote field site and the traffic signal controller, and
- power supply for the remote field site.

The first component has been previously discussed, so the focus of this section will be on the remaining three. There are several different available technologies and methods that can perform these functions.

The advancements made in the Intelligent Transportation System (ITS) initiative over the past few years has had a significant impact on the vehicle detection segment of the traffic control industry. There are several types of detection technologies that exist in today's market. Table 3 lists the most common types and provides a brief description of how each functions.

INDOT has had experience with most of these technologies in the past. Phase I of the Borman Expressway Advanced Traffic Management System (ATMS) involved the functional testing and evaluation of different traffic detection devices. Because of the substantial effort made by INDOT in the process of conducting these tests, it was important to include their findings as part of the information used to select a detector for the platoon accommodation strategy. In conversations with personnel from INDOT and Iron Mountain Systems, INDOT's system integration contractor for Phase II of the Borman ATMS project, it was recommended that two detector technologies be considered. The technologies were inductive loop detectors and sidefire radar [Boyd and Anderson, 1998]. Both of these detector technologies can reliably provide vehicle presence data needed for platoon detection. However, both technologies have different advantages and disadvantages.

Table 3 Current Available Detection Technologies [MinDOT and SRF Consultants, 1997].

Technology	Description
Passive Infrared	Passive infrared devices detect the presence of vehicles by comparing the infrared energy naturally emanating from the road surface with the change in energy caused by the presence of a vehicle. Since the roadway may generate either more or less radiation that a vehicle depending on the season, the contrast in heat energy is what is detected.
Active Infrared	Active infrared devices detect the presence of vehicles by emitting a low-energy laser beam(s) at the road surface and measuring the time for the reflected signal to return to the device. The presence of a vehicle is measured by the corresponding reduction in time for the signal return.
Magnetic – Passive and Active	Passive magnetic devices measure the change in the earth's magnetic flux created when a vehicle passes through a detection zone. Active magnetic devices, such as inductive loops, apply a small electric current to a coil of wires and detect the change in inductance caused by the passage of a vehicle.
Microwave – Doppler, Radar and Passive Millimeter	Doppler microwave devices transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed. Radar devices use a pulsed, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar devices have the additional ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability. A third type of microwave detector, passive millimeter, operates at a shorter wavelength than other microwave devices. It detects the electromagnetic energy in the millimeter radiation frequencies from all objects in the target area.
Passive Acoustic	Passive acoustic devices consist of an array of microphones aimed at the traffic stream. The devices are passive in that they are listening for the sound energy of passing vehicles.
Ultrasonic – Pulse and Doppler	Pulse devices emit pulses of ultrasonic sound energy and measure the time for the signal and utilize the Doppler principle to measure the shift in the reflected signal.
Video	Video devices use a microprocessor to analyze the video image input from a video camera. Two basic analysis techniques are used: tripline and tracking. Tripline techniques monitor specific zones on the video image to detect the presence of a vehicle. Video tracking techniques employ algorithms to identify and track vehicles as they pass through the field of view. The video devices use one or both of these techniques.

As was discussed in Chapter 2, inductive loops are not a new technology in traffic control operations. They provide a reliable and relatively low cost form of traffic detection.

Depending on the type of detector arrangement used vehicle volume, presence and speeds can be observed. The major drawback to using loop detectors is that they require lane closures to install. This can have a significant negative impact in locations where high volumes of traffic are present. The cost of a typical loop installation is approximately $500 per loop [Shamo, 1998].

Sidefire radar is a non-intrusive form of detection in that it does not require any disruption to traffic flow during installation. Unlike many non-intrusive forms of detection, the sidefire radar does not have to be located overhead of the lanes or pointed at oncoming traffic. The sidefire radar unit can be located along the side of the roadway perpendicular to traffic and still detect multiple lanes [MinDOT and SRF Consultants, 1997]. The sidefire unit recommended, which will be discussed in Chapter 5, has the ability to emulate loop detector outputs and therefore can provide vehicle presence, volumes and speeds if multiple detection zones are configured. An additional benefit of sidefire radar is that it can be moved from once location to another. Loop detectors do not provide this flexibility. The major drawback of sidefire radar is its excessive cost. The base price for one unit is $3,300 [MinDOT and SRF Consultants, 1997].

The communications element of the system also has several technologies to provide the desired functionality. The three technologies considered were that of hardwire, spread-spectrum radio, and low-power FM radio. For the relatively small amounts of data, which needed to be communicated in this system, the available bandwidth of all these technologies exceed the expected amount needed. Therefore, bandwidth was not a factor in the selection of a particular technology. The primary factors that were considered were that of cost and amount of integration required to interface with the other components of the system.

A hardwire connection would provide for a direct physical connection between the remote detection site and the traffic signal control cabinet. While this type of medium is arguably the most reliable of the three options, it has a substantial cost associated with the installation. In discussions with INDOT's Traffic Design Section, it was estimated that the cost to install a conduit containing the necessary wire would be $10.60 per linear foot. Assuming that the remote detector is at least 0.5 miles (2640 feet) away from the intersection, the cost of this option would be approximately $28,000. As the distance increases between the remote site and the intersection, this cost continues to grow. The other two types of communications technologies considered are wireless. The reliability of the two methods when properly configured is similar. However, the FM radio, which will be described in Chapter 5, has some distinct advantages. It costs approximately $200 less than the spread spectrum radio and has normally open and normally closed contacts as inputs and outputs. These are the states provided from a loop detector and detectors that emulate the output of loop detectors as well as the type of input required by the PLC.

The final piece of equipment to be discussed is that of a remote power supply. There are several methods that can be used for providing power to electronic devices. The most obvious is that of energy obtained from a utility company. When this option is available, it is usually the most economic alternative. However, when utility power lines are not available other forms of power must be considered. Of all the various methods of generating power available, solar power has been the method used most often in transportation related systems, such as motorist call boxes. Therefore, the two types of power supplies considered in Chapter 5 are that of solar and electricity provided by a public utility company.

Chapter 5 will discuss the recommended equipment for field deployment along with their associated costs.

CHAPTER 4 WORK PLAN

The previous chapter described a strategy for accommodating platoons at isolated intersections. This was a new concept for which performance characteristics were unknown. In order to begin to gain an understanding of how this strategy performed, it was decided to use a microscopic computer simulation as a tool from which an evaluation could be conducted.

The Traffic Software Integrated System (TSIS) package developed by Kaman Sciences Corporation for the Federal Highway Administration was the selected simulation software for conducting the simulations. This package consisted of both the CORSIM microscopic traffic simulation application and the CORSIM output processor, TRAFVU. TSIS is a Windows® based program which runs on a standard personal computer [Kaman, 1997A]. In addition to TSIS, the Interactive Traffic Network Data Editior (ITRAF) was used for creating the data files that serve as inputs to CORSIM. The decision to use simulation over that of a field experiment was due to several reasons. These were as follows [Kaman, 1997B]: simulation was a more economical approach than a field experiment, data generated by simulation, including measures of effectiveness criteria would be difficult to obtain in field experiments, simulation would not disrupt actual live traffic, wide variations in traffic conditions, which may seldom or never occur in the field, can be evaluated, and many variables of the traffic control problem can be held constant.

At the core of the TSIS package is the use of the TRAFfic (TRAF) system, which is an integrated set of simulation models that represent the traffic environment. TRAF was developed by the Federal Highway Administration (FHWA) in the 1970's. The motivation for its development was because of the need for a user friendly simulation package that was capable of representing traffic flow in a large urban area which contained freeway and surface street networks [Kaman, 1997B].

The CORSIM simulation model consists of both the FREESIM and NETSIM models developed as a part of TRAF. It is a microscopic simulation model capable of simulating very detailed strategies. In microsimulation, the models represent movements of individual vehilces influenced by driver behavior [Kaman, 1997B].

The files used for the inputs to the CORSIM simulator are .trf files. As was indicated earlier, these files can be created using the ITRAF editor. ITRAF uses a graphical user interface to create or modify the individual records contained in each .trf file. These records contain information on the following model inputs [Kaman, 1997B]:

- geometric data (node locations, link locations, number of lanes, length of turn lanes, number of lanes, lane widths, etc.),
- traffic control data (control type, control settings, etc.),
- vehicle data (volumes, turning percentages, percent trucks, etc.), and
- run controls (simulation intervals, random number seeds, etc.)
- Figure 16 shows the ITRAF editor dialog box for entering geometric data for a link.

In 1997, Bullock and Catarella introduced a real-time simulation environment for evaluating traffic signal systems. This environment consisted of an enhancement made to the CORSIM package described above which allows for physical control equipment to be connected to CORSIM. This type of simulation is refered to as hardware-in-the-loop simulation.

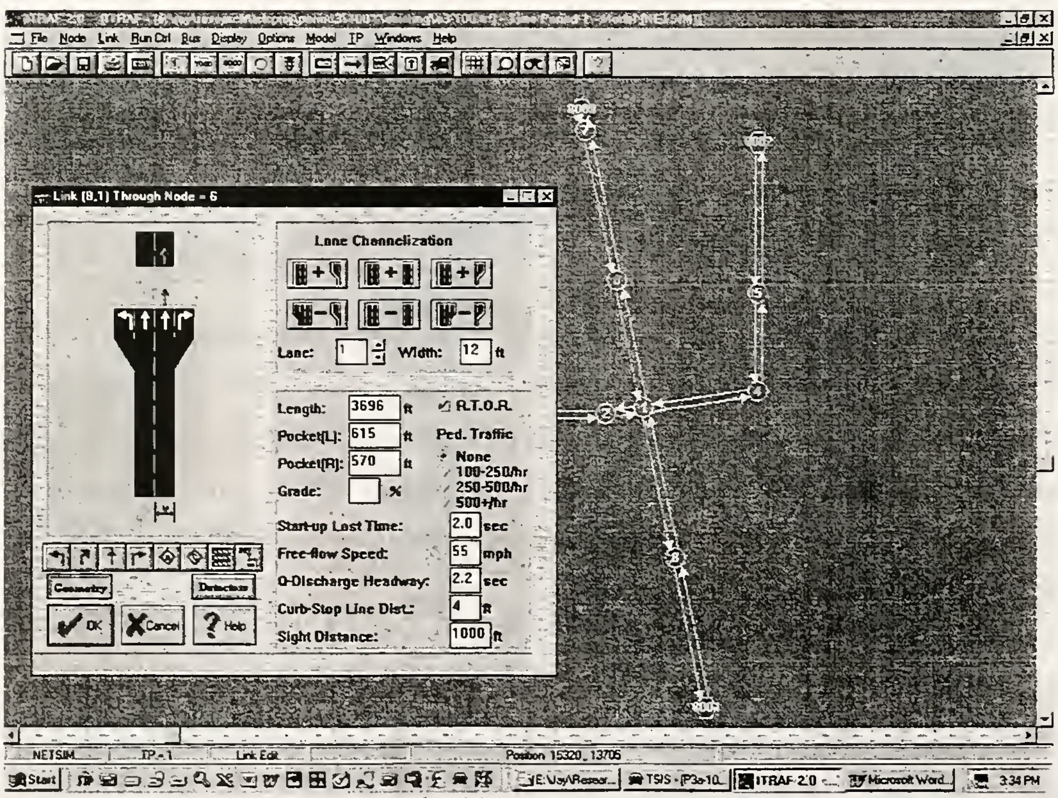


Figure 16 ITRAF User Interface for Link Characteristics

The connection between CORSIM and the control hardware is achieved through the use of the Controller Interface Device (CID) shown in Figure 17. The CID allows CORSIM to conduct the microscopic simulation (movement of individual vehicles) and tabulation of measures of effectivness (MOE) data, but CORSIM does not use its internal control algorithms. CORSIM uses the CID to send detector information to the controller and to read back phase indications. Current CID devices are made to interface with hardware conforming to the NEMA TS1 specifications for detector inputs and phase outputs. The CID type of CORSIM control was not found to be statistically different than than of internal control when identical timing plans were evaluated [Bullock and Catrella, 1997]. The advantage of hardware-in-the-loop simulation is that actual field equipment, which has more features than CORSIM's internal control algorithm, can be used in making control decisions in the simulation.

Figure 17 Controller Interface Device Connected to NEMA TS1 Compliant Controller [Bullock and Catarella, 1997]

The platoon accommodation algorithm descripted in Chapter 3 was developed based on the use of a programable logic controller (PLC). The use of this device was necessary to supplement the logic contained in the typical actuated controller. Consequentially, in order to conduct an evaluation of this strategy, it became necessary to use hardware-in-the-loop simulation. The reasons for this are that the internal control algorithms of CORSIM do not have preeption features and the current version of CORSIM does not have the ability to emulate the PLC functionality. Therefore, a simulation environment using the CORSIM computer, CID, PLC, and a NEMA TS1 complient traffic signal cabinet was constructed. This environment is shown in Figure 18.

Once the simulation environment was established, it became necessary to define a test case for which the new strategy could be evaluated. It was desired that an isolated intersection would be selected near the Purdue University campus in West Lafayette, Indiana. This intersection was to be controlled by an actuated controller and have a significant amount of platooning behavior for traffic on at least one approach to the intersection.

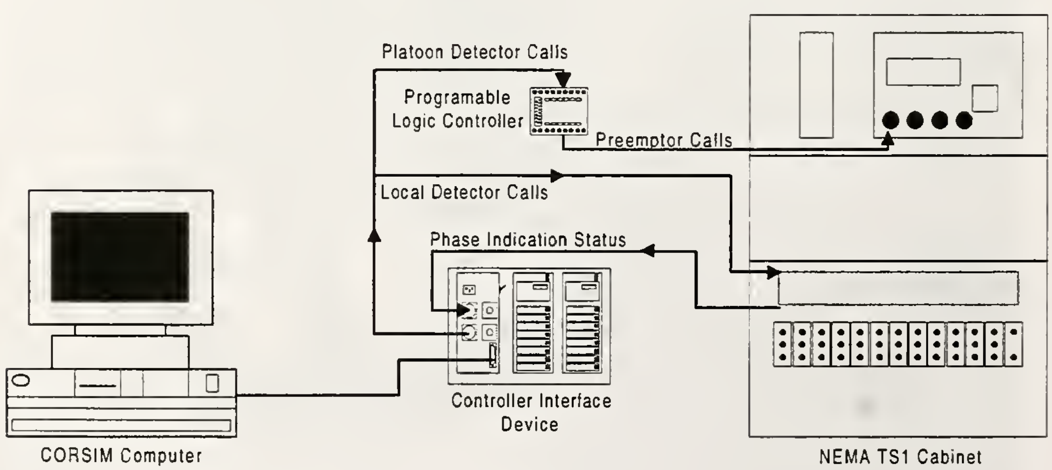


Figure 18 Simulation Environment Configuration

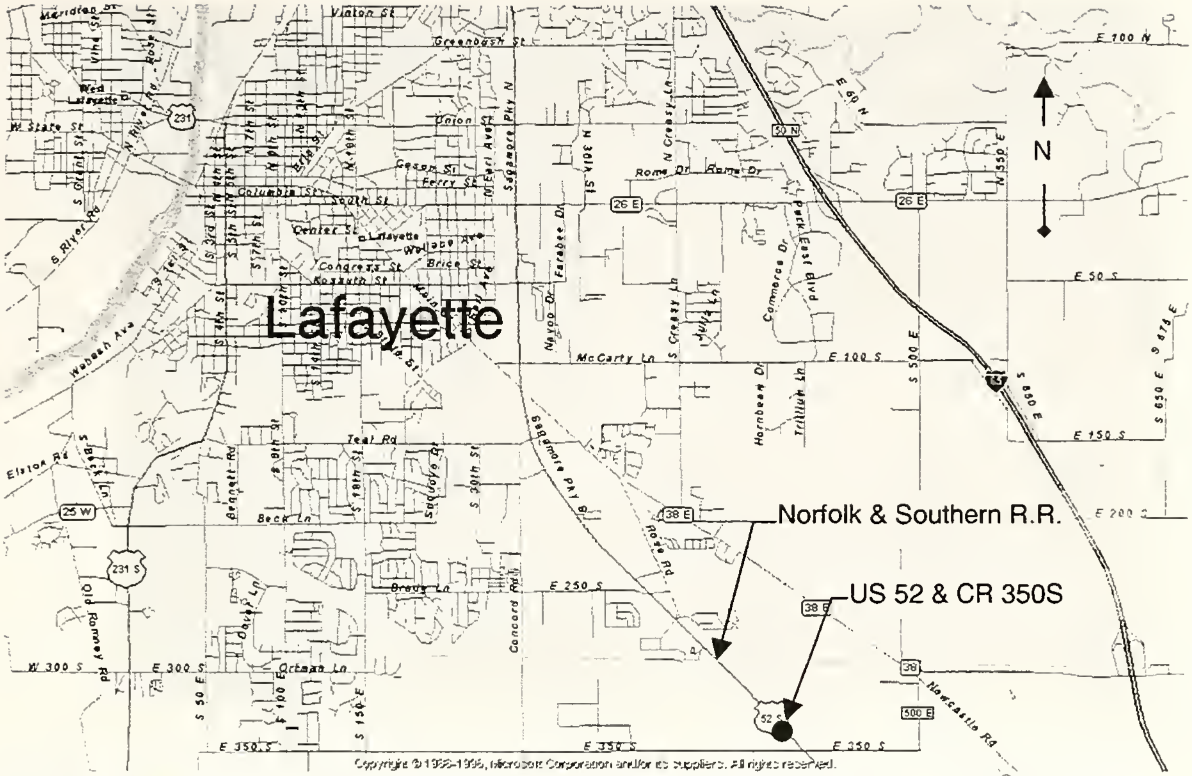


Figure 19 Map Showing Study Intersection Location [Adapted from Microsoft® Automap, 1997]

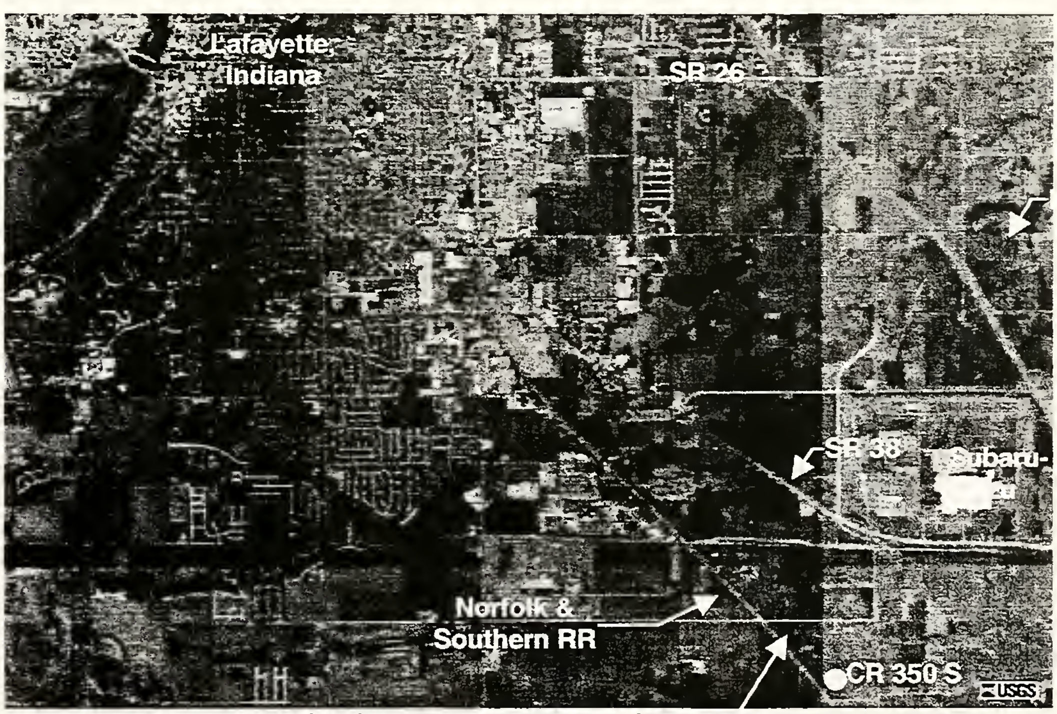


Figure 20 Arial Photo of Lafayette Area [Microsoft, 1998]

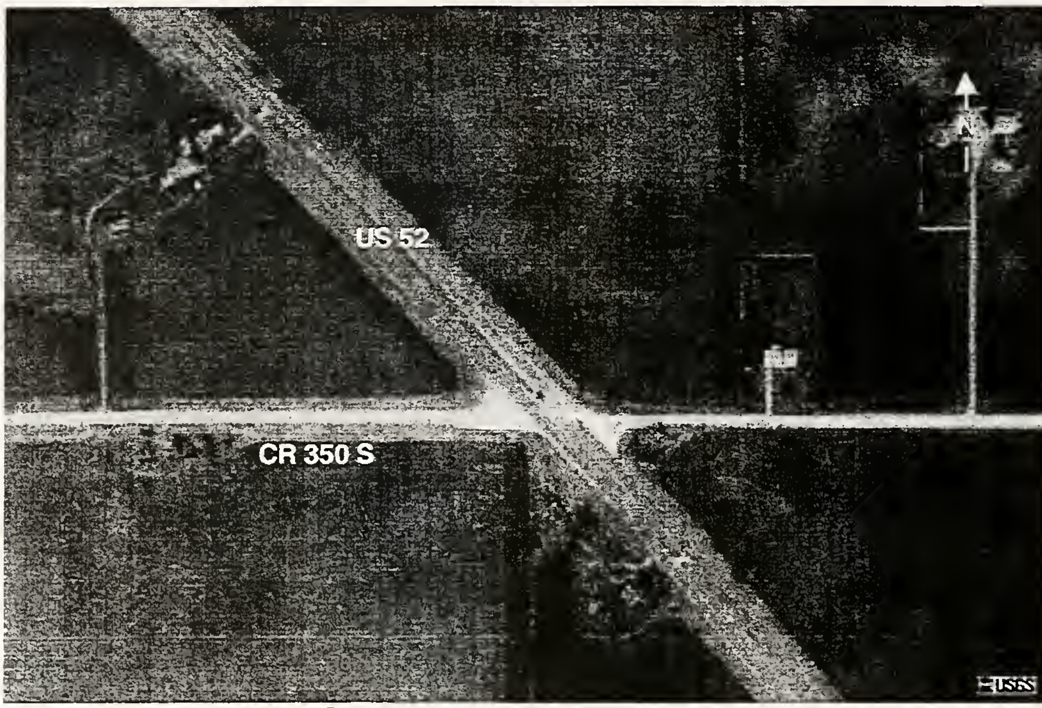


Figure 21 Arial Photo of Study Intersection [Microsoft, 1998]

The selected intersection is shown in Figure 19, Figure 20, and Figure 21. It is located at the intersection of C.R. 350 South and U.S. 52 in Tippecanoe County south of Lafayette. This intersection was controlled by an actuated controller with detection on all aproaches. Platoons of traffic were observed to exist on the southbound approach of the intersection. These platoons were generated by an active railroad crossing 0.6 miles to the north.

This rail line operated by Norfolk and Southern served the Suburu-Isusu Assembly plant located northeast of the intersection. During some times of the day trains would occupy the crossing for several minutes resulting in the formation of large platoons of southbound vehicles north of the crossing. Once the train traversed the track, these platoons would be released creating a significant peak in this approach's demand for green time at the intersection. It was felt this situation would be a suitable test case because of the random occurrences of large platoons.

Data Collection

Before simulation was initiated, relevant data was collected to serve as input into the CORSIM simulator. Geometric data was collected through field measurements. This information included: lane widths, turn bay lengths, and detector locations. Figure 22 shows this information. Timing data for this signal was provided from the Indiana Department of Transportation's Crawfordsville District. Table 4 shows the important controller timing parameters for the ring structure shown in Figure 22. Dave Cochran of Purdue University's School of Civil Engineering collected traffic volume data. Mr. Cochran provided counts for all four approaches aggregated into 1-minute intervals. This data spanned the course of 1 week. In addition to the volume data collected, turning movement data was collected for all approaches during a series of 15-minute intervals during the week in which volume data was collected.

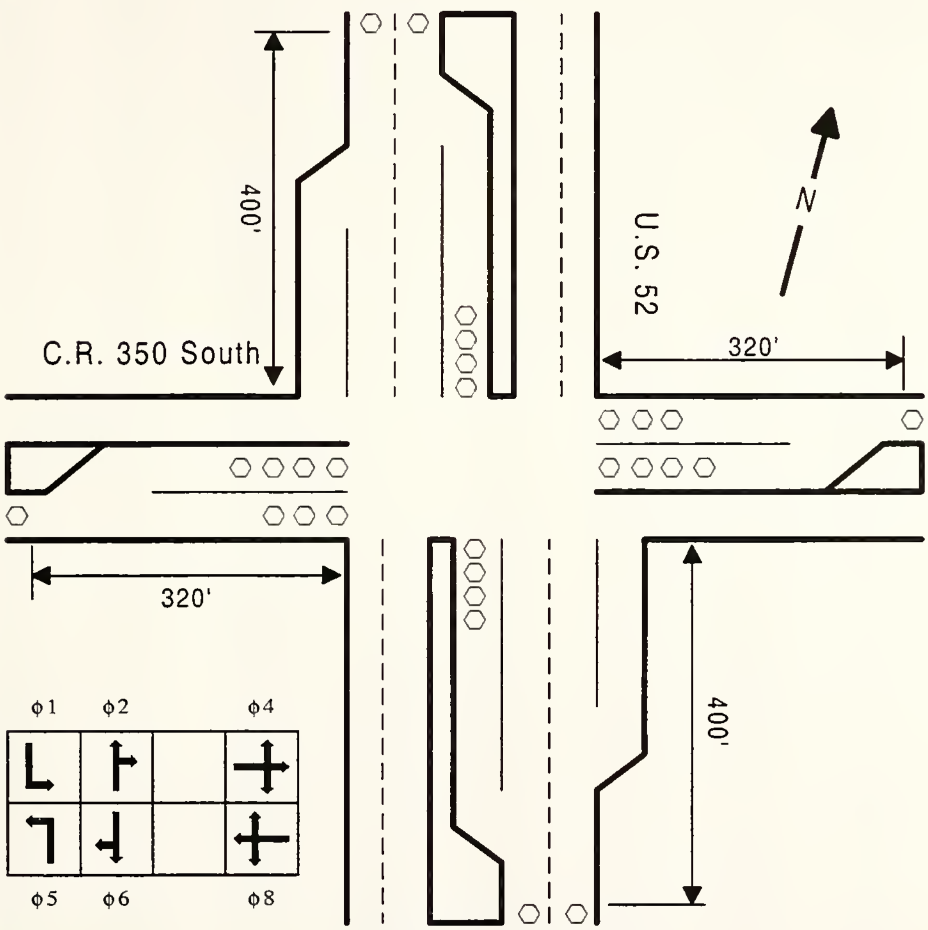


Figure 22 Study Intersection Layout and Phasing

Table 4 Study Intersection Timing and Control Settings [INDOT, 1998]

Phase	1	2	3	4	5	6	7	8
Minimum Green	6	15	0	8	6	15	0	8
Vehicle Extension	1.5	5.0	0	2.0	1.5	5.0	0	2.0
Yellow	3.5	4.5	0	3.5	3.5	4.5	0	3.5
All Red	1.5	2.0	0	1.5	1.5	2.0	0	1.5
Maximum Green	25	50	0	35	25	50	0	35
Seconds Per Actuation	0	1.5	0	0	0	1.5	0	0
Time Before Reduction	0	23	0	0	0	23	0	0
Time to Reduce	0	20	0	0	0	20	0	0
Minimum Gap	0	3.5	0	0	0	3.5	0	0
Maximum Initial	0	35	0	0	0	35	0	0
Locking Memory		X				X		
Soft Recall		X				X		

Table 5 Volume Data For Study Intersection

	Southbound US 52		Northbound US 52		Eastbound CR 350S		Westbound CR 350S	
Interval Time	*Minute Volume*	*Equivalent VPH*	*Minute Volume*	*Equivalent VPH*	*Minute Volume*	*Equivalent VPH*	*Minute Volume*	*Equivalent VPH*
16:00	0	0	4	240	8	480	3	180
16:01	0	0	6	360	7	420	3	180
16:02	0	0	9	540	7	420	7	420
16:03	0	0	6	360	6	360	5	300
16:04	1	60	5	300	8	480	15	900
16:05	0	0	1	60	6	360	13	780
16:06	0	0	15	900	6	360	7	420
16:07	0	0	8	480	10	600	3	180
16:08	0	0	7	420	7	420	7	420
16:09	57	3420	11	660	10	600	10	600
16:10	33	1980	8	480	13	780	4	240
16:11	28	1680	9	540	15	900	7	420
16:12	9	540	3	180	6	360	6	360
16:13	13	780	2	120	9	540	8	480
16:14	4	240	7	420	6	360	4	240
16:15	15	900	9	540	9	540	10	600
16:16	7	420	4	240	11	660	3	180
16:17	9	540	8	480	9	540	2	120
16:18	14	840	6	360	8	480	5	300
16:19	17	1020	4	240	8	480	2	120
16:20	7	420	6	360	7	420	8	480
16:21	11	660	3	180	10	600	10	600
16:22	6	360	4	240	4	240	3	180
16:23	6	360	3	180	6	360	5	300
16:24	3	180	4	240	3	180	6	360
16:25	1	60	3	180	6	360	4	240
16:26	0	0	6	360	3	180	7	420
16:27	0	0	6	360	4	240	8	480
16:28	1	60	4	240	3	180	3	180
16:29	0	0	9	540	4	240	7	420
16:30	0	0	6	360	0	0	11	660
16:31	41	2460	3	180	1	60	1	60
16:32	22	1320	7	420	10	600	1	60
16:33	0	0	9	540	4	240	2	120
16:34	0	0	6	360	7	420	5	300
16:35	3	180	8	480	6	360	1	60
16:36	2	120	3	180	4	240	5	300
16:37	2	120	7	420	2	120	15	900
16:38	39	2340	1	60	4	240	3	180
16:39	5	300	6	360	4	240	7	420
16:40	7	420	5	300	10	600	7	420
16:41	14	840	4	240	4	240	8	480
16:42	3	180	9	540	8	480	6	360
16:43	10	600	5	300	6	360	3	180
16:44	10	600	4	240	2	120	5	300

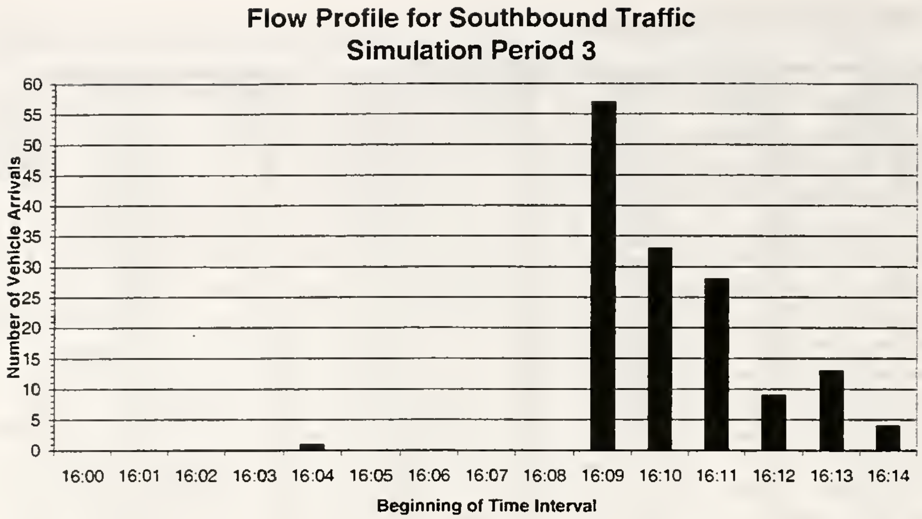


Figure 23 Flow Profile for US 52 East on April 8, 1998 from 16:00 to 16:15 PM

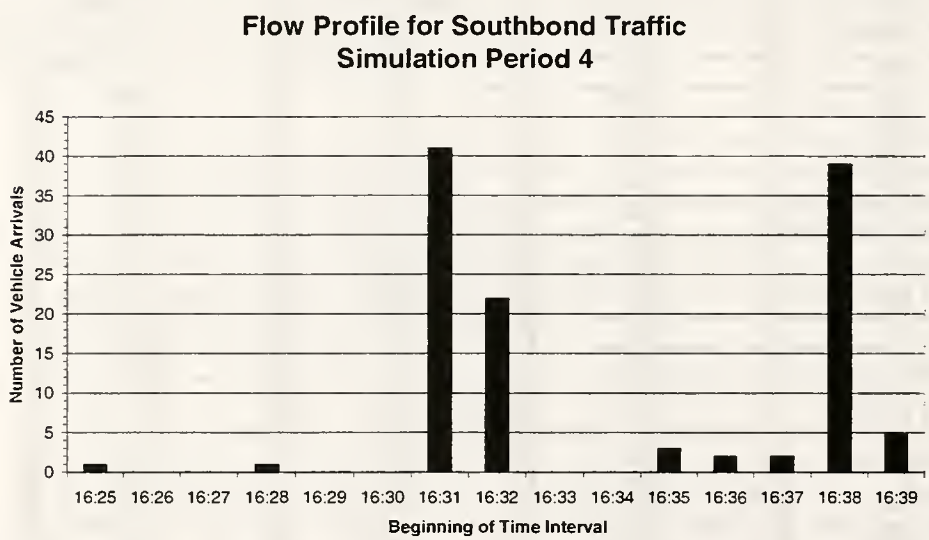


Figure 24 Flow Profile for US 52 East on April 8, 1998 from 16:25 to 16:39 PM

Once the volume data was processed, two time periods were initially selected and denoted as Periods 1 and Period 2. For reasons, which will be explained later, these 30-minute intervals were later reduced to 15-minute periods referred to as Period 3 and Period 4. The volume data for these periods are shown in Table 5. Period 3 consisted of the time interval from 16:00 to 16:15. This first 15-minute period consisted of a period of time in which one train occupied the crossing for approximately 9 minutes. The shaded areas in Table 5 indicates the time of the trains' presence. The second 15-minute period of volume data, Period 4, was from 16:25 to 16:40. Period 4 included the passage of two trains, which occupied the crossing for approximately 6 minutes and 5 minutes, respectively. These two time intervals provided for two unique traffic flow profiles in which platooning behavior could be easily seen. Figure 23 and Figure 24 show the southbound traffic upstream from the intersection during Periods 3 and 4, respectively. Table 6 shows turning movement data collected the same afternoon as that of the two selected periods.

Table 6 Turning Movement Data

Approach	*Left*	*Through*	*Right*
Northbound	10%	86%	4%
Southbound	12%	70%	18%
Eastbound	18%	54%	28%
Westbound	26%	69%	5%

Simulation Procedure

The data collection effort discussed in the previous section, allowed for the simulation experiments to be conducted. Due to the type of simulation environment being used for this evaluation, input data was needed for the following components:

- CORSIM (traffic and geometric data),
- Traffic Signal Controller (supplied timing plan plus supplemental bus preemptor plan), and
- Programmable Logic Controller (platoon detection setting which consists of a specified number of vehicles arrivals in a specified amount of time).

The input data for the simulations were broken into two groups. These groups are fixed data, which was held constant for all simulation runs, and variable data, which was allowed to vary. Table 7 shows the data parameters from both groups and a description of each.

Table 7 Data Input Parameters for Simulations

Fixed Inputs	
Parameter	Description
Geometric	Information relative to roadway dimensions and detector placements
Controller Timing Data for Normal Control	Information pertaining to the control parameters by the traffic signal when operated under normal operation (minimum times, maximum times, clearance times, vehicle extension times, etc.)
Turning Percentages	Percentage of vehicles making left, through, and right movements from a particular approach
Vehicle Classifications	Vehicle classifications consisted of 98% passenger cars and 2% trucks
Main Street (US 52) Volumes	Volume of northbound and southbound traffic
CORSIM Random Number Seed Sets	CORSIM uses three random numbers to control the following: Emission headways Generated traffic driver responses to traffic choices [Kaman, 1997B].
Variable Inputs	
Parameter	Description
Minor Street (C.R. 350) Volume	Volume on eastbound and westbound approaches defined as a certain percentage of the collected volume
Bus Preemption Settings	Parameters discussed in Table 2 including: maximum time, minimum time, reservice time, delay time, and inhibit time.
Programmable Logic Controller Settings	The PLC determines platoon existence based on: Minimum number of vehicles in a platoon Maximum headway between the first and last vehicles in the specified minimum platoon size
Platoon Detector Location	Distance upstream from the stop bar in which the traffic detection device used for platoon identification is located

The fixed inputs discussed in Table 7 were entered once and remained constant throughout all the simulation periods. The last parameter in the fixed input portion of the table consisted of 20 sets of random number seeds. The values for these random number seeds are shown in Table B-1 of Appendix B. For this evaluation, every simulation trial consisted of 20 runs using each group of random number seeds once.

To expedite the task of creating .trf input files and processing CORSIM output files, a set of macros were developed for Microsoft® Word and Excel. The preprocessor operated in Word and essentially took an established .trf file, referred to as the base file, and created 20 .trf files each containing a different set of the random number seeds shown in Appendix B. The preprocessor also created a script file that CORSIM used to process multiple .trf files sequentially without operator intervention. The postprocessor consisted of two parts. The first part was a Word macro that extracted various MOE performance indicators from each of the individual output files for the 20 runs and saved these selected results as .txt files. This was followed by the second part consisting of an Excel macro, which tabulated all of the extracted data contained in the .txt files from part one and generated a summary page as shown in Appendix C. Figure 25 shows the file management strategy used in this research.

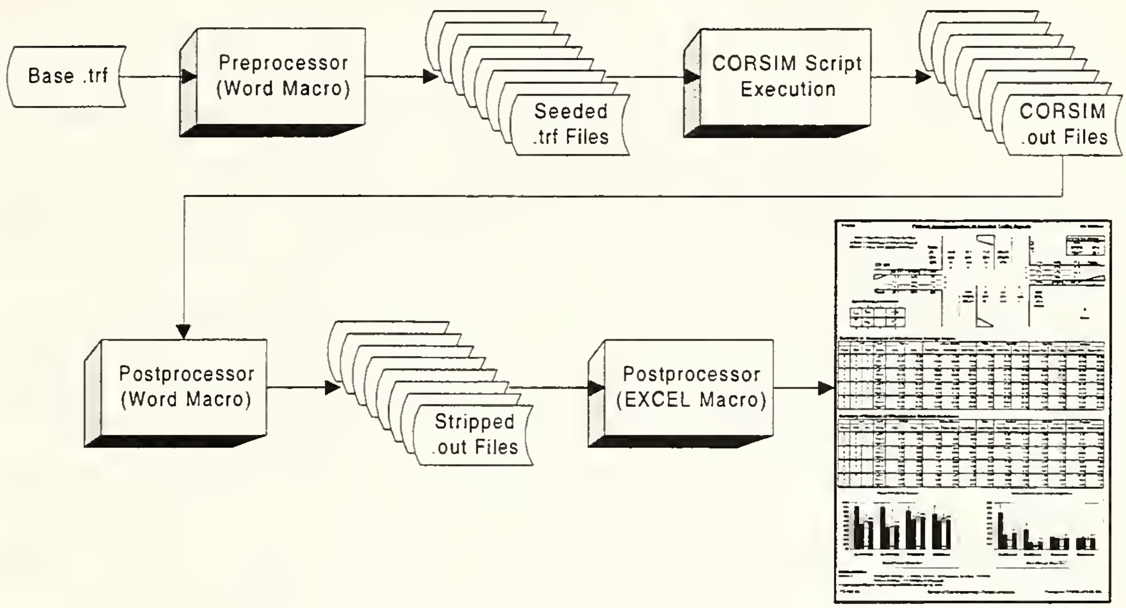


Figure 25 File Management Strategy

As can be seen above, Table 7 consists of several variable inputs which impact the performance of the intersection. A detailed sensitivity analysis of each of these parameters would involve a great deal of effort beyond that of this research. However, in order to begin to gain an understanding of what the potential impact platoon accommodation can have on intersection performance several different combinations were evaluated.

Table 8 shows the combinations evaluated in this project. The configurations designated E-100 and E-50 represent the baseline conditions for 100% and 50% of the collected volume along C.R. 350 South, respectively. In all cases tested, the volume along U.S. 52 was 100% of that which was collected and only CR 350 volumes were allowed to deviate from 100%. The reason for evaluating the cases in which 50% of the collected side street volume existed was that it was felt that there was not enough discrepancy between the volume for the major road (U.S. 52) and the minor road (C.R. 350). For all cases, the platoon detector was located on the southbound approach and the through movements for the southbound and northbound movements were tied to the preemption sequence. There were initially many runs that were processed, but they are not shown in Table 8. These runs were a series of trial and error procedures used to gain a preliminary understanding of the simulation environment and to serve as a functionality test for the equipment, simulator, preprocessor and postprocessors.

Two key elements came out of this process. The first was that 30-minute simulations containing the level of railroad activity discussed earlier tended to mask the impact of the platoon accommodation strategy. Once this period was shortened to 15-minutes, the effects of the platoon accommodation could be observed. The decision of using 15-minute simulation intervals is supported by Chapter 9 of the Highway Capacity Manual (HCM). Equation 9-9 in the HCM shows the process by which hourly volumes are converted to peak 15-minute periods for analysis [National Research Council, 1994]. The second was the importance of the preemption inhibit timer which limits the controller in servicing conflicting phases at the end of the delay period. Initially this factor was set to 0, which resulted in the sluggish response of the controller to a preemption call. Once this value was set to a higher value the signal's response to the preemption call became more consistent.

Table 8 Simulation Configurations Evaluated

Configuration Designation	*Side Street Volume %*	*Platoon Setting*	*Maximum Hold Time*	*Minimum Hold Time*	*Reservice Time*	*Delay Time*	*Inhibit Time*	*Detector Location from Stop Bar*
A-100	100%	11 veh. in 10 sec.	45	0	60	25	13	2640'
B-100	100%	16 veh. in 15 sec.	45	0	60	20	13	2640'
C-100	100%	6 veh. in 10 sec	45	0	60	25	13	2640'
D-100	100%	6 veh. in 5 sec	45	0	60	30	13	2640'
E-100	100%	Baseline Conditions for 100% Side Street Volume – No Preemption Timing Plan Used						
A-50	50%	11 veh. in 10 sec.	45	0	60	25	13	2640'
B-50	50%	16 veh. in 15 sec.	45	0	60	20	13	2640'
C-50	50%	6 veh. in 10 sec	45	0	60	25	13	2640'
D-50	50%	6 veh. in 5 sec	45	0	60	30	13	2640'
E-50	50%	Baseline Conditions for 50% Side Street Volume – No Preemption Timing Plan Used						

After a good understanding of the system was grasped, the simulation trials shown inTable 9 were conducted. The results from these trials are shown in Appendix C as the figure indicated the corresponding cell of Table 9.

Table 9 Simulation Trials Completed

Configuration Evaluated	*Period 3*	*Period 4*
A-100	Figure C-1	Figure C-11
B-100	Figure C-2	Figure C-12
C-100	Figure C-3	Figure C-13
D-100	Figure C-4	Figure C-14
E-100 (Existing Conditions)	Figure C-5	Figure C-15
A-50	Figure C-6	Figure C-16
B-50	Figure C-7	Figure C-17
C-50	Figure C-8	Figure C-18
D-50	Figure C-9	Figure C-19
E-50 (Existing Conditions)	Figure C-10	Figure C-20

Simulation Results

The results of the trials, which are shaded in Table 9, will be discussed in detail. These trials are for Period 3 configuration D-100 and Period 3 configuration E-100 that is the associated baseline case. The evaluation of the different platoon accommodation strategies was accomplished by comparing the delay time (sec/veh) and percent stops for all movements an all approaches between the baseline conditions and that of the selected strategy. The output generated by CORSIM and processed by the postprocessor macros discussed in the previous section computed the average values and standard deviations for all positive turning movements at the intersection. Computing the test statistic for two means with unequal variances compared the two scenarios. The hypothesis for this evaluation is H_o: $\mu_1=\mu_2$.

Table 10 Summary of Simulation Results Contained in Appendix C

Configuration Evaluated	Period 3		Period 4	
	Delay (seconds)	*% Stops*	*Delay (seconds)*	*% Stops*
A-100	29.9	55	13.7	36
B-100	35.8	66	14.1	37
C-100	32.4	59	12.1	31
D-100	28.7	54	11.8	32
E-100 (Existing Conditions)	35.7	65	13.5	35
A-50	22.0	46	9.1	25
B-50	22.7	47	8.7	24
C-50	21.5	44	9.1	25
D-50	21.1	43	9.0	24
E-50 (Existing Conditions)	23.5	50	9.0	25

The test statistic shown in Equation 4-1 was computed to determine if there was a statistically significant difference between the means for the two cases. For all cases evaluated, the number of observations was 20 and these observations were assumed to have a normal distribution. The critical values for a two-tailed test of the test statistic at the 0.05 significance level for 18 degrees of freedom are ± 2.101. The magnitude of this value is denoted as Z^*. The decision rule for the hypothesis is as follows:

If $|Z'| > Z^*$, then H_o is rejected.

Therefore, if we reject the null hypothesis, we can be 95% confident that the computed means for the baseline and platoon accommodation strategy are statistically different.

$$Z' = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} - \frac{s_2^2}{n_2}}} \qquad \text{Equation 4-1}$$

Where

Z' is the computed test statistic

n_i is the number of observations in group i

μ_i is the mean of the observations in group i

s_i is the standard deviation of the observations in group i

Table 11 shows the means, standard deviations, and test statistics for Period 3 configuration D-100. It was shown that the platoon accommodation strategy implemented statistically reduced the percent stops and delay for the southbound approach without any statistical impact on the other movements. In this case the southbound movement had the percent stops reduced from 65.5% to 53.6% and the delay time reduced from 37.8 seconds/vehicle to 28.7 seconds/vehicle. Therefore, it was shown that platoon accommodation can improve the operational efficiency of isolated intersections.

It has been shown that platoon accommodation can improve the operational efficiency of isolated intersections. However, if the system is improperly configured a less than desirable result can occur. Figure D-21 in Appendix D shows the results from a case ran during the trail and error period from Period 4 in which the platoon identification parameters were improperly set. When compared to the baseline conditions (configuration E-100) for the corresponding traffic volume, it can be observed that the platoon accommodation strategy used in Figure D-21 actually degraded the performance of the intersection. Therefore, a clear understanding of each of the variables' impact on performance should be examined further prior to making recommendations for deployment configurations.

Chapter 5 describes the technical and financial issue with implementing this technology. Chapter 6 presents an analysis of the platooning characteristics of CORSIM to determine if the extent of platooning observed in CORSIM is reasonable to expect in the field.

Table 11 MOEs and Test Statistics for Period 3 Configuration D-100

Delay Per Vehicle (Seconds Per Vehicle)						
N=	20	Average 1 (Existing)	Average 2 (Proposed)	Standard Deviation 1 (Existing)	Standard Deviation 2 (Proposed)	Test Statistic
Northbound	Left	33.23	38.73	7.80	11.37	-1.78
	Through	12.82	13.23	1.22	1.44	-0.97
	Right	8.86	8.06	5.35	3.98	0.54
Southbound	Left	69.68	71.62	15.87	14.83	-0.40
	Through	35.75	28.69	12.18	7.13	**2.24**
	Right	19.15	19.01	4.48	5.34	0.09
Eastbound	Left	24.51	25.55	5.64	5.33	-0.60
	Through	22.90	22.07	4.13	5.03	0.57
	Right	20.52	19.76	5.12	5.18	0.47
Westbound	Left	20.23	21.37	6.13	6.56	-0.57
	Through	22.60	23.36	3.32	3.43	-0.71
	Right	20.35	21.03	4.89	4.76	-0.45
Percent Stops						
N=	*20*	*Average 1 (Existing)*	*Average 2 (Proposed)*	*Standard Deviation 1 (Existing)*	*Standard Deviation 2 (Proposed)*	*Test Statistic*
Northbound	Left	90.17	91.52	7.96	8.72	-0.51
	Through	46.69	46.93	5.10	5.91	-0.13
	Right	55.22	49.05	38.49	36.55	0.52
Southbound	Left	94.21	92.54	8.39	9.34	0.59
	Through	65.48	53.56	15.16	12.65	**2.70**
	Right	66.43	59.53	13.70	14.05	1.57
Eastbound	Left	82.89	82.48	10.13	8.89	0.14
	Through	64.05	64.23	6.73	8.02	-0.07
	Right	69.89	70.36	8.15	9.40	-0.17
Westbound	Left	75.47	76.23	18.18	17.95	-0.13
	Through	60.91	61.05	7.00	8.01	-0.06
	Right	67.36	66.98	11.62	9.89	0.11

CHAPTER 5 ANALYSIS

Chapter 4 showed, using computer simulation, that the strategy of platoon accommodation at isolated intersections has the potential to improve intersection efficiency. In order to gain a preliminary understanding of the system's economic impacts, attention will now be focused on the examination of the expected costs and benefits related to the deployment of such a system. As was indicated at the end of Chapter 4, further research is needed to determine the optimal setting of the system. Once this optimal configuration has been determined, it is likely that a detailed analysis will be performed. Therefore, this analysis is only to provide a general view of this complex process.

System Costs

Chapter 3 discussed several possible technologies that could be used in deploying this system. The four primary components of the system that were identified are: a traffic detection device, a remote power source, a communications system, and a programmable logic controller (PLC). The centralized processing approach (see Figure 14) in which the programmable logic controller was located in the traffic signal control cabinet was considered the preferred system architecture. The primary reason for this is that the PLC has additional capacity that could allow for the system to expand to multiple approaches. The primary concern in using this approach is that the remote power requirements for transmitting all the detector information may exceed that which can be supplied by an alternative power source. Therefore, before this approach can be used it must be shown to be feasible.

The primary question, which needs to be addressed in looking at the centralized architecture, is that of the remote power requirements in cases where alternative energy sources are to be used. The remote site will consist of a traffic detection device and a radio transmitter. (Hardwire connection between the remote site and the traffic signal cabinet was determined to be too expensive to implement.) Of the two technologies of traffic detection discussed, inductive loops use the least amount of power. The RTMS sidefire radar unit, shown in Figure 26, operates on 12-volts DC with a current draw of 500 milliamps [Electronic Integrated Systems Inc., 1998]. A loop detector amplifier can be purchased that operates on the same 12-volt DC circuit, but only draws 60 milliamps. Even in situations where two loop detector amplifiers are used to detect multiple lanes, the power consumption is still less than that of the RTMS device. Another factor, which supports the use of inductive loop detectors, is that there is considerable capital cost savings over that of sidefire radar. Since platoon accommodation is targeted for deployment at isolated intersections often located in rural areas, the potential negative impact on traffic during the installation of inductive loops is expected to be minor. However, due to the inability of a loop installation to be relocated, it is important that they are properly placed during installation.

In addition to the two inductive loop detectors used to identify platoons in multiple lanes, a radio transmitter is to be located at the remote site (see Figure 14). Based on the discussion in Chapter 3, the use of the FM radio offered some distinct advantages over that of the spread-spectrum radio system. As was previously indicated, it costs less than the spread spectrum radio and uses the same inputs and outputs used by the detector and PLC. The FM transmitter operates using 12-volts DC. It operates in one of two modes which are either transmit mode or standby mode. In transmit mode the device draws 2 amps and in standby mode the device draws 15 microamps. The radio would be configured to transmit for one second each time a vehicle entered the detection

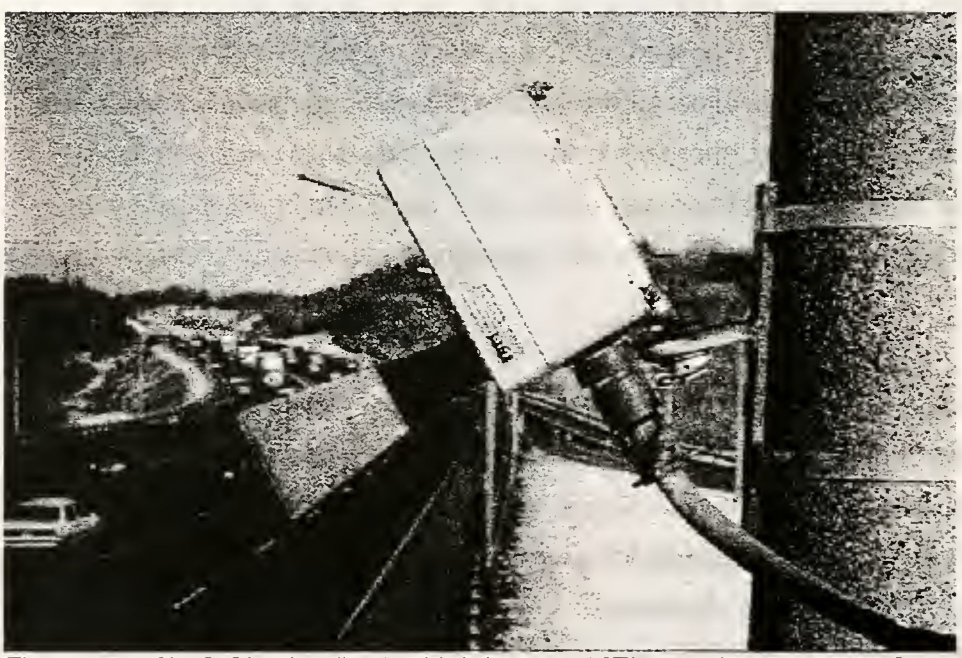


Figure 26 RTMS Sidefire Radar Unit Installed [Electronic Integrated Systems Inc., 1998]

zone and remain in standby mode during subsequent vehicle actuations. For the basis of making preliminary calculations it was assumed that the radio would transmit for approximately 6 hours a day. This is considered a conservative estimate by allowing the transmission of over 20,000 calls a day. The solar supply system consists of a photovoltic module, a battery storage system, and a charge control.

Table 12 shows the calculations used to determine the solar power load requirements and array sizing for the remote site. Table 13 shows the calculations used to determine the power storage requirements for the remote site.

Table 12 shows that the remote site can be powered by solar energy. The power supply for this site consists of a 90-watt Photovoltaic Module manufactured by BP solar (see Figure 28), which produces 12-volts DC and has a 10-year warranty. The battery storage system for this consists of two 6-volt DC deep cycle batteries (see Figure 29) wired in series to provide 12-volt DC current. These batteries have a life expectancy of up to 5 years. A charge control is needed to prevent the batteries from being overcharged.

Table 12 Remote Site Power Requirements [Adapted from Alternative Energy Engineering, 1998]

Solar Power Load and Array Sizing Worksheet for Remote Site						
Line Number	Item	Watts	X	Hours Used Per Day	=	Watt Hours Per Day
1	Traffic Detector	1.44		24		34.56
2	Radio Transmitting	24.00		6		144.00
3	Radio in Standby Mode	0.01		18		0.18
4	Total Watt Hours Per Day (Sum Lines 1-3)				=	178.74
5	DC System Voltage				=	12.00
6	Total Amp Hours Per Day (Divide Line 4 by 5)				=	14.90
7	Compensation From Battery Charger Loss (Line 6 x 1.2)				=	17.87
8	Average Sun Hours Per Day (From DOE Data[1])				=	4.21
9	Solar Array Amps Required (Line 7 by Line 8)				=	4.25
10	Peak Amps Produced by Solar Model Used				=	4.86
11	Minimum Number of Solar Modules Required in Parallel (Divide Line 9 by Line 10)				=	0.87
12	Total Number of Solar Modules (Round Line 11 Up)				=	1.00
[1] Figure 27 shows the average number of sun hours for the United States.						

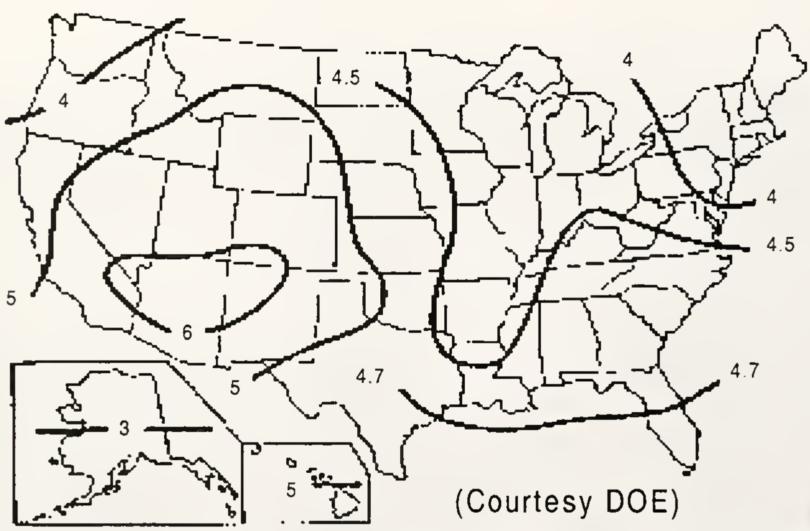


Figure 27 Map of United States Showing Average Sun Hours a Day [Alternative Energy Engineering, 1998]

Table 13 Remote Site Power Storage Requirements [Alternative Energy Engineering, 1998]

Solar Battery Sizing Worksheet for 12-Volts DC Remote Site			
Line Number			
1	*Total Amp Hours Per Day (From Line 6 Above)*	=	14.90
2	*Maximum Number of Cloudy Days Expected in Area*	=	7
3	*Total Amps Needed During the Cloudy Period(Line 1 Multiplied by Line 2)*	=	104.27
4	*Total Amps Needed to Maintain 20% Reserve After Deep Discharge (Line 3 Divided by 0.8)*	=	130.33
5	*Lead-Acid Battery Temperature Multiplier (From Table)*	=	1.59
6	*Optimum Battery Size in Amp-Hours (Line 4 Multiplied by Line 5)*	=	207.23
7	*Amp-Hours of Selected Battery*	=	220
8	*Minimum Number of Batteries needed in Parallel (Divide Line 6 by Line 7)*	=	0.94
9	*Number of Batteries Needed in Parallel (Round Line 8 Up)*	=	1
10	*Ratio of Volts Supplied by Battery to Volts Needed*	=	0.5
11	*Minimum Number of Batteries Needed in Series (1 Divided by Line 10)*	=	2
12	*Total Number of Batteries Needed in Series (Round Line 8 Up)*	=	2
13	*Total Number of Batteries Needed for Complete System (Multiply Line 9 by Line 12)*	=	2

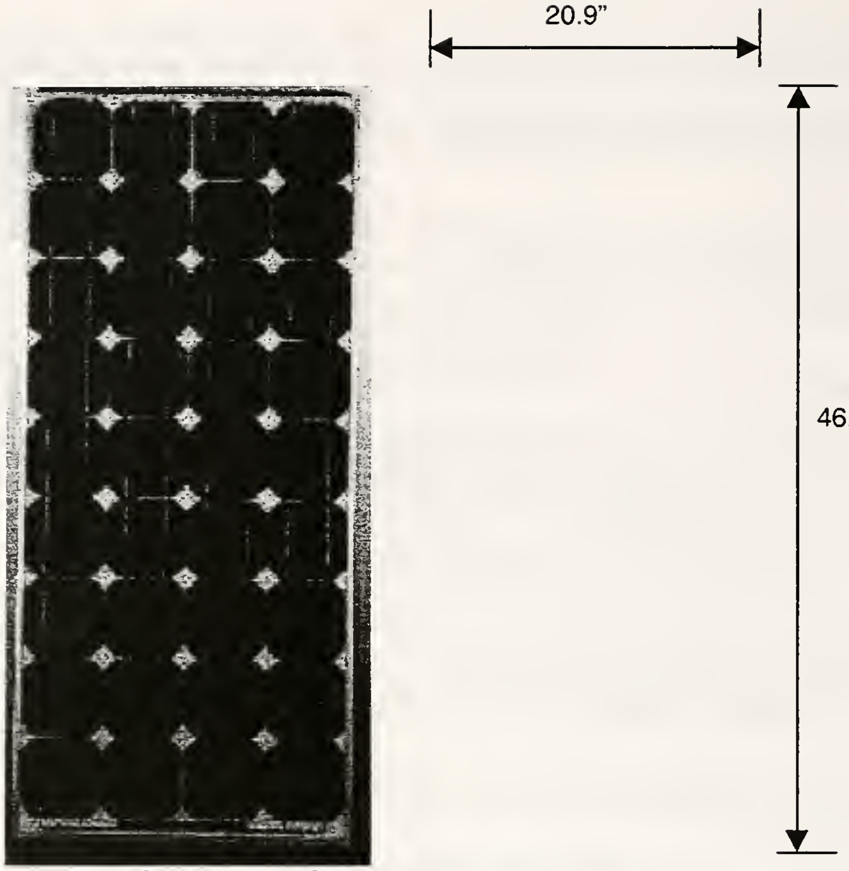


Figure 28 Solar Power Supply [Alternative Energy Engineering, 1998]

Figure 29 6-volt 220 Amp-Hour Lead-Acid Battery [Alternative Energy Engineering, 1998]

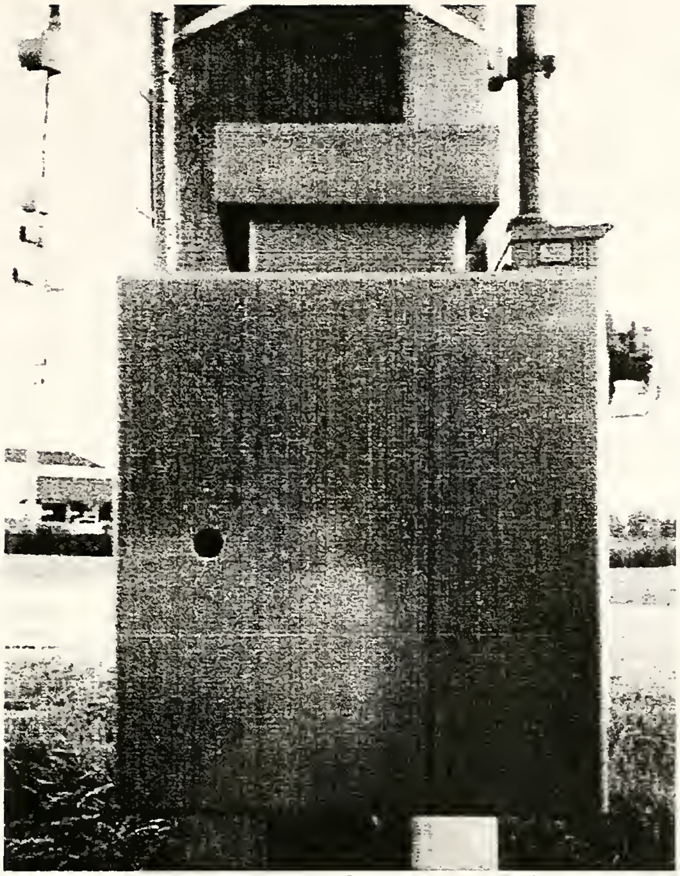


Figure 30 Typical Control Cabinet Used for Flashers

It is envisioned that the power supply, radio transmitter, and all detection equipment will be located on a pole adjacent to the roadway outside of the clear zone. The equipment, which must be kept in a closed environment, will be contained in a small traffic control cabinet mounted on the pole similar to that shown in Figure 30.

The costs of the system are calculated based on two detection zones and a 10-year life cycle. All costs are presented in adjusted 1995 dollars. All of the capital cost is expended at the beginning of year one except for cost of two replacement batteries at the end of year 5. No salvage values are considered in the cost calculations. An interest rate of 5.0% is assumed for all calculations [Steckler, 1998]. While interest rates do vary, this number was selected to provide a starting point from which the economic impact could be evaluated. Table 14 shows the prices of the components needed to construct the system. All values were converted to constant 1995 dollars using the Consumer Price Index (CPI) values in contained in Table 15

Table 14 Component Prices for System

Item	Purchase Date	Price (1998 $)	Price (1995 $)
2 Reno A&E Model H-12-F Inductive Loop Detectors Amphilfiers[1]	Start of Year 1	$280.00	$263.08
2 Loop Detector Instalations[2]	Start of Year 1	$720.00	$676.50
Flasher Type Control Cabinet[2]	Start of Year 1	$700.00	$657.71
Pole for Mounting Remote Site Equipment[2]	Start of Year 1	$300.00	$281.87
Linear Midrange XT Transmitter (1-Channel) and Receiver (4-Channel)[3]	Start of Year 1	$300.00	$281.87
GE Fanac Automation Series 90 Micro PLC[4]	Start of Year 1	$200.00	$187.92
BP Solar 90-Watt Photovoltic Module[5]	Start of Year 1	$600.00	$563.75
2-220 Amp-Hour 6-volt Golf Cart Battery[5]	Start of Year 1	$170.00	$159.73
8-Amp 12-volt Automatic Control Regulator[5]	Start of Year 1	$50.00	$46.98
Miscellaneous (Connectors, etc.)	Start of Year 1	$200.00	$187.92
2-220 Amp-Hour 6-volt Golf Cart Battery[5]	Start of Year 6	$170.00	$159.73
[1][Zabel, 1998] [2][Shamo, 1998] [3][Central Security, 1998] [4][Martin, 1998] [5][Alternative Energy Engineering, 1998]			

Table 15 Selected Price Indexes for Computing Equivalent Dollars

Index	1995	1998[1]
Consumer Price Index, CPI (All Categories)	152.4	162.2
Producer Price Index, PPI (All Categories)	124.7	124.9
[1]Average for January 1998 through May, 1998.		

Therefore, the estimated net present value for the cost of the entire system for the 10-year life cycle is $3,479. The equation used for this calculation is shown in Equation 5-1.

$$Cost = X + Y\frac{1}{(1+i)^n} \qquad \text{Equation 5-1}$$

Where $Cost$ = Present Value of System Costs (1995 Dollars)

X = Initial Capital Costs = $3,307.32

Y = Cost at end of Year 5 = $218.84

i = interest rate = 5.0%

n = number of interest periods = 5

System Benefit

Chapter 4 showed that platoon accommodation can improve the operational efficiency of isolated intersections through reducing delay and percent stops. The economic impact of this can be expected in the form of savings in vehicle hour savings and fuel consumption. The output from the trial for Period 3 configuration D-100 discussed in Chapter 4 was analyzed on the basis of fuel consumption. While there appeared to be a slight reduction for all approaches, this difference was not significant at the 0.05 significance level. Therefore, this benefit analysis was based solely on vehicle hour savings for this trial. This is considered to be a conservative approach to the benefit analysis.

This approach used a very conservative estimate to determine a lower bound on the benefits. It was assumed that over the 10-year life of the system there would be an average of 40 weeks a year in which 5 days of the week would have at least 4 platoons on the southbound approach. Table 16 shows the value of time for different vehicle types.

Table 17 shows a detailed description of how the total benefit is calculated for the 10-year life cycle of the system. It should be noted that in the future this process would likely involve the calculation of benefits from the reduction in fuel consumption. This benefit will be included into the calculation as an annual benefit added to that of the travel time reduction amount prior to converting the annual benefits to a net present value.

Table 16 Value of Time for Different Vehicle Types

Vehicle Type	Index	Base Year	Value of Time (Base Year $)	Value of Time (1995 $)
Passenger Car	CPI	1987	$6.00[1]	$8.03
Single Unit Truck	PPI	1990	$25.42[2]	$27.26
Combination Truck	PPI	1990	$28.33[2]	$30.38
[1] [Reiss and Dunn, 1991] [2] [Federal Highway Administration, 1995]				

Table 17 Description of Benefits of System for Conservative Case

Description	Amount
15 Minute Volume for Southbound Approach =	91
Percent Passenger Cars =	98%
Percent Single Unit Trucks =	1%
Percent Combination Trucks =	1%
Cars per 15-minute period =	89
Single Unit Trucks per 15-minute period =	1
Combination Trucks per 15-minute period =	1
Time Saved for Autos =	622.8 Seconds
Time Saved for SU Trucks =	7.2 Seconds
Time Saved for Combination Trucks =	7.2 Seconds
Value of Passenger Car Time Saved =	$1.39
Value of Single Unit Truck Time Saved =	$0.05
Value of Combination Unit Truck Time Saved =	$0.06
Benefit for Whole Platoon =	$1.50
Number of Platoons a Day =	4
Number of Days a Week =	5
Number of Weeks a Year =	40
Year Savings =	$1200
Number of Years =	10
Interest Rate =	5.0%
Net Present Benefit of 10 Year Life[1] =	$9266
[1] Calculated using Uniform Series Present Worth Factor for 5.0% interest for 10 years (see Equation 5-2).	

$$Benefit = A\frac{(1+i)^n - 1}{i(1+i)^n} \qquad \text{Equation 5-2}$$

Where

$Benefit$ = Present Value of System Benefits (1995 Dollars)

A = Annual Benefits = $1,200

i = interest rate = 5.0%

n = number of interest periods = 10

For this case it can been seen that the benefits of the system exceed those of the cost. In the example above, the benefit/cost ratio was 2.66 and the net present value was $5,787. It is believed that this is a conservative estimate of the system's potential benefits. Once a better understanding of the various parameters is obtained, this value is expected to improve.

CHAPTER 6 PLATOON DISPERSION

One of the fundamental assumptions of this research is that platoons exist and CORSIM reasonably models their dispersion. It's well known that groups of vehicles, also known as platoons, form at signalized intersections and behind slow moving groups of vehicles. For example, in Figure 31a, a dense platoon is shown. If that figure is assumed to be characteristic of a platoon arriving at a downstream intersection, significant benefits will accrue by coordinating the start of green with the arrival of the platoon. Similarly, Figure 31b shows a moderately dense platoon. Although not as dense as Figure 31a, significant benefits will accrue by coordinating the start of green with the arrival of the platoon shown in Figure 31b. However, Figure 31c shows a platoon that has almost entirely dispersed and would not warrant coordinating a down stream signal for.

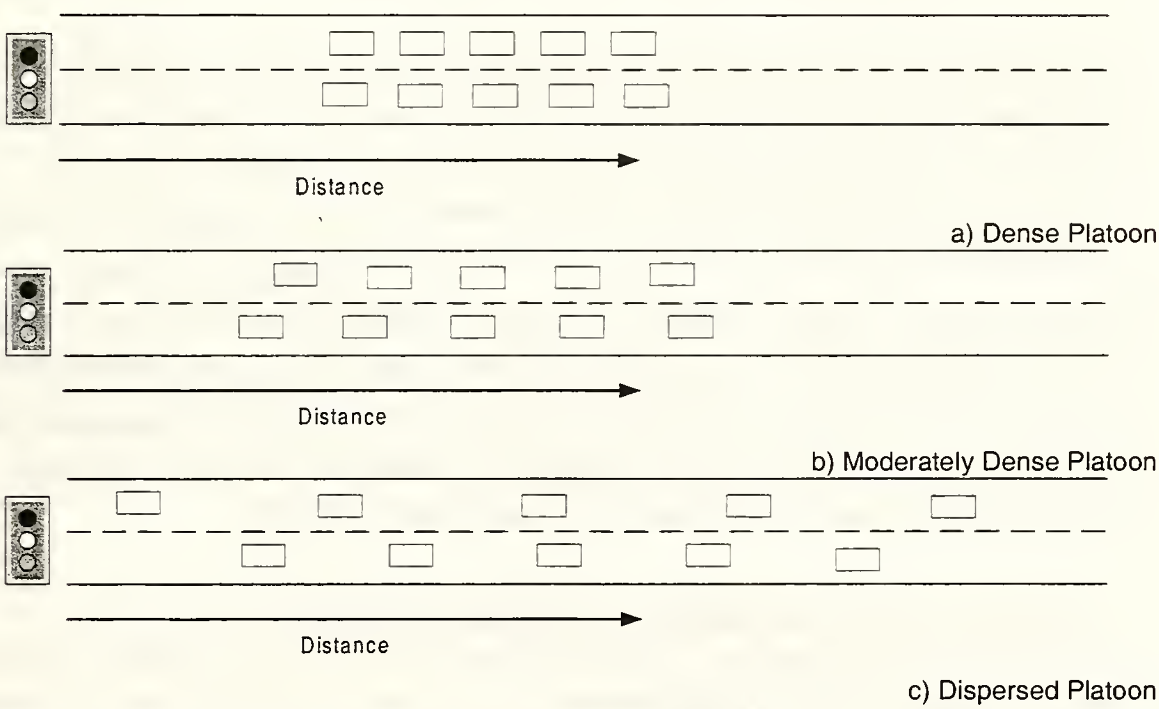


Figure 31: Example Vehicle Platoons.

Literature Review

There have been several papers published that describe various platoon dispersion models. The earliest reported work is on diffusion theory [Pacey, 1956, Rouphail et al, 1992]. That model states that if speeds in a platoon are normally distributed, then the dispersion of vehicles in the platoon can be described by the dispersion in speeds. Subsequent research led to the development of the recurrence model, an empirical platoon dispersion model using a discrete iterative technique. The recurrence model is also known as the Robertson's model [Rouphail et al, 1992, Robertson ,1969] utilized in the TRANSYT software package. The Robertson model operates under the assumption of the binomial distribution of vehicle travel time and is considered an improvement on the Pacey model [Rouphail et al, 1992, Denney, Richard ,1989] because of the ease of computation.

Many researchers have used data collection procedures similar to the one presented in subsequent sections of this report. However, much of the previous research has focused on calibrating the platoon dispersion parameters used in computer programs such as TRANSYT [Rouphail et al, 1992,Manar, Baass, 1996, Baass,et al, 1988, McCoy,,1983, Castle,1985]. Denney tested the diffusion and recurrence models that are used to replicate platoon dispersion. Manar and Baass and Baass and Lefebvre researched the effects of external and internal friction on the calibration factors respectively. Castle and Bonniville researched the calibration of TRANSYT dispersion factors with respect to long road links. Several other researchers have also suggested their own calibrated dispersion factors [McCoy, 1983, Sneddon,1972, Collins and Gower, 1974, Lam, 1977].

The Robertson model is represented by the following equation:

$$q_2(j) = \frac{1}{1+\alpha\beta\tau} q_1(j) + (1 - \frac{1}{1+\alpha\beta\tau}) q_2(j-1)$$

Where:

α = *platoon dispersion factor,*

β = *travel time factor,*

τ = *average travel time*

The Robertson model is a platoon diffusion model that can be used to develop histograms that represent a platoon as it proceeds downstream. The histograms developed by this model can be used for the purpose of signal optimization and network analysis. The TRANSYT software uses the flow histogram at the upstream traffic stop bar and transforms it using the Robertson model to obtain the arrival pattern at the downstream signal. The model can be varied by changing the platoon dispersion factor, α, and the travel time factor, β. The TRANSYT manual suggests values for these two parameters for a variety of conditions and many researchers have performed additional research calibrating and analyzing these parameters [McCoy, 1983, Sneddon,1972, Collins and Gower, 1974, Lam, 1977].Table 18 shows the suggested platoon dispersion factors from previous research.

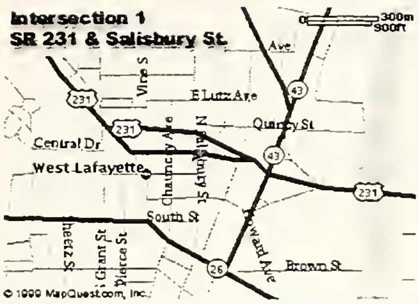
Table 18: Suggested Platoon Dispersion Factors from Previous Research.

Type of Arterial	α	β	$\alpha\beta$	**Reference:**
Four-lane divided	0.15	0.97	0.146	McCoy
Low External Friction	0.25	0.80	0.200	TRANSYT-7F manual
Moderate External Friction	0.35	0.80	0.280	TRANSYT-7F manual
Heavy External Friction	0.50	0.80	0.400	TRANSYT-7F manual
Two-way two-lane	0.21	0.97	0.204	McCoy
Three-lane dual carriageway (10-15% commercial vehicles)	0.40	0.80	0.320	Sneddon
Two-way road w/ two narrow lanes in direction studied	0.63	0.80	0.504	Sneddon
Three-lane dual carriageway (no commercial traffic)	0.20	0.80	0.160	Collins and Gower
Four-lane two-way suburban arterial street w/ left turn bays	0.24	0.80	0.192	Lam

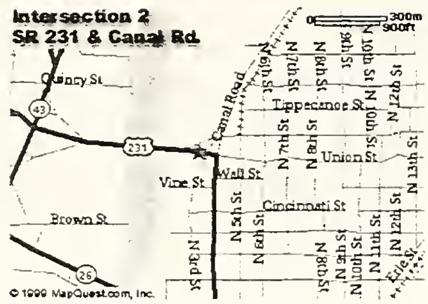
Our research procedure was similar to those already described to obtain actual platoon dispersion data from the field. Although previous research is invaluable for users of the TRANSYT software it is not tabulated in a manner that allows comparison with microscopic simulation models or useful for estimating an upper bound on the arrival types defined in Table 9-2 of the Highway Capacity Manual. In this research we have developed a graphical method by which the percentage of traffic arriving at a downstream traffic signal during an allocated green time can be estimated. This is not only important for evaluating the CORSIM model, but it is also useful to practitioners that need to estimate an upper bound on the arrival type used in chapter 9 of the Highway Capacity Manual.

FIELD WORK

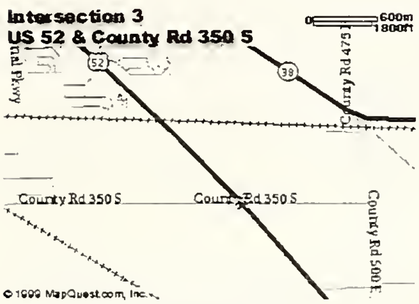
Several field data collection sites were selected such that a downstream-signalized intersection would not interfere with the platoon (Figure 32). To insure that a downstream-signalized intersection would not impact the platoon, sites were chosen with a distance of at least 5000 feet between signalized intersections. It was also desirable to have a minimal impact on the platoon from merging and diverging vehicles. Therefore, sites with a minimum number of side streets and driveways were selected. Data collection occurred during peak and off-peak hours in order to gain platoon dispersion data for varying sizes of platoons. Table 19-a shows the number of platoons collected in the field for each combination of speed, platoon discharge and downstream distance. Table 19-b shows the number of vehicles collected for the same combinations of speed, platoon discharge and downstream distance.



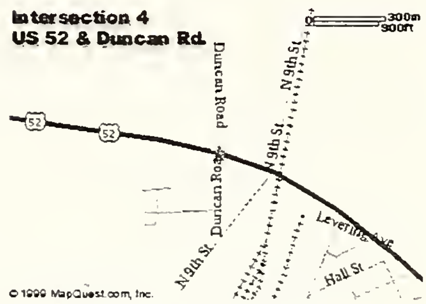
a) U.S. 231 and North Salisbury
location in West Lafayette, IN.



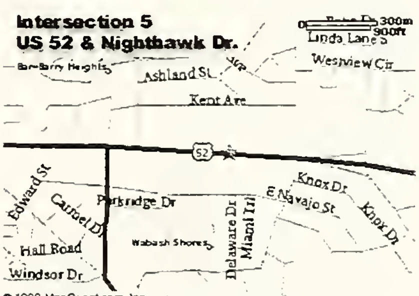
b) U.S. 231 and Canal Rd.
location in Lafayette, IN



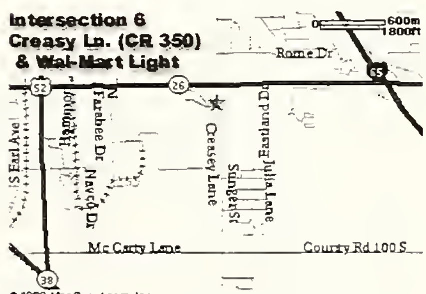
c) U.S. 52 and CR 350 S
location in Lafayette, IN.



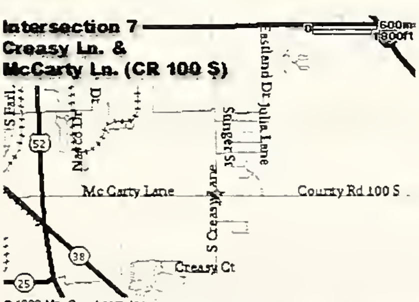
d) U.S. 52 and Duncan Road
location in Lafayette, IN.



e) U.S.52 and Nighthawk Dr.
location in West Lafayette, IN.



f) Creasy Lane at Wal-Mart
location in Lafayette, IN.



g) Creasy Lane at CR 100 S
location in Lafayette, IN.

Figure 32: Data Collection Sites

Table 19: Number of Data Points Collected at Each Distance for Varying Speeds and Initial Discharge.

a) Number of Platoons in Each Cell

Speed (mph)	Discharge (sec)	D/S Distance (ft)								
		500	1000	1500	2000	2500	3000	3500	4000	4500
30	10	22	22	20	11	17	14	2	-	-
	20	8	8	19	26	19	15	8	-	-
	30	4	1	3	15	10	10	5	-	-
	40	11	17	4	7	1	1	2	-	-
40	10	20	7	23	23	20	19	21	21	-
	20	7	2	11	11	11	11	18	17	-
50	10	8	9	9	10	9	9	9	8	8
	20	6	5	5	9	10	8	5	5	5
55	10	10	-	11	9	5	4	7	8	-
	20	3	-	1	2	1	1	1	-	-
60	10	5	8	12	12	8	8	5	5	5
	20	10	10	9	11	12	11	5	5	5

b) Number of Vehicles in Each Cell

Speed (mph)	Discharge (sec)	D/S Distance (ft)								
		500	1000	1500	2000	2500	3000	3500	4000	4500
30	10	101	108	92	67	77	73	8	-	-
	20	66	70	184	323	188	159	64	-	-
	30	50	15	39	250	142	159	63	-	-
	40	215	338	65	144	15	35	37	-	-
40	10	78	31	87	108	79	79	88	88	-
	20	92	27	117	116	92	99	150	143	-
50	10	35	37	40	41	37	42	41	60	60
	20	53	64	64	113	132	109	67	67	67
55	10	36	-	45	17	13	14	17	31	-
	20	25	-	7	15	10	11	4	-	-
60	10	33	32	63	63	46	46	29	29	34
	20	131	130	84	126	144	132	62	62	53

A Hewlett Packard 48GX scientific calculator was used to record the observations. One HP 48 was used to record the signal transition times and a second HP 48 was used to record downstream arrival times of every vehicle. Five keys on the calculator were programmed for the upstream observer at the traffic signal.

To start the data collection for a site, a reference time was recorded and displayed on the calculator using two pre-programmed keys. The signal observer used three pre-programmed keys to collect information about the intersection. The three pre-programmed buttons were start of green, end of green and vehicle count. The signal observer used the vehicle count key to record each time that a vehicle enters the downstream side of the arterial. This count included vehicles performing through movements through the intersection as well as vehicles making left and right turns onto the downstream side of the arterial. The start of green and end of green was recorded using the two remaining pre-programmed buttons. The sampling locations are illustrated in Figure 33. Initially the size of the platoon is limited by the length of the green time, which is recorded by the signal state observer. As the platoon travels downstream it becomes dispersed because vehicles in the platoon maintain different speeds.

The calculator used by the downstream observer was programmed the same as the calculator used at the upstream end. However, since the downstream observer was not observing the traffic signal, it was only necessary to record the vehicle arrival times at the downstream location. The downstream observations occurred at 500-foot intervals from the upstream traffic signal. The vehicle arrival observer recorded the times that vehicles within the platoon arrived at his location. This information is correlated with the departure times that are recorded by the signal state observer. Relevant platoon arrivals are vehicles that were released by the upstream traffic signal during a green time. Data obtained from these vehicles was used to generate downstream histograms for the platoon.

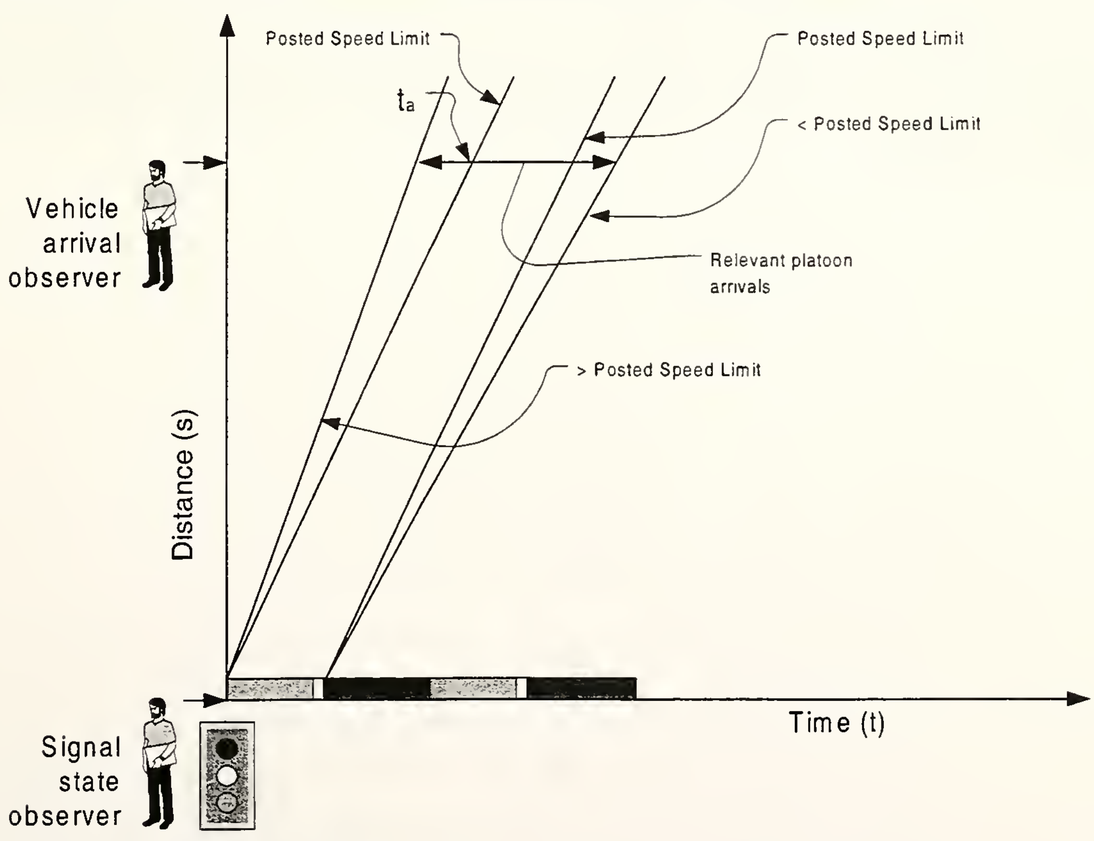


Figure 33: Sampling Procedure.

DATA PROCESSING

The data collected by the calculators was downloaded to a desktop computer using the serial ports on the computer and HP 48. The data was extracted into a database using the MS Visual Basic Data Access Object. The database consisted of six tables: the intersection table, the observation table, the field green table, the field data table, the CORSIM green table and the CORSIM data table. Table 20 describes the attributes of the various tables included in the database and Figure 34 illustrates the relational schema. The intersection table includes a sketch of the intersection and an average value for the speed of traffic at the intersection. The observation table includes information about the location and start time of the downstream observation. The location was recorded as the distance downstream from the upstream signal location. It also has information regarding the physical characteristics of the site including the number of lanes and the width of each lane. The field green table contains the green start times and green end times for the upstream traffic signal. The field data table has each vehicle ID number recorded and the time that they arrived at the downstream observer. The vehicle ID number is simply a sequential number assigned to each vehicle by the software. The first vehicle recorded would be numbered one and each subsequent vehicle is numbered by an increment of one. The CORSIM green and CORSIM data tables are used to save the simulation data generated by the CORSIM traffic simulation software.

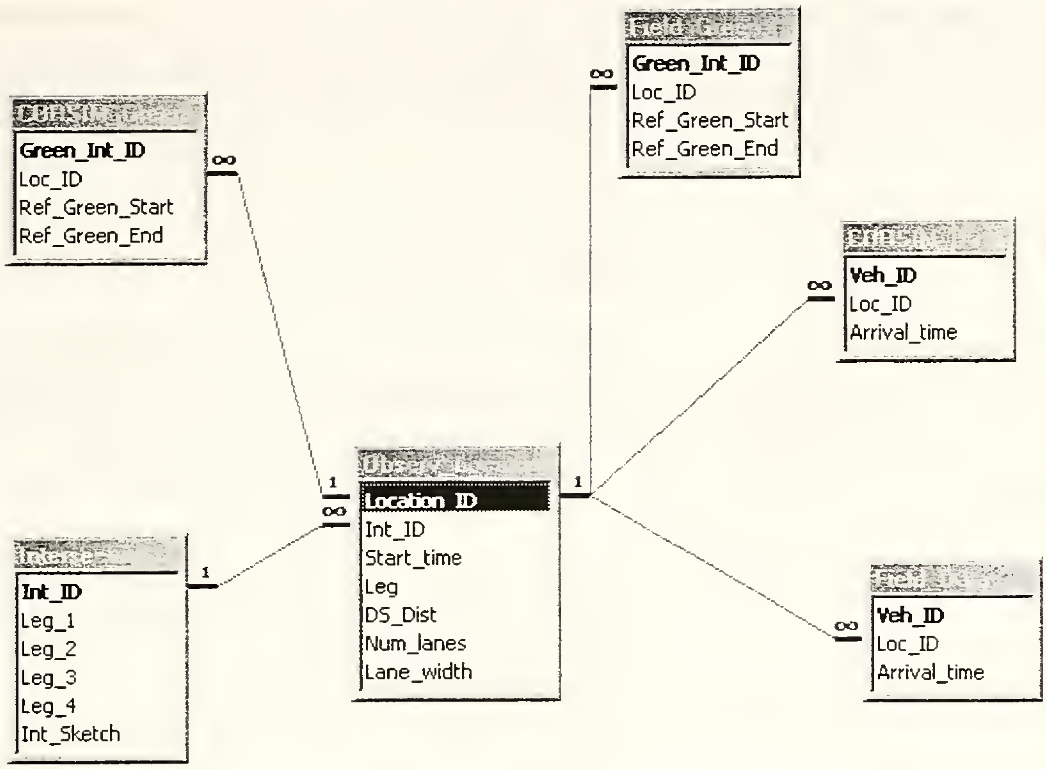


Figure 34: Database Schema

Table 20: Database Field Definitions

Table Name	Term	Definition
Observations	Observation_ID	Uniquely identifies a specific data collection point and time.
	Int_ID	A unique identifier for each location where data was collected.
	Start_time	Approximate base starting time (nearest second) and date
	Leg	Number of Legs in each intersection
	DS_Dist	Distance downstream to the observation location measured from the upstream-signalized intersection.
	Num_lanes	Number of lanes at observation location.
	Lane_Width	Approximate lane width at observation location.
Field_Data	Veh_ID	Sequential ID numbers for each vehicle.
	Observation_ID	Uniquely identifies a specific data collection point and time.
	Arrival_time	The time at which a vehicle arrives at the downstream observation location, measured in seconds since the start of the collection time.
Field_Green	Green_Int_ID	Sequential ID numbers for each platoon.
	Observation_ID	Uniquely identifies a specific data collection point and time.
	Ref_Green_Start	Reference to start of green time.
	Ref_Green_End	Reference to end of green time.
Intersection	Int_ID	A unique identifier for each location where data was collected.
	Leg_1, Leg_2, Leg_3, & Leg_4	Text description of the name of Leg_1, Leg_2, Leg_3 and Leg_4
	Int_Sketch	Sketch of the data collection site.
	Veh_Speed	Average speed of vehicles at the observation location.
CORSIM_Data	Veh_ID	Sequential ID numbers for each vehicle in CORSIM Simulation
	Observation_ID	Uniquely identifies a specific data collection point and time in CORSIM Simulation
	Arrival_time	The time at which a vehicle arrives at the downstream observation location, measured in seconds since the start of the collection time in CORSIM Simulation
CORSIM_Green	Green_Int_ID	Sequential ID numbers for each platoon in CORSIM Simulation
	Observation_ID	Uniquely identifies a specific data collection point and time in CORSIM Simulation
	Ref_Green_Start	Reference to start of green time in CORSIM Simulation
	Ref_Green_End	Reference to end of green time in CORSIM Simulation

After the data was organized into the database it could be easily retrieved for analysis. Using the query tool within the database, the data needed for analysis could be extracted and analyzed in a spreadsheet. An example of data contained in the database is provided in Table 21.

Table 21: Summary of Data Contained in Database (Example Data)

Intersection Data Table:

Intersection ID	Intersection Sketch	Avg. Vehicle Speed (mph)
4	i4.jpg (photo)	50
5	i5.jpg (photo)	60
6	i6.jpg (photo)	40

Observation Data Table:

Observation ID	Intersection ID	Downstream Distance (feet)	Number of Lanes	Lane Width (feet)
1	1	500	2	12
2	1	1000	2	12
3	1	1500	2	12

Field Green Data Table:

Observation ID	Ref. Green Start	Ref. Green End
1	3.705078	32.55505
1	65.40063	104.8799
1	143.9196	186.3683

Field Data Table:

Vehicle ID	Observation ID	Vehicle Arrival Time
471	1	32.1284
472	1	34.52232
473	1	36.54966

DATA ANALYSIS

Field data, simulation, and theoretical models were analyzed in this research. The objective was to quantify the percentage of platoon that could pass through a particular green time window downstream given the downstream distance and the initial platoon discharge. Field observed data was compared with that obtained from CORSIM and the Robertson model to determine how well CORSIM modeled field conditions

FIELD DATA REDUCTION

A platoon is initially limited in size by the green window at the upstream location. As the platoon travels downstream, it disperses because of vehicles in the front of the platoon traveling faster than the speed limit and vehicles at the end of the platoon traveling slower than the speed limit. However, a platoon is expected to reach a downstream location within an expected range of time depending on the downstream distance, average travel speed, and initial platoon discharge length. The time t_a in Figure 33 represents the expanded time during which the dispersed platoon is expected to arrive. This time is obtained by projecting the upstream green window using a speed faster than the speed limit to locate the start of t_a and a speed lower than the speed limit when locating the end of t_a.

Field data reduction was therefore performed in two steps: The first step was to extract the vehicle arrival times lying within the time period t_a from the data base using a data base query, and the second step was to extract the platoon from that window.

Different traffic conditions (gaps between successive platoons) were observed to affect the speed of platoon, making it a nontrivial task to predict the exact time of platoon arrival at the downstream location within the extracted window. A platoon was hence recognized within the t_a window as a group of narrow gapped vehicles that came immediately after a wide gap measured from the start of t_a.

CORSIM SIMULATION

CORSIM simulations were run for different combinations of travel speed and initial platoon discharge lengths that replicated observed field data conditions. Initial platoon discharge predetermined lengths were obtained by putting the main street traffic in oversaturated condition and setting the main street green time to the required length. This insured that the green time would be fully utilized by the waiting vehicles. The arrival time of vehicles at particular downstream distances at 500 ft. intervals were obtained by the extracting vehicle positions from the CORSIM animation file. Start of platoon was easily identified in the simulation part of the analysis since no right turn on red were allowed in simulation. The headway gap between different platoon was made distinguishable by setting long side-street greens with no traffic at that period.

DETERMINATION OF GREEN WINDOWS FOR PARTICULAR PERCENTAGES OF PLATOONS

The green-windows needed for particular percentages of platoon to pass through were determined by analyzing the vehicle arrival times. After the different platoons were identified, arrival times of vehicles in each platoon were referenced to the arrival time of the start of their platoon. A histogram analysis was then conducted for all the platoons at different downstream locations to determine the percentage of platoons arriving at different points in time measured from the start of platoon. Figure 35 shows the platoon distribution for a 20-second initial platoon discharge and a 30 MPH posted speed limit.

The histogram plots were useful to find the green window required for different percentages of the platoon at varying downstream distances. The green window needed represents the time required for a certain percentage of the platoon to pass when the first vehicle in the platoon arrives at the start of green at a certain downstream location. For example, t_{50} for Figure 35-e would represent the time that it takes for 50% of a platoon to pass an observation point 2000 ft. downstream. In other words, t_{50} is the time difference between the passage of the 50^{th} percentile vehicle and the first vehicle.

In order to obtain the percentage of platoon passing at each cumulative bin time, the histograms were standardized by dividing the number of vehicles in each bin range by the total number of vehicles in the analysis period. The time at which specific percentages of the platoon (e.g. 100%, 95 %, 75%, 50%, and 25%) passed were then determined by interpolation.

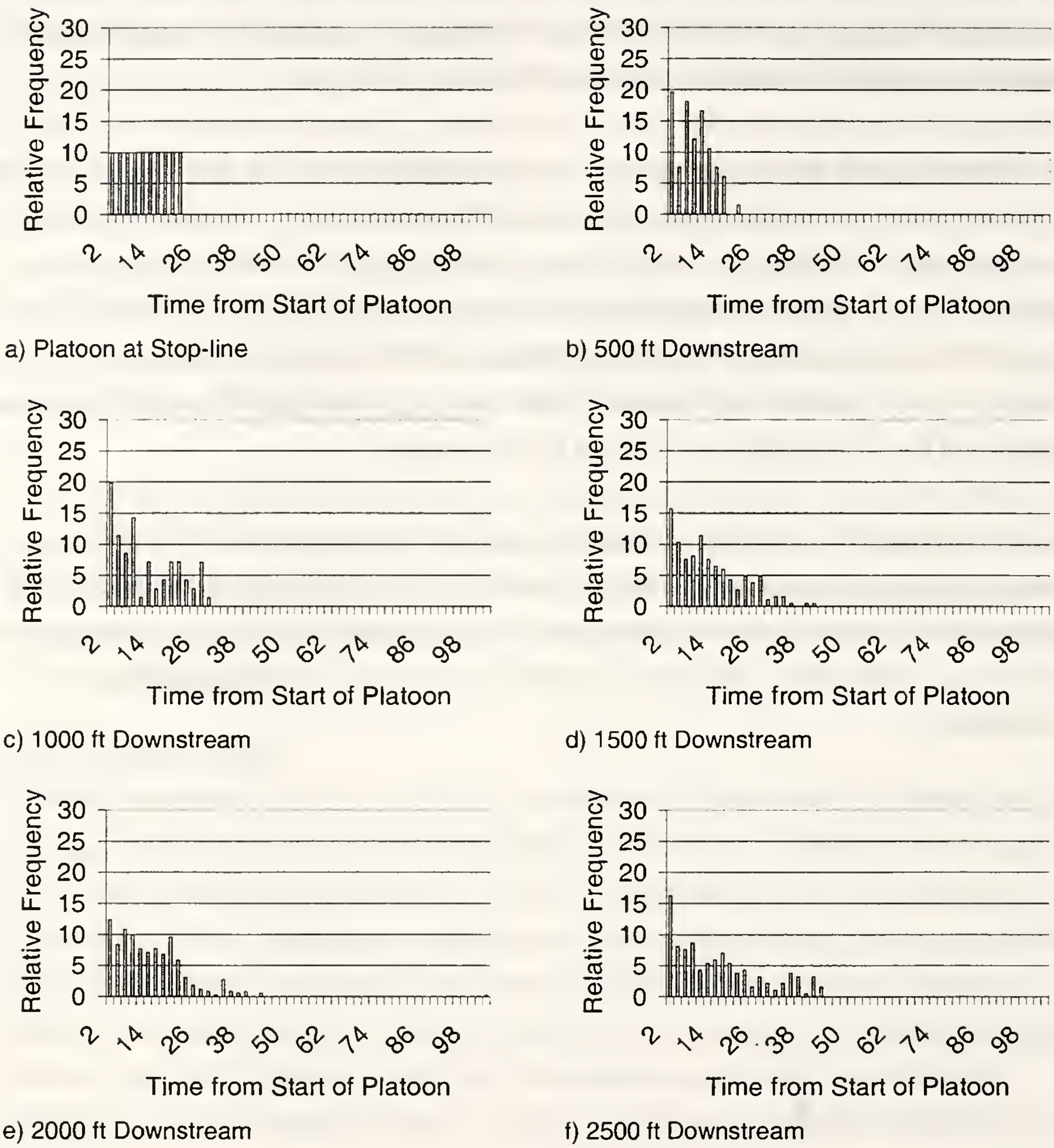


Figure 35: Platoon Distribution at Various Downstream Observation Points

PLOTS OF GREEN WINDOWS REQUIRED BY DIFFERENT PERCENTAGES OF THE PLATOON

Times at which predetermined percentages (100%, 95 %, 75%, 50%, and 25%) of the platoon passed when the first vehicle in the platoon arrived at the start of green were tabulated and plotted versus several downstream locations. The plots were produced for 30 and 40 mph posted speed limit and an initial platoon discharge of 20 seconds. A regression analysis was then conducted for arrival times for the specified percentages of the platoon versus the downstream distance and resulting regression models were used to plot the relationships. For example, the time at which 75% of the platoon passed could be determined by the regression model:

$$t_{75} = a_{75} + b_{75}X + c_{75}X^2$$

Where:

a = the intercept,

b = the linear coefficient,

c = the quadratic coefficient,

t_{75} = time at which 75% of the platoon pass,

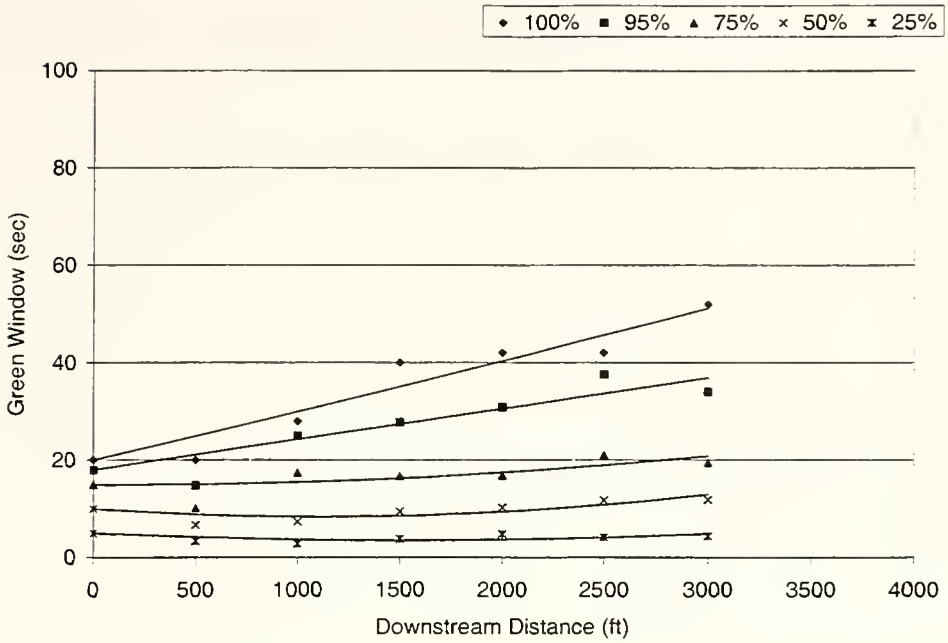
X = the downstream distance in thousand feet.

Theoretical Histograms obtained from Robertson model for 20, 40, and 60 seconds discharge platoons and speed limit of 30, 40, and 50 miles per hour are presented in appendix B. Arrival times and green window's plots for the same platoon discharge and speed limits are also presented in appendix B.

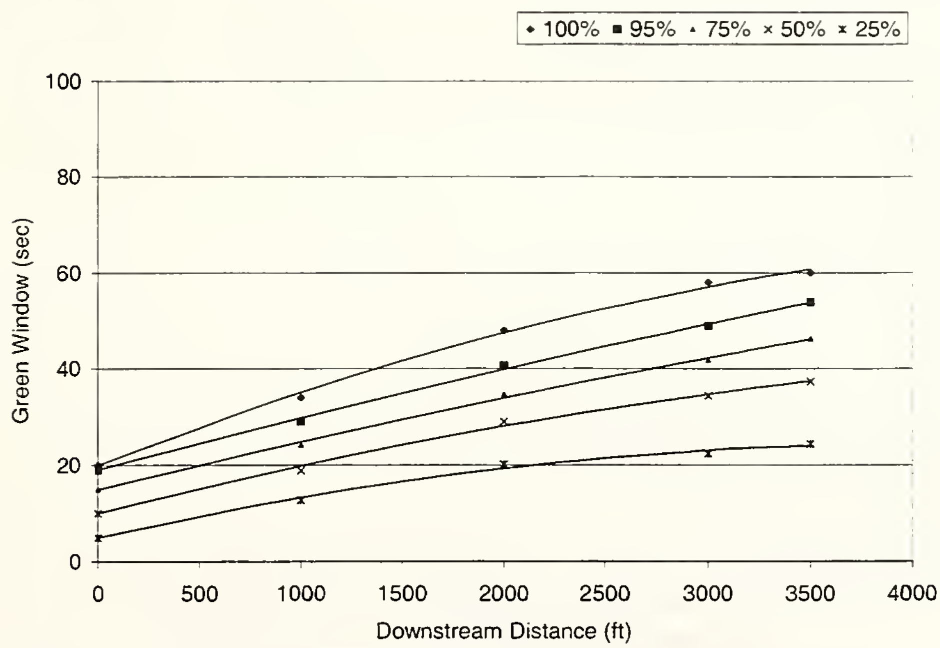
Table 22 summarizes the regression analysis coefficients for reduced data and CORSIM simulation. Figure 36 and Figure 37 show plots of row data with regression lines for the observed field data and CORSIM data, respectively.

Table 22: Regression Analysis Coefficients for Data and CORSIM Simulation

Green Window required to pass X% of the platoon (t_x)	Equation $t = a + bX + cX^2$ Coefficients		
	a	B	c
a) Field Data (20 second saturated platoon, Speed: 30 MPH)			
t_{100}	20.00	9.70	0.22
t_{95}	18.00	6.24	0.02
t_{75}	15.00	-0.22	0.72
t_{50}	10.00	-2.87	1.29
t_{25}	5.00	-1.87	0.61
b) Field Data (20 second saturated platoon, Speed: 40 MPH)			
t_{100}	20.00	11.38	-0.20
t_{95}	18.00	9.97	-1.17
t_{75}	15.00	1.37	0.06
t_{50}	10.00	0.47	-0.06
t_{25}	5.00	-0.65	0.18
c) CORSIM Simulation (20 second saturated platoon, Speed: 30 MPH)			
t_{100}	20.00	16.56	-1.41
t_{95}	19.00	11.11	-0.33
t_{75}	15.00	10.23	-0.38
t_{50}	10.00	10.67	-0.81
t_{25}	5.00	9.42	-1.13
d) CORSIM Simulation (20 second saturated platoon, Speed: 40 MPH)			
t_{100}	20.00	11.38	-0.21
t_{95}	19.00	6.90	0.45
t_{75}	15.00	6.31	0.35
t_{50}	10.00	6.62	0.03
t_{25}	5.00	5.87	-0.25

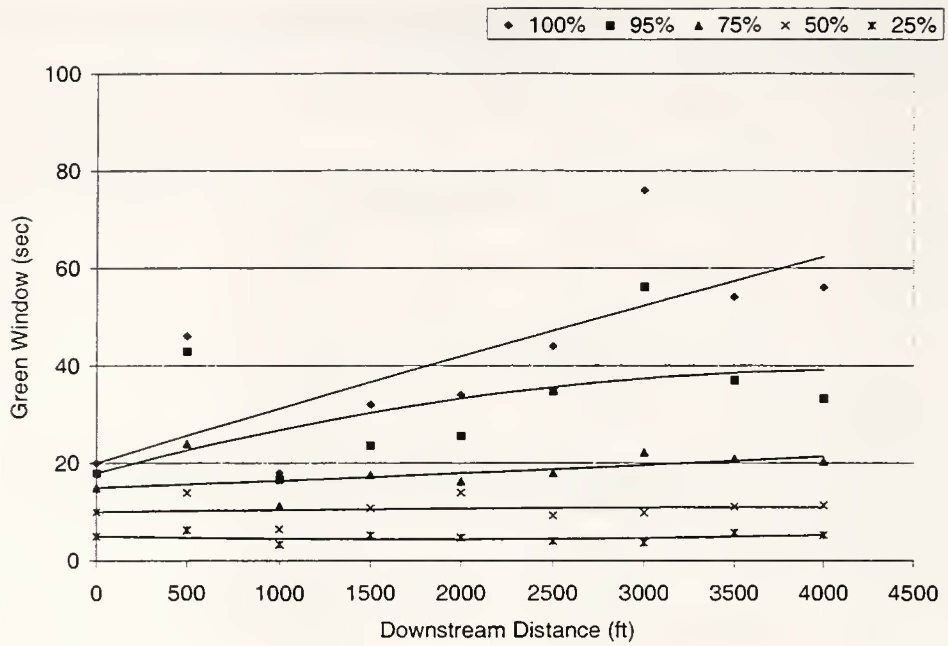


a) Reduced field data.

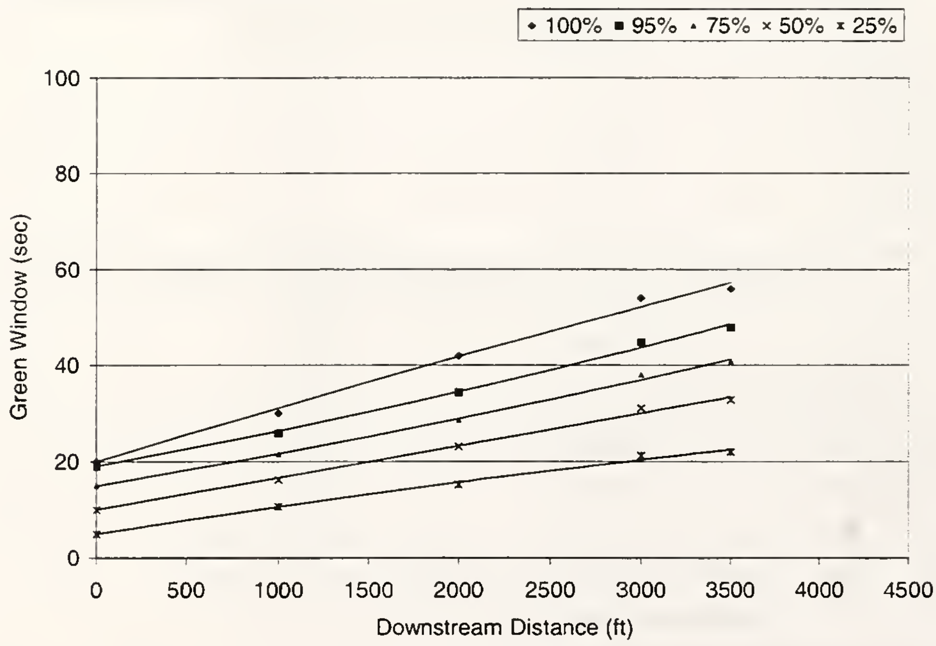


b) Reduced data from CORSIM simulation.

Figure 36: Platoon Dispersion (20 Second Saturated Platoon, Speed: 30 MPH)



a) Reduced field data.



b) Reduced data from CORSIM simulation.

Figure 37: Platoon Dispersion (20 Second Saturated Platoon, Speed: 40 MPH)

THEORETICAL MODELS

The Robertson model is a popular platoon dispersion model because it allows the user to transform an upstream platoon histogram into a histogram representing the platoon further downstream. With the aid of a computer spreadsheet it was relatively simple to transform histograms using the Robertson model. The spreadsheet developed for this research allowed the user to vary the average arterial speed, the initial platoon size and the platoon dispersion parameters. The parameters used to generate the histograms were the ones suggested by the TRANSYT manual for low, moderate and heavy external friction as well as those suggested by McCoy for a typical four-lane two-way arterial. Histograms were generated for the platoon dispersion parameters at speeds of 30 and 40 MPH for saturated platoons of 20 seconds. Arrival times were calculated for 5, 25, 50, 75, 95, and 99 percent of the platoon using the theoretical Robertson model. The arrival time graphs were adjusted to reference time to the arrival time of the first vehicle in a platoon. The graphs developed using the Robertson model are presented in Figure 38 and Figure 39. Appendix B contains all the graphs obtained from Robertson model for 20, 40, and 60 seconds platoon discharge and speed limit of 30, 40, and 50 miles per hours for the same model parameters of Figure 38 and Figure 39.

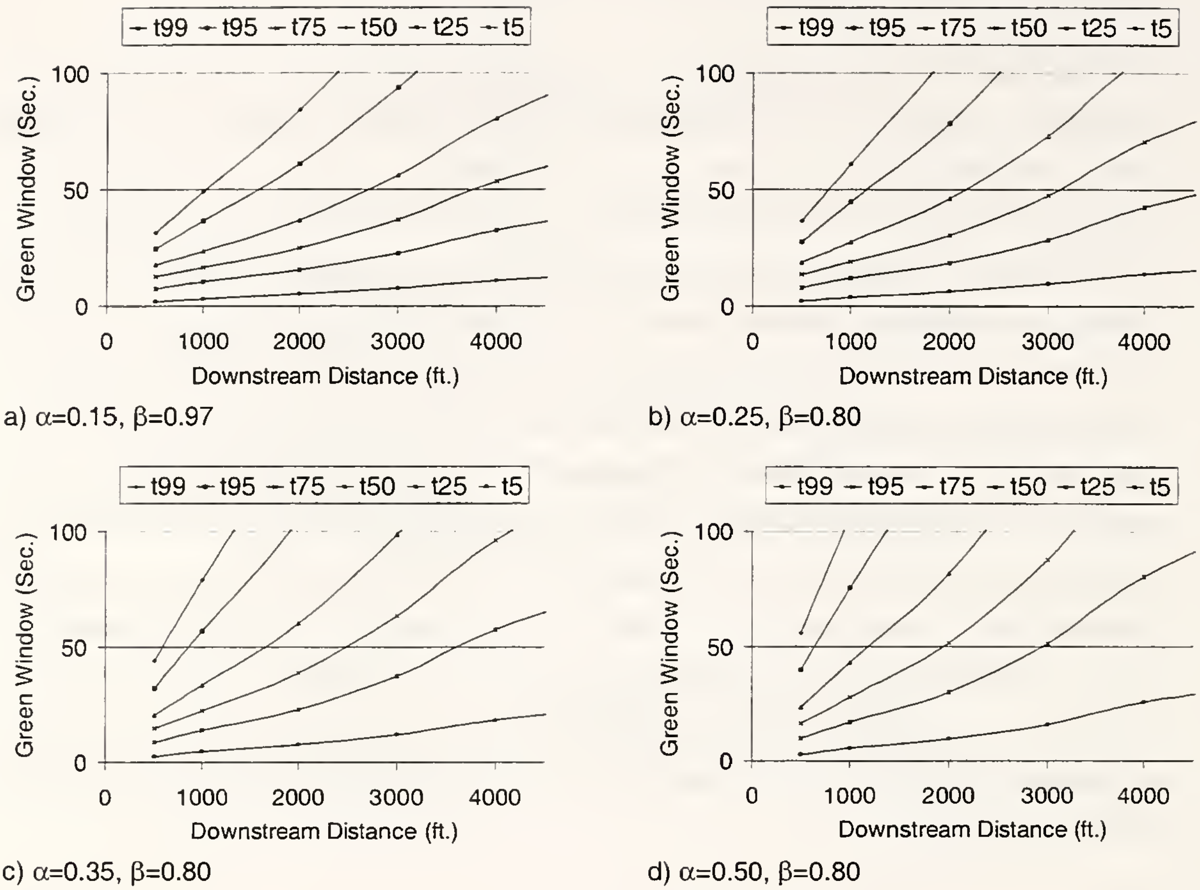
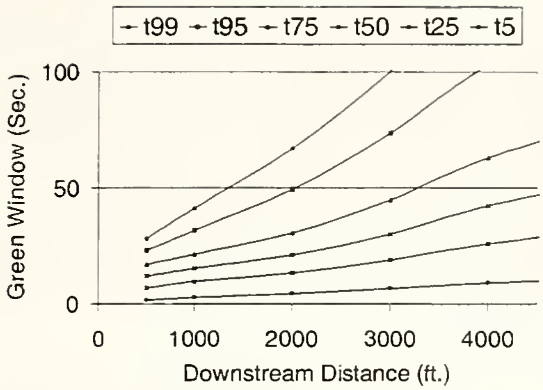
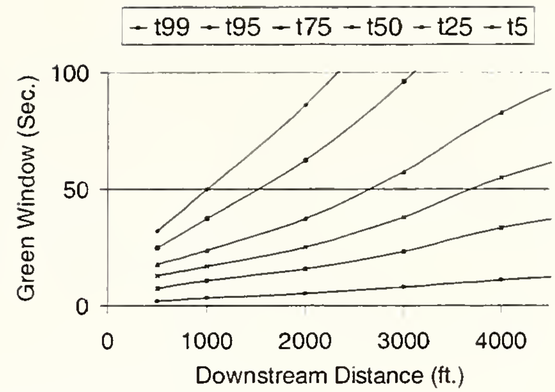


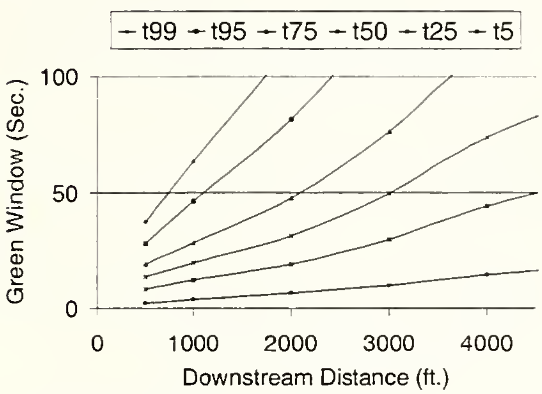
Figure 38: Green Window From Robertson's Model (20 second saturated platoon, Speed: 30 MPH)



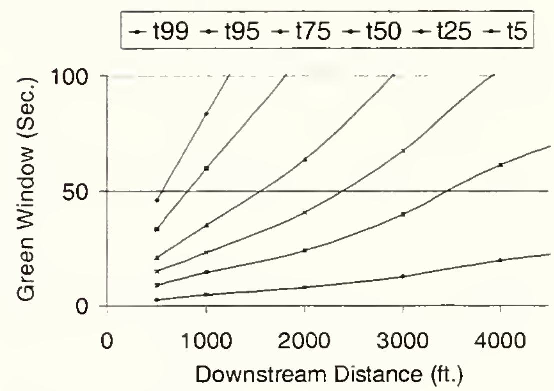
a) α=0.15, β=0.97



b) α=0.25, β=0.80



c) α=0.35, β=0.80



d) α=0.50, β=0.80

Figure 39: Green Window From Robertson's Model (20 second saturated platoon, Speed: 40 MPH)

DISCUSSION

Several interesting trends can be observed in the figures produced in this study. As the arterial speed is increased, the platoon will obviously reach each downstream location much more quickly. The size of the platoon discharge will also effect its behavior as it proceeds downstream. In this paper, platoons with a saturated discharge of 20 seconds were presented because the best sample size distribution was obtained for the field data collected for that period. This is illustrated by examining Table 19.

Although obviously dependent on the model coefficient, the theoretical Robertson model demonstrated platoon dispersion that was much larger than the reduced field data or CORSIM simulation. As the product of the two platoon dispersion parameters increased, the platoon disperses even more quickly in the Robertson model. This is illustrated by comparing Figure 38d with Figure 38a and Figure 39d with Figure 39a.

CORSIM simulation demonstrated an overall platoon dispersion similar to the field data, as can be seen by comparing Figure 36 and Figure 37. However, the CORSIM simulation package tended to have more platoon dispersion in the beginning of the platoon when compared to the real data. For example, Figure 36b and Figure 37b show that the lines for 25% of the platoon are much higher than their equivalents in Figure 36a and Figure 37a. This trend is probably because of the car following logic in the CORSIM simulation that tends to more aggressively disperse the front vehicles in the platoon. This logic makes CORSIM simulation somewhat conservative in quantifying the benefits of coordinating downstream signals for smaller green windows downstream as it suggests that a smaller percentage of the platoon benefits from that coordination.

The graphs presented in this report provide valuable information when evaluating the benefits of coordinating two traffic signals by quantifying the percentage of platoon that would benefit of a particular green window provided at the downstream intersection. Or alternatively suggesting the green time required at the downstream intersection if a certain percentage of a platoon passage was desired.

The R_p ratio used in equation (9-7) in the Highway Capacity Manual uses the proportion of all vehicles in movement arriving during the green phase, the effective green time, and the cycle length to estimate the progression quality and hence the arrival type. The arrival type is one of the most important factors in determining the level of service for signalized intersections, yet it merely remains a general categorization representing the quality of progression in an approximate manner. If the offset of the traffic signal downstream was perfectly tuned such that the first vehicle in the platoon arrives at the start of green, then it would be possible to use the graphs presented in this paper to quantify the percentage of platoon that would pass through a particular green window provided downstream. This information allows the practitioner to determine an upper bound on the R_p ratio used in equation (9-7) in the Highway Capacity Manual to determine the arrival type, which in turn can be used to determine the level of service for signalized intersections.

To summarize, CORSIM modeled field conditions reasonably well, but tended to introduce more dispersion than observed in the field. Therefore, from an analysis perspective CORSIM would tend to underestimate the benefits of accommodating platoons. Consequently, the benefits tabulated in chapter 5 are likely on the conservative side.

CHAPTER 7 RECOMMENDATIONS

As was mentioned in Chapter 4, a sensitivity study is needed to provide additional insight into the parameters' individual and collective impact on the performance of the platoon accommodation algorithm in improving the operational efficiency of isolated intersections (Case D-100 for Period 3). Chapter 4 illustrated an example in which platoon accommodation had a significant positive effect on the intersection's operation. Chapter 5 has shown that the complete system can be an add-on feature to existing traffic control systems already deployed resulting in a cost which is quite low. Chapter 6 illustrated that the CORSIM platoon dispersion model is reasonable for this type of analysis. Because the potential of the system has been demonstrated, it is important the maximum possible benefits can be obtained when the system is implemented. To accomplish this additional research is needed. Therefore, it is recommended that a follow-up study be conducted for the following tasks:

1) A parameter study should be conducted to determine the sensitivity of all of the various parameters identified in this research including:

- Maximum Preemption Hold Time
- Minimum Preemption Hold Time
- Preemption Reservice Time
- Preemption Delay Time
- Preemption Inhibit Time
- Platoon detector location
- Minimum platoon size
- Maximum headway between first and last vehicles in minimum platoon size

2) A prototype field deployment should be conducted. This deployment will demonstrate the functionality of the various components under live traffic and provide real world data.

3) Warrants should be developed to provide guidance to INDOT for selecting intersections for early deployment.

Each of these tasks will be discussed below.

Parameter Sensitivity Study

As was discussed, Task 1 is necessary to provide further information as to the relative impacts of all the various parameters identified in this research effort. Through the development of the platoon accommodation algorithm and the preliminary evaluation of its potential effects, several key findings have been made relating to the configuration of the various parameters described in Table 8.

Table 23 summarizes these findings and defines the range of values to be examined is a parameter study. It should be noted that some of the comments for these parameters are based on the specific controller used in the original research effort. It is expected that the parameter study could be completed in six months.

Table 23 Summary of Information Regarding System Parameters

Parameter	Range	Comments
Minimum Platoon Size	5 - 25	This is one of the two parameters that control the sensitivity of the PLCs identification of platoons in the traffic stream. Through discussions held in study advisory committee meetings, it is felt that this number should range between 5 and 25 vehicles for isolated intersections.
Maximum Headway Between First and Last Vehicles in Minimum Size Platoon	5 – 20	This is the second of the two parameters that control the sensitivity of the PLCs identification of platoons in the traffic stream. The ranges of this parameter depend on the minimum platoon size and the number of lanes for which vehicles are being detected for platoon recognition.
Maximum Hold Time	0 – 30	It is thought that this parameter has little impact on the performance of the platoon algorithm. The reason for this is that one single call is placed to the controller to initiate the preemption sequence. The controller retains this call during the delay time if the locking memory setting of the preemptor is active.
Minimum Hold Time	0 – 15	This parameter does have a significant effect on the system. However, this value should be very low (likely zero) when the preempted approach has localized detection. In this case, the minimum hold is not needed because the local detectors can determine when the platoon has traversed the intersection.
Reservice Time	0 – 90	In situations when the minor phases have low to moderate volumes, this parameter should be set to zero. The controller has a reservice element already built into the preemption logic to guarantee that minor phases do not receive excessive delays from multiple preemption calls occurring within a short time span. Before the controller can reinitiate a preemption sequence that has terminated, it must service all phases on which detector calls are present.
Delay Time	0 – 45	This is an important setting for the strategy. It is a function of the distance of the detector upstream from the intersection, maximum platoon headway value, and average speed of platoon. When the minimum hold time is set low this setting must allow the proper amount of time to elapse for the platoon to reach the area of local detection.
Inhibit Time	0 – 20	This parameter influences the responsiveness of the controller to activating the beginning of a preemption hold. It should be set no lower than the maximum clearance time for any conflicting phase.
Detector Location	0.5 miles – 1.0 miles	This parameter is likely to have an impact on the operation of the system. Little effort has been spent on understanding the sensitivity of this parameter. However, the minimum distance should be no less than the average speed of the platoon multiplied by the sum of the inhibit time and the maximum platoon headway time.

Prototype Field Deployment

Due to the significant progress made in this research effort, the study advisory committee has recommended that a move be made towards prototype field deployment. It is felt that once the parameter study is completed, adequate information will exist to provide guidance as to the proper setting of the system. This section will provide some preliminary information as to how this task would be completed.

The prototype system will consist of a centralized processing approach (see Figure 14) similar to that of the expected permanent system. However, certain components of the prototype will differ from that of the envisioned system discussed in Chapter 5. The primary differences include the traffic detector and remote power supply that will be used. The RTMS unit manufactured by EIS, which was discussed in Chapter 3, will be the traffic detector used. INDOT already has one of these units in operation along the Borman Expressway that can be used for the prototype system [Boyd, 1998]. A portable generator will serve as the power supply for the remote site. INDOT can provide this equipment from one of its facilities, such as the Research Division located in West Lafayette, Indiana. The remaining equipment described in Chapter 5 including the programmable logic controller (PLC), radio equipment and traffic signal controller will be identical to the envisioned final system. These indicated changes are to allow for flexibility in testing several parameter combinations and to allow for quick set-up and take down in the field.

The prototype system is planned for deployment at one and possibly more intersections located in central Indiana. The intersection is likely to be in the jurisdiction of INDOT's Greenfield District Office. A site on U.S. 31 between Indianapolis and Kokomo has been discussed. The isolated intersection should be one in which a fully actuated controller is in use. The prototype will function as a mechanism to prove the functional operation of the equipment under live traffic conditions. It also serves as an information source for the completion of Tasks 1 and 3.

Warrants for System Deployment

To this date little has be done relevant to this task. A key component of this involves an understanding of the expected benefits of a well-calibrated installation. Task 1 should help in providing this information. Some possible concepts that may want to be incorporated into warrant guidelines include:

Minimum total volume for intersection,

Critical ratio between volumes on the major and minor roads, Relative speed difference between the major roads,

Development of some type of platooning index which could be easily applied, and

High number of rear-end type accidents along a roadway.

These concepts should serve as a starting point from which this task can develop.

Future Enhancements

This research has demonstrated that platoon accommodation can have a significant impact on the operational efficiency of an isolated intersection. In the future, it is likely that this strategy will evolve to increased levels of sophistication.

For example, the current system only detects platoons on one approach to the intersection. It is reasonable to infer that it would be desirable to have a strategy that will accommodate platoons from two or more directions. As this task of identifying platoons on multiple approaches develops, it may become necessary to monitor the current state of the signal in order to determine the accommodation technique that should be implemented.

The system architecture developed in the research effort can accommodate this expansion. The deployment of additional remote sites connected to the same communications system, which provides the PLC with vehicle arrival data, can be constructed. The program logic in the PLC can be modified to deal with multiple input sources and to provide multiple outputs enabling different accommodation strategies to be implemented. Therefore, there is great potential for this system to evolve through multiple generations when new strategies are conceived.

LIST OF REFERENCES

Alternative Energy Engineering. "Photovoltaic Solar Cells and Panels." http://www.asis.com/aee/, 1998.

Andrews, Christina M., S. Manzur Elahi and James E. Clark. "Evaluation of New Jersey Route 18 OPAC/MIST Traffic-
Control System." Transportation Research Record 1603. TRB, National Research Council, Washington D.C., 1997.

Baass, Karsten G. and Lefebvre, Serge. Analysis of Platoon Dispersion with Respect to Traffic Volume. *Transportation Research Record 1194,* TRB, National Research Council, Washington, D.C., 1988, pp. 64-76

Bang, K.L. "Optimal Control of Isolated Traffic Signals." Traffic Engineering and Control. 1976.

Boyd, Troy and Rick Anderson. Phone interview on June 2, 1998.

Boyd, Troy. Phone interview. Indiana Department of Transportation, 1998.

Bullock, Darcy and Alison Caterella. "A Real-Time Simulation Environment for Evaluating Traffic Signal Systems." Proceedings from the 77th Annual Meeting of the Transportation Research Board. Preprint #980837. TRB, Washington D.C., 1998.

Castle, David E., and Bonniville, John W. Platoon Dispersion over Long Road Links. *Transportation Research Record 1021,* TRB, National Research Council, Washington, D.C., 1985, pp. 36-44

Central Security. Phone Interview with Joe Ext. 22. Indianapolis, IN 1998.

Collins, J.F., and Gower, P. Dispersion of Traffic Platoons on A4 in Hounslow. *TRRL Report SR 29UC,* U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1974.

Dell 'Olmo, P., and P.B. Mirchandani. "REALBAND: An Approach for Real-Time Coordination of Traffic Flows on a Network." Transportation Research Record 1494. TRB, National Research Council, Washington D.C., 1985.

Denney, Richard W. Traffic Platoon Dispersion Modeling. *Journal of Transportation Engineering,* March 1989.

Econolite Control Products. "ECONOLITE ASC/2 SERIES NEMA TS1 & TS2 ACTUATED CONTROLLERS." http://www.econolite.com/, 1998.

Econolite Control Products. Advanced System Controller ASC/2 Programming Manual. Anaheim, CA, 1996.

Electronic Integrated Systems Inc. RTMS User Manual. North York, Ontario, Canada, 1998.

FHWA. "Real-Time, Traffic Control for IVHS." Solicitation Number DTFH61-92-R00001. United States Department of Transportation, Washington D.C., 1991.

FHWA. Estimating the Impacts of Transportation Alternatives. Report Number FHWA-HI-94-053. United States Department of Transportation, Washington D.C., 1995.

Gartner, Nathan H. "Discussion of Improved Estimation of Traffic Flow for Real Time Control." Transportation Research Record 95. TRB, National Research Council, Washington D.C., 1981.

Gartner, Nathan H. "OPAC: A Demand-Responsive Strategy for Traffic Signal Control." Transportation Research Record 906. TRB, National Research Council, Washington D.C., 1983.

Gartner, Nathan H., Chronis Stamatiadis, and Phillip J. Tarnoff. "Development of Advanced Traffic Signal Control Strategies for Intelligent Transportation Systems: Mulitlevel Design." Transportation Research Record 1494. TRB, National Research Council, Washington D.C., 1995.

Gartner, Nathan H., Philip J. Tarnoff and Christina M. Andrews. "Evaluation of Optimized Policies for Adaptive Control Strategy." Transportation Research Record 1324. TRB, National Research Council, Washington D.C., 1991.

GE Fanuc Automation. Series 90™ Micro PLC User's Manual. Charlottesville, VA, 1997.

Gordon, Robert I., R.A. Reiss, H. Haenel, E.R. Case, R.L. French, A. Mohaddes, and Wolcott. Traffic Control Systems Handbook. FHWA, United States Department of Transportation, Washington D.C., 1996.

Head, K. Larry, Pitu B. Mirchandani and Dennis Sheppard. "Hierarchical Framework for Real-Time Traffic Control." Transportation Research Record 1360. TRB, National Research Council, Washington D.C., 1992.

Head, K. Larry, Pitu B. Mirchandani and Steve Shelby. "The RHODES Prototype: A Description and Some Results." Proceedings from the 77th Annual Meeting of the Transportation Research Board. TRB, Washington D.C., 1998.

Head, K. Larry. "EventBased Short-Term Traffic Flow Prediction Model." Transportation Research Record 1510. TRB, National Research Council, Washington D.C., 1995.

Homburger, Wolfgang S., James H. Kell and David D. Perkins. Fundamentals of Traffic Engineering. 13th Edition. Institute of Transportation Studies, University of California, 1992.

Hunt, P.B., D.I. Robertson, R.D. Bretherton and R.I. Winton. "SCOOT- A Traffic Method of Coordingating Signals." Laboratory Report No. LR 1014. Transportation and Road Research, Crowthorne, Bershire, England, 1981.

Kaman Sciences Corporation. TSIS User's Guide. Version 4.01. Colorado Springs, CO, 1997A.

Kaman Sciences Corporation. CORSIM User's Manual. Version 1.03. Colorado Springs, CO, 1997B.

Kell, J. H. and I. J. Fullerton. Manual of Traffic Signal Design. 2nd Edition. Institute of Transportation Engineers. Prentice Hall, Englewood Cliff, New Jersey, 1991.

Lam, J.K. Studies of a Platoon Dispersion Model and Its Pratical Applications. Seventh International Symposium on Transportation and Traffic Theory, Institute of Systems Science Research, Kyoto, Japan, 1977.

Lin, Feng-Bor, N. Wang and S. Vijayakumar. “Development of an Intelligent Adaptive Signal Control Logic.” Presented at the Engineering Foundation Conference on Management and Control of Urban Traffic. Henniker, N.H. 1987.

Lin, Feng-Bor. “Comparative Analysis of Two Logics for Adaptive Control of Isolated Intersections.” Transportation Research Record 1194. TRB, National Research Council, Washington D.C., 1988.

Linkenheld, J.S., R. F. Benekohal, and J. H. Garrett. “Knowledge-based System for Design of Signalized Intersections.” Journal of Transportation Engineering. Volume 118, Number 2. American Society of Civil Engineers, New York, NY, 1992.

Lowrie, P.R. “SCATS – Sydney Co-Ordinated Adaptive Traffic System – A Traffic Responsive Method of Controlling Urban Traffic.” Roads and Traffic Authority, Sydney Australia, 1992.

Manar, Abdelaziz, and Baass, Karsten G. Traffic Platoon Dispersion Modeling on Arterial Streets. *Transportation Research Record 1566,* TRB, National Research Council, Washington, D.C., November 1996, pp. 49-53.

Martin, Randy. Phone interview. Indianapolis GE Supply, 1998.

McCoy, Patrick T., Balderson, Elizabeth A., Hsueh, Richard T., and Mohaddes, Abbas K. Calibration of TRANSYT Platoon Dispersion Model for Passenger Cars Under Low-Friction Traffic Flow Conditions. *Transportation Research Record 905,* TRB, National Research Council, Washington, D.C., 1983, pp. 48-52

McShane W.R. and R. Roess. Traffic Engineering. Prentice-Hall, New York, NY, 1990.

Microsoft® Corporation. "Microsoft® TerraServer." www.terraserver.microsoft.com/, 1998.

Microsoft® Corporation. Microsoft® Automap Streets Plus. 1997 Edition., 1996.

Minnesota Department of Transportation and SRF Consulting Group, Inc. "Field Test of Urban Vehicle Operations Using Non-Intrusive Technologies." FHWA, Untied States Department of Transportation, Washington D.C., 1997.

National Electrical Manufacturers Association. Traffic Controller Assemblies. Standards Publication Number TS 2. Washington D.C., 1992.

National Research Council, Transportation Research Board. Highway Capacity Manual. 3rd Edition. Washington D.C., 1994.

Pacey, G.M., The progress of a bunch of vehicles released from a traffic signal. *Research Note No. RN/2665/GMP,* Road Research Laboratory, Crowthorne, Berkshire, England., 1956.

Petruzella, Frank D. Programmable Logic Controllers. McGraw-Hill, Inc., 1989.

Reiss, R. and W. Dunn. Freeway Incident Management Handbook. FHWA, United States Department of Transportation, Washington D.C., 1991.

Robertson, D.I., TRANSYT: A Traffic Network Study Tool. *Report No. LR253.* Transport and Road Research Laboratory, U.K., 1969.

Rouphail, Nagui., Tarko, Andrzej., Li, Jing. Traffic Flow at Signalized Intersections. *Traffic Flow Theory: A State-of-the-Art Report,* Transportation Research Board, 1992.

Sen, Suvrajeet, and K. Larry Head. "Controlled Optimization of Phases at an Intersection." Transportation Science. Vol. 31, No.1, 1997.

Shamo, Dan. Personal interview held on July 15, 1998.

Simpson, Colin D., Programmable Logic Controllers. Regents/Prentice Hall, Englewood Cliffs, NJ, 1994.

Sneddon, P.A., Another Look at Platoon Dispersion – 3: The Recurrence Relationship. Traffic Engineering and Control, Feb. 1972, pp. 442-444.

Steckler, Brad. Interview with INDOT Preliminary Engineering Staff. July 24, 1998.

Stephanedes, Y.J., P.G. Michalopoulous, and R.A. Plum. "Improved Estimation of Traffic Flow for Real-Time Control." Transportation Research Record 795. TRB, National Research Council, Washington D.C., 1981.

Stewart, J. Allan, Katrin Lepik, and M. Van Aerde. "Benefit Sensitivities of Adaptive Traffic Control Strategies at Isolated Traffic Signals" Proceedings from the 77th Annual Meeting of the Transportation Research Board. TRB, Washington D.C., 1998.

Tarnoff, P.J. "The Results of FHWA Urban Traffic Control Research: An Interim Report". Traffic Engineering. Vol. 45. 1975.

Vincent, R.A. and C.P. Young. "Self-Optimizing Traffic Signal Control Using Microprocessors – the TREL 'MOVA' Strategy for Isolated Intersections." Traffic Engineerinig. Vol. 27, No. 7/8. 1986.

Zabel, Carl. Phone Interview. Reno A&E. Reno, NV, 1998.

APPENDIX A

PLC LADDER LOGIC FOR PLATOON DETECTION ALGORITHM

```
|LOOPDET +------+                                                        DS#1
+--] [---+ TMR  +------------------------------------------------------------( )-
|        |0.10s|
|        |      |
| CONST -+PV    |
| +00000 |      |
|        +------+
|        %R0001
|
| DS#1   +------+                                                        DS#2
+--] [---+MOVE_+-------------------------------------------------------------( )-
|        | WORD|
|        |      |
|%R0001 -+IN  Q+-%R0100
|        | LEN |
|        |00001|
|        |      |
|        +------+
|
|LOOPDET +------+                                                        DS#4
+--] [---+ONDTR+-------------------------------------------------------------(^)-
|        |0.10s|
|        |      |
| DS#5   |      |
+--] [---+R     |
|        |      |
| CONST -+PV    |
| +00100 |      |
|        +------+
|        %R0010
|
| DS#4   +------+                                                        DS#5
+--] [---+MOVE_+-------------------------------------------------------------( )-
|        | INT |
|        |      |
| CONST -+IN  Q+-%R0101
| +09999 | LEN |
|        |00005|
|        |      |
|        +------+
|
|LOOPDET                                                                 DS#3
+--]/[-----------------------------------------------------------------------(^)-
|
| DS#3                                                                   DS#5
+--] [-----------------------------------------------------------------------( )-
|
|LOOPDET  DS#3    +------+
+--]/[-----] [---+SHFR_+-----------------------------------------------------(+)-
|                 | WORD|
|                 |      |
|%I0002           |      |
+--] [-----------+R    Q+-%R0106
|                 | LEN |
|                 |00005|
|                 |      |
|        %R0100 -+IN    |
|                 |      |
|        %R0101 -+ST    |
|                 +------+
```

Figure A-1 PLC Platoon Accommodation Algorithm

```
|        +-----+                  +-----+                  +-----+
+--(+)---+ ADD_+------------------+ ADD_+------------------+ ADD_+-----------(+)-
|        | INT |                  | INT |                  | INT |
|        |     |                  |     |                  |     |
|%R0101 -+I1  Q+-%R0040   %R0040 -+I1  Q+-%R0041   %R0041 -+I1  Q+-%R0042
|        |     |                  |     |                  |     |
|%R0102 -+I2   |          %R0103 -+I2   |          %R0104 -+I2   |
|        +-----+                  +-----+                  +-----+
|
|        +-----+
+--(+)---+ ADD_+-------------------------------------------------------------(+)-
|        | INT |
|        |     |
|%R0042 -+I1  Q+-%R0050
|        |     |
|%R0105 -+I2   |
|        +-----+
|
|        +-----+                                                         DS#6
+--(+)---+ LE_ |+------------------------------------------------------------(^)-
|        | INT ||
|        |     ||
|%R0050 -+I1  Q++
|        |     |
| CONST -+I2   |
| +00050 +-----+
|
| DS#6   +-----+                                                         DS#20
+--]/[---+ TMR +-------------------------------------------------------------( )-
|        |0.10s|
|        |     |
| CONST -+PV   |
| +00015 |     |
|        +-----+
|        %R0205
|
| DS#20  +-----+                                                         DS#8
+--]/[---+ TMR +-------------------------------------------------------------( )-
|        |0.10s|
|        |     |
| CONST -+PV   |
| +00010 |     |
|        +-----+
|        %R0215
|
| DS#7    DS#8    +-----+                                                DS#9
+--]/[-----]/[---+ TMR +-----------------------------------------------------( )-
|                |0.10s|
|                |     |
|         CONST -+PV   |
|         +00005 |     |
|                +-----+
|                %R0210
|                                                                    Bus Preempt
| DS#9     DS#7                                                                        on %Q1
+--]/[-----]/[----------------------------------------------------------( )----
```

Figure A-1 PLC Platoon Accommodation Algorithm (continued)

Table A-1 PLC Ladder Logic Functions

Function	Description
TMR	Timer that increments time while receiving power and resets when power is lost.
MOVE_WORD	Copies data from one memory location to another.
ONDTR	Timer that counts down time when receiving power.
MOVE_INT	Pastes data into a specified range of cells.
SHFR_WORD	Shift-register of a specified number of memory locations.
ADD_INT	Adds the contents of two memory locations and writes the answer into a different location.
LE_INT	Less than or equal logical function.

APPENDIX B

TRANSFORMING PLATOON HISTOGRAMS USING ROBERTSON'S MODEL

This appendix contains the theory used to construct the graphs summarized in chapter 6. The following text illustrates how the observed histogram in Figure B-1 is transformed to the histogram in Figure B-2, which represents the conditions at 500 ft. downstream. Subsequent text, figures, and tables explain how the final tabulations in chapter 6 were derived.

$$q_2(j) = \frac{1}{1+\alpha\beta\tau} q_1(j) + (1 - \frac{1}{1+\alpha\beta\tau}) q_2(j-1) \qquad \text{(Robertson Model – General Equation)}$$

α and β are platoon dispersion parameters that can be changed to better represent the conditions on a given roadway. In the following example, the two parameters were chosen to best represent a four-lane two-way road according to McCoy. The two parameters used in this example are:

$\alpha = 0.15$

$\beta = 0.97$

The average travel time factor is represented by τ. This factor is the average time it takes a vehicle to travel the distance between two histograms. For example, if the stop-line histogram is being transformed to represent the platoon at 500 ft. downstream then the travel time factor would simply be the average time it takes a vehicle to travel 500 ft. In this example, we are transforming the stop-line histogram to a distance of 500 ft downstream with an average arterial speed of 30 mph. Therefore the average travel time is calculated to be 11.4 seconds.

$q_1(j)$ is taken from the histogram that is being transformed (Figure B-1) and is equal to the number of vehicles in the bin that corresponds to the bin that is being calculated in the transformed histogram.

$q_1(j) = 12.55$ (Figure B-1)

$q_2(j-1)$ is taken from the transformed histogram (Figure B-2). It is equal to the number of vehicles in the bin immediately preceding the bin that is being calculated.

$q_2(j-1) = 7.09$ (Figure B-2)

$q_2(j)$ is the bin in the transformed histogram that is being computed. The calculation is completed using the Robertson model as follows:

$$q_2(j) = \frac{1}{1+\alpha\beta\tau} q_1(j) + (1 - \frac{1}{1+\alpha\beta\tau}) q_2(j-1)$$

Computing: $\frac{1}{1+\alpha\beta\tau} = \frac{1}{1+(0.15)(0.97)(11.4)} = 0.369$

$q_2(j) =$ (0.369)*(12.55)+(1-0.369)*(7.00)

$q_2(j) =$ 9.15

Histograms were generated for each of the platoon dispersion parameters at speeds of 30, 40 and 50 MPH. Additionally, for each combination of parameters and arterial speeds, theoretical histograms were developed for saturated platoons of 20, 40 and 60 seconds. The histograms developed by the spreadsheet are presented in figures and are summarized below.

Figure B-3, Figure B-4, Figure B-5, and Figure B-6 contain the theoretical histograms for a 20 second discharge platoon on a 30 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-7, Figure B-8, Figure B-9, and Figure B-10 contain the theoretical histograms for a 20 second discharge platoon on a 40 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-11, Figure B-12, Figure B-13, and Figure B-14 contain the theoretical histograms for a 20 second discharge platoon on a 50 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-15, Figure B-16, Figure B-17, and Figure B18 contain the theoretical histograms for a 40 second discharge platoon on a 30 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-19, Figure B-20, Figure B-21, and Figure B-22 contain the theoretical histograms for a 40 second discharge platoon on a 40 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-23, Figure B-24, Figure B-25, and Figure B-26 contain the theoretical histograms for a 40 second discharge platoon on a 50 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-27, Figure B-28, Figure B-29, and Figure B-30 contain the theoretical histograms for a 60 second discharge platoon on a 30 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-31, Figure B-32, Figure B-33, and Figure B-34 contain the theoretical histograms for a 60 second discharge platoon on a 40 MPH arterial using the first four α and β values shown in Table B-1.

Figure B-35, Figure B-36, Figure B-37, and Figure B-38 contain the theoretical histograms for a 60 second discharge platoon on a 50 MPH arterial using the first four α and β values shown in Table B-1.

The figures containing the histogram plots are again summarized in Table B-1.

Several interesting trends can be observed in the figures that have been summarized above. As the product of the two platoon dispersion parameters increase, the platoon disperses more quickly. As a platoon becomes more and more dispersed the histogram representing that platoon will spread out and become flatter. Larger dispersion parameters will also cause the center of the platoon to take longer to arrive at the downstream location. These trends are apparent when comparing the histograms for a location of 2000 ft. downstream with varying dispersion parameters. Compare Figure B-3d, Figure B-4d, Figure B-5d, and Figure B-6d. These same trends will continue and become even more pronounced as the platoon continues further downstream. Compare B-3h, Figure B-4h, Figure B-5h, and Figure B-6h which represent a platoon at 8000 ft. downstream. The figures just discussed consider an arterial with an average speed of 30 MPH and a 20-second saturated platoon discharge. The observed trends remained similar when the size of the platoon discharge and the average arterial speed was changed. With an average arterial speed of 50 MPH the same trend can be seen by comparing Figure B-11h with Figure B-14h. The only variables that are different in these two histograms are the platoon dispersion parameters.

If the platoon dispersion parameters are held constant, changes in the histograms can be observed which are only dependent on speed and platoon size. As the arterial speed is increased, the center of the platoon will obviously reach each downstream location much more quickly. Also, the platoon will not disperse quite as quickly. These trends can be observed by comparing Figure B-3d, Figure B-7d, and Figure B-11d. This trend is somewhat more obvious as the platoon travels further downstream to a distance of 8000 ft. as can be seen in Figure B-3h, Figure B-7h, and Figure B-11h.

The size of the platoon will also effect its behavior as it proceeds downstream. In this research, saturated platoons of 20, 40 and 60 seconds were used. The same basic trends discussed in previous paragraphs are also apparent for these larger platoon discharges. Initially the histograms representing the different platoon discharges will be very different but as they proceed downstream the histograms will take nearly the same shape. These trends can be evaluated by comparing Figure B-3, Figure B-15, and Figure B-27. Note that in Figure B-3d, Figure B-15d, and Figure B-27d that the histograms are very different but in Figure B-3h, Figure B-15h, and Figure B-27h that the histograms are nearly identical. Additional comparisons can be made with the other figures provided which will yield similar observations.

From the histogram plots it is also useful to find the arrival times of the platoon at varying downstream distances. The arrival times represent the time it takes for a certain percentage of the platoon to arrive at a certain downstream location. For example, t_{50} at 2000 ft. would represent the time that it takes for 50% of the platoon to travel 2000 ft. Such information can be useful when determining whether or not it is beneficial to coordinate a downstream signal with the upstream signal that originally generates the platoon. Arrival times have been calculated for 5, 25, 50, 75, 95, and 99 percent of the platoon. The procedure for reading arrival times has been shown in Figure B-39. The histogram represents a 20-second saturated platoon traveling at a speed of 30 MPH when it has a reached a point of 2000 ft. downstream.

The arrival times are summarized in tables and have been organized as follows:

Table B-2: 20-second saturated platoon, Speed: 30 MPH
Table B-3: 20-second saturated platoon, Speed: 40 MPH
Table B-4: 20-second saturated platoon, Speed: 50 MPH
Table B-5: 40-second saturated platoon, Speed: 30 MPH
Table B-6: 40-second saturated platoon, Speed: 40 MPH
Table B-7: 40-second saturated platoon, Speed: 50 MPH
Table B-8: 60-second saturated platoon, Speed: 30 MPH
Table B-9: 60-second saturated platoon, Speed: 40 MPH
Table B-10: 60-second saturated platoon, Speed: 50 MPH

From the histogram plots it is possible to find the arrival times for any percentage of the platoon at a certain distance downstream. The arrival time graphs can be adjusted to represent the green window necessary at the downstream signal to allow a certain percentage of the platoon to pass. The arrival times can be adjusted to green window times by simply subtracting the time it takes for the first vehicle in the platoon to arrive at the downstream signal. The arrival times that were found by reading Figure B-39 are plotted in Figure B-40. The arrival times in Figure B-40 have been transformed to green window times in Figure B-41. The arrival times for a 20-second saturated platoon and a speed of 40 MPH is presented in Figure B-42 and adjusted to green window time in Figure B-43.The necessary green window for a downstream signal is valuable information when evaluating the benefits of coordinating two traffic signals. For the purpose of this research, the theoretical graphs that were developed are compared to graphs of data that was generated by simulation and by data that was observed in the field. For convenience, the theoretical green window time graphs for a 20-second platoon and arterial speeds of 30 and 40 MPH are presented in Figure B-53 and Figure B-54.

As discussed before, as the product of the two platoon dispersion parameters increases so does the dispersion observed in the platoon. Therefore, it would be expected that a platoon with a higher degree of dispersion would require a larger downstream green window to service the platoon. There is a dramatic difference in the amount of green window time necessary when comparing parts a) and c) in Figure B-44. The arterial speed will also affect the green window times. By comparing Figure B-44 and Figure B-46 it can be seen that a higher speed will require a lower green window time when compared to a lower speed. The times for these figures can be read in Table B-3 and Table B-4. Finally, the size of the platoon will also impact the green window time. Obviously, a larger platoon will require more green time than will a smaller platoon. This tendency can be seen in Figure B-44, Figure B-47 and Figure B-50.

Table B-1: Summary of histogram figures.

Platoon Length	Arterial Speed (MPH)	Dispersion Parameters		Figure
		α	β	
Twenty (20) second saturated platoon	30	0.15	0.97	Figure B-3
		0.25	0.80	Figure B-4
		0.35	0.80	Figure B-5
		0.50	0.80	Figure B-6
	40	0.15	0.97	Figure B-7
		0.25	0.80	Figure B-8
		0.35	0.80	Figure B-9
		0.50	0.80	Figure B-10
	50	0.15	0.97	Figure B-11
		0.25	0.80	Figure B-12
		0.35	0.80	Figure B-13
		0.50	0.80	Figure B-14
Forty (40) second saturated platoon	30	0.15	0.97	Figure B-15
		0.25	0.80	Figure B-16
		0.35	0.80	Figure B-17
		0.50	0.80	Figure B-18
	40	0.15	0.97	Figure B-19
		0.25	0.80	Figure B-20
		0.35	0.80	Figure B-21
		0.50	0.80	Figure B-22
	50	0.15	0.97	Figure B-23
		0.25	0.80	Figure B-24
		0.35	0.80	Figure B-25
		0.50	0.80	Figure B-26
Sixty (60) second saturated platoon	30	0.15	0.97	Figure B-27
		0.25	0.80	Figure B-28
		0.35	0.80	Figure B-29
		0.50	0.80	Figure B-30
	40	0.15	0.97	Figure B-31
		0.25	0.80	Figure B-32
		0.35	0.80	Figure B-33
		0.50	0.80	Figure B-34
	50	0.15	0.97	Figure B-35
		0.25	0.80	Figure B-36
		0.35	0.80	Figure B-37
		0.50	0.80	Figure B-38

Table B-2: Arrival times at different downstream distances (20 second saturated platoon, speed: 30 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	**1000 ft.**	**2000 ft.**	**3000 ft.**	**4000 ft.**	**6000 ft.**	**8000 ft.**
t_5	2.4	5.2	10.5	18.6	30.0	47.0	70.9
t_{25}	7.8	12.6	20.8	33.5	51.5	78.6	115.8
t_{50}	13.2	18.9	30.0	47.9	72.5	109.2	158.8
t_{75}	18.3	25.6	42.0	66.9	99.8	148.8	213.7
t_{95}	25.1	38.7	66.2	104.6	152.4	224.7	318.1
t_{99}	31.9	51.1	89.4	139.6	200.2	294.0	412.3

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	**1000 ft.**	**2000 ft.**	**3000 ft.**	**4000 ft.**	**6000 ft.**	**8000 ft.**
t_5	2.8	6.4	13.3	23.9	39.1	62.4	95.2
t_{25}	8.6	14.7	25.6	42.9	67.7	104.9	156.1
t_{50}	14.2	21.7	37.3	62.0	95.9	146.4	214.5
t_{75}	19.4	30.2	53.1	87.5	132.8	200.2	289.4
t_{95}	28.2	47.4	85.6	138.4	204.1	303.6	431.9
t_{99}	37.1	63.8	116.8	185.8	269.1	398.1	560.7

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	**1000 ft.**	**2000 ft.**	**3000 ft.**	**4000 ft.**	**6000 ft.**	**8000 ft.**
t_5	3.2	8.1	17.0	31.2	52.4	84.9	130.8
t_{25}	9.7	17.6	32.4	56.6	91.4	143.5	215.1
t_{50}	15.6	26.0	48.0	82.7	130.3	201.0	296.4
t_{75}	21.3	37.2	69.6	117.9	181.3	275.6	400.5
t_{95}	33.1	60.4	114.2	188.2	280.2	419.4	599.0
t_{99}	44.9	82.7	157.2	253.8	370.3	550.9	778.4

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	**1000 ft.**	**2000 ft.**	**3000 ft.**	**4000 ft.**	**6000 ft.**	**8000 ft.**
t_5	3.9	10.2	22.2	42.0	72.1	118.5	184.2
t_{25}	11.0	21.5	42.5	77.2	126.9	201.4	303.7
t_{50}	17.5	32.5	64.2	113.9	181.9	282.9	419.1
t_{75}	24.6	47.9	94.4	163.5	254.1	388.8	567.3
t_{95}	40.8	80.2	157.3	263.0	394.3	593.2	849.7
t_{99}	56.9	111.3	217.9	355.9	522.1	780.1	1105.1

Table B-3: Arrival times at different downstream distances (20 second saturated platoon, Speed: 40 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	2.2	4.4	8.5	14.9	23.7	36.6	54.6
t_{25}	7.2	11.0	17.6	27.2	40.7	61.0	88.9
t_{50}	12.4	16.9	25.2	38.5	56.9	84.4	121.6
t_{75}	17.5	22.7	34.7	53.2	77.8	114.5	163.2
t_{95}	23.2	33.1	53.4	82.1	117.9	172.1	242.2
t_{99}	28.6	42.8	71.2	108.8	154.3	224.6	313.4

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	2.4	5.3	10.7	19.0	30.7	48.3	72.9
t_{25}	7.8	12.7	21.2	34.3	52.9	80.8	119.1
t_{50}	13.2	19.1	30.6	49.1	74.5	112.3	163.4
t_{75}	18.4	26.0	42.9	68.6	102.5	153.0	219.9
t_{95}	25.4	39.4	67.8	107.4	156.7	231.3	327.5
t_{99}	32.3	52.1	91.6	143.4	205.9	302.6	424.6

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	2.8	6.6	13.8	24.8	40.8	65.2	99.7
t_{25}	8.7	15.1	26.4	44.6	70.7	109.8	163.4
t_{50}	14.4	22.2	38.6	64.6	100.2	153.2	224.7
t_{75}	19.6	31.1	55.2	91.3	138.9	209.6	303.3
t_{95}	28.8	49.0	89.2	144.6	213.6	318.1	452.8
t_{99}	38.0	66.1	121.8	194.3	281.7	417.2	587.9

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	3.4	8.4	18.0	33.0	55.7	90.5	139.7
t_{25}	9.9	18.3	34.1	60.1	97.3	153.2	229.9
t_{50}	15.9	27.1	50.7	87.9	138.9	214.7	316.8
t_{75}	21.8	39.0	73.7	125.5	193.4	294.5	428.3
t_{95}	34.3	63.7	121.4	200.6	299.2	448.4	640.8
t_{99}	46.9	87.5	167.3	270.8	395.6	589.1	832.9

Table B-4: Arrival times at different downstream distances (20 second saturated platoon, Speed: 50 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	0.4	3.8	7.2	12.5	19.8	30.3	44.8
t_{25}	6.8	10.0	15.5	23.4	34.2	50.5	72.8
t_{50}	12.0	15.6	22.3	32.9	47.6	69.6	99.3
t_{75}	17.0	21.0	30.3	45.1	64.7	94.0	132.9
t_{95}	22.0	29.8	45.8	68.7	97.3	140.6	196.6
t_{99}	26.7	37.9	60.4	90.4	126.8	183.0	254.0

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	2.2	4.6	9.1	16.1	25.6	39.7	59.5
t_{25}	7.4	11.5	18.6	29.1	44.0	66.3	97.0
t_{50}	12.6	17.5	26.6	41.3	61.6	91.9	132.7
t_{75}	17.7	23.5	36.9	57.3	84.4	124.8	178.3
t_{95}	23.7	34.8	57.3	88.8	128.2	187.9	264.9
t_{99}	29.6	45.3	76.6	118.0	168.0	245.4	342.9

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	2.5	5.8	11.7	20.8	33.8	53.3	81.0
t_{25}	8.1	13.5	22.8	37.4	58.2	89.5	132.4
t_{50}	13.6	20.0	33.0	53.7	82.2	124.6	181.8
t_{75}	18.7	27.5	46.6	75.4	113.4	170.0	244.9
t_{95}	26.3	42.3	74.2	118.5	173.7	257.3	365.1
t_{99}	33.9	56.3	100.7	158.7	228.6	337.0	473.6

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	3.0	7.2	15.2	27.6	45.8	73.6	113.0
t_{25}	9.1	16.2	29.0	49.8	79.5	124.2	185.6
t_{50}	14.9	23.8	42.6	72.4	113.1	173.7	255.4
t_{75}	20.3	33.7	61.3	102.7	157.1	237.9	345.0
t_{95}	30.6	53.9	99.9	163.3	242.1	361.5	515.5
t_{99}	40.9	73.2	137.0	219.8	319.7	474.5	669.5

Table B-5: Arrival times at different downstream distances (40 second saturated platoon, Speed: 30 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.0	7.6	14.1	23.5	36.3	54.6	79.3
t_{25}	13.2	18.9	28.8	42.6	61.0	88.3	125.5
t_{50}	23.3	29.7	41.3	58.7	83.1	119.6	169.0
t_{75}	33.3	39.8	54.6	78.6	110.9	159.6	224.2
t_{95}	42.2	53.8	79.4	116.7	163.9	235.8	328.9
t_{99}	49.0	66.3	102.6	151.8	211.8	305.2	423.2

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.5	9.2	17.4	29.8	46.5	70.6	104.0
t_{25}	14.2	21.6	34.3	52.4	77.3	114.7	165.9
t_{50}	24.5	33.0	48.4	72.7	106.3	156.7	224.7
t_{75}	34.5	43.8	65.1	98.8	143.6	210.7	299.8
t_{95}	44.6	61.6	98.0	150.0	215.3	314.4	442.5
t_{99}	53.4	78.1	129.3	197.5	280.3	408.9	571.3

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.2	11.2	22.0	38.2	60.5	93.6	140.0
t_{25}	15.6	25.2	41.7	66.3	101.1	153.4	225.0
t_{50}	26.2	37.5	58.9	93.2	140.6	211.2	306.5
t_{75}	36.3	50.0	81.1	128.8	191.9	286.0	410.8
t_{95}	48.5	73.7	126.0	199.3	291.0	430.0	609.4
t_{99}	60.2	96.0	169.0	265.0	381.2	561.5	788.9

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	6.2	14.0	28.3	49.9	80.8	127.6	193.6
t_{25}	17.5	30.2	52.2	87.0	136.7	211.3	313.6
t_{50}	28.6	43.8	74.8	124.2	192.1	293.1	429.2
t_{75}	38.9	60.0	105.5	174.1	264.6	399.1	577.5
t_{95}	55.1	92.6	168.5	273.8	404.9	603.6	860.0
t_{99}	71.3	123.8	229.2	366.8	532.8	790.5	1115.4

Table B-6: Arrival times at different downstream distances (40 second saturated platoon, Speed: 40 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	3.6	6.5	11.6	19.1	29.1	43.4	62.4
t_{25}	12.4	16.9	24.8	35.8	49.9	70.5	98.6
t_{50}	22.5	27.3	36.4	49.5	67.6	94.9	131.9
t_{75}	32.5	37.4	47.8	65.3	89.3	125.5	173.9
t_{95}	40.9	49.0	67.4	94.8	129.9	183.5	253.2
t_{99}	46.2	58.9	85.3	121.7	166.4	236.1	324.5

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.1	7.8	14.3	24.1	37.2	56.0	81.3
t_{25}	13.2	19.1	29.3	43.5	62.4	90.5	128.9
t_{50}	23.4	29.9	41.9	59.9	85.0	122.7	173.6
t_{75}	33.4	40.2	55.4	80.2	113.6	163.8	230.5
t_{95}	42.4	54.5	80.9	119.4	168.1	242.3	338.2
t_{99}	49.4	67.3	104.8	155.6	217.5	313.7	435.4

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.6	9.4	18.1	30.8	48.3	73.5	108.5
t_{25}	14.4	22.1	35.3	54.1	80.3	119.5	173.3
t_{50}	24.7	33.5	49.7	75.2	110.6	163.5	234.9
t_{75}	34.8	44.5	67.1	102.5	149.7	220.1	313.7
t_{95}	45.0	63.1	101.5	156.1	224.7	328.8	463.3
t_{99}	54.2	80.3	134.2	205.9	292.9	428.0	598.5

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.4	11.7	23.1	40.2	63.9	99.3	148.9
t_{25}	15.9	26.1	43.5	69.8	107.1	163.0	239.8
t_{50}	26.6	38.5	61.5	98.4	149.2	224.9	326.9
t_{75}	36.8	51.6	85.1	136.3	204.0	304.9	438.6
t_{95}	49.5	76.8	133.1	211.7	309.9	458.9	651.2
t_{99}	62.0	100.6	179.0	282.0	406.4	599.6	843.3

Table B-7: Arrival times at different downstream distances (40 second saturated platoon, Speed: 50 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	3.3	5.7	10.0	16.3	24.6	36.5	52.1
t_{25}	12.0	15.6	22.2	31.4	43.1	59.8	82.3
t_{50}	22.0	25.9	33.4	44.0	58.4	80.1	109.7
t_{75}	32.0	35.9	44.0	57.6	76.5	105.3	143.8
t_{95}	40.0	46.3	60.4	81.9	109.7	152.3	207.9
t_{99}	44.7	54.6	75.1	103.8	139.4	194.9	265.4

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	3.7	6.8	12.3	20.4	31.3	46.8	67.5
t_{25}	12.6	17.5	26.0	37.9	53.3	75.9	106.6
t_{50}	22.7	28.0	37.9	52.3	72.2	102.3	143.0
t_{75}	32.7	38.2	49.8	69.2	95.7	135.7	189.0
t_{95}	41.3	50.4	70.9	101.3	140.0	199.1	275.8
t_{99}	47.1	61.1	90.4	130.6	180.0	256.7	354.0

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.2	8.3	15.5	26.2	40.6	61.3	89.5
t_{25}	13.6	20.0	31.1	46.7	67.8	99.2	142.2
t_{50}	23.8	31.0	44.2	64.5	92.7	134.9	192.0
t_{75}	33.8	41.4	58.9	86.9	124.4	180.7	255.4
t_{95}	43.2	57.0	87.0	130.4	185.1	268.2	375.8
t_{99}	50.8	71.2	113.6	170.6	240.1	348.0	484.3

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.9	10.2	19.8	34.1	53.5	82.2	122.0
t_{25}	14.9	23.5	38.1	59.4	89.3	134.0	195.4
t_{50}	25.3	35.3	53.6	82.9	123.5	184.0	265.6
t_{75}	35.4	46.8	73.0	113.7	167.8	248.4	355.3
t_{95}	46.5	67.6	111.9	174.6	253.1	372.2	525.9
t_{99}	56.8	87.0	149.1	231.2	330.7	485.2	680.1

Table B-8: Arrival times at different downstream distances (60 second saturated platoon, Speed: 30 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.3	9.5	16.7	27.1	41.0	60.6	86.5
t_{25}	18.3	24.4	35.3	50.5	69.9	97.6	135.1
t_{50}	33.3	39.8	52.3	69.9	93.9	130.2	179.4
t_{75}	48.3	54.9	68.4	91.2	122.8	170.8	235.2
t_{95}	60.5	70.6	94.1	130.0	176.4	247.6	340.2
t_{99}	67.3	83.3	117.5	165.4	224.5	317.1	434.6

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	6.0	11.3	20.5	34.0	52.1	77.7	112.0
t_{25}	19.4	27.5	41.6	61.1	86.6	124.2	175.6
t_{50}	34.5	43.4	59.7	83.7	117.0	167.1	235.0
t_{75}	49.5	58.6	78.2	110.8	155.0	221.7	310.5
t_{95}	62.3	77.5	111.8	162.5	227.1	325.7	453.4
t_{99}	71.2	94.1	143.2	210.2	292.3	420.3	582.3

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	6.8	13.7	25.7	43.4	67.2	101.5	148.5
t_{25}	21.0	31.6	49.9	75.6	110.7	163.1	234.8
t_{50}	36.3	48.3	70.1	104.0	151.1	221.5	316.7
t_{75}	51.4	64.1	93.5	140.3	202.9	296.7	421.3
t_{95}	65.5	88.6	138.9	211.2	302.3	440.9	620.1
t_{99}	77.3	111.1	181.9	277.0	392.6	572.5	799.6

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	8.0	16.9	32.7	56.3	88.5	136.1	202.5
t_{25}	23.2	37.3	61.3	96.6	146.5	221.1	323.5
t_{50}	38.9	55.3	85.8	134.8	202.5	303.3	439.4
t_{75}	54.0	73.2	117.2	185.2	275.3	409.6	587.8
t_{95}	71.2	106.4	180.6	285.1	415.8	614.3	870.5
t_{99}	87.3	137.7	241.4	378.2	543.8	801.2	1126.0

Table B-9: Arrival times at different downstream distances (60 second saturated platoon, Speed: 40 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.9	8.2	13.9	22.2	33.1	48.5	68.8
t_{25}	17.5	22.2	30.8	42.9	58.2	79.6	107.9
t_{50}	32.5	37.4	47.0	60.7	78.6	105.7	142.4
t_{75}	47.5	52.4	62.3	78.6	101.6	137.2	185.1
t_{95}	59.5	66.4	83.0	108.9	143.1	195.8	264.9
t_{99}	64.9	76.4	101.0	136.0	179.8	248.6	336.3

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.4	9.6	17.0	27.7	42.0	62.1	88.6
t_{25}	18.4	24.7	35.9	51.4	71.3	99.8	138.4
t_{50}	33.4	40.1	52.9	71.0	95.8	133.2	184.0
t_{75}	48.4	55.2	69.2	92.8	125.4	175.0	241.4
t_{95}	60.6	71.2	95.6	132.7	180.6	254.0	349.5
t_{99}	67.6	84.1	119.6	169.0	230.1	325.6	446.8

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	6.1	11.6	21.2	35.2	54.1	80.7	116.6
t_{25}	19.6	28.0	42.6	63.0	89.7	129.1	183.0
t_{50}	34.8	44.0	61.0	86.2	121.3	173.9	245.2
t_{75}	49.8	59.2	80.1	114.4	161.0	231.0	324.3
t_{95}	62.7	78.8	115.1	168.6	236.5	340.1	474.2
t_{99}	71.9	96.2	147.9	218.5	304.8	439.3	609.5

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	7.0	14.3	26.9	45.6	70.9	107.3	157.6
t_{25}	21.4	32.6	51.9	79.2	116.7	172.7	249.6
t_{50}	36.8	49.5	72.7	109.1	159.6	235.2	337.2
t_{75}	51.8	65.6	97.4	147.7	215.0	315.5	449.1
t_{95}	66.4	91.5	145.8	223.5	321.2	469.8	661.8
t_{99}	78.9	115.4	191.8	293.8	417.8	610.6	854.0

Table B-10: Arrival times at different downstream distances (60 second saturated platoon, Speed: 50 MPH)

α=0.15 & β=0.97, Four-Lane Divided (McCoy):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	4.6	7.3	12.1	19.0	28.1	40.9	57.7
t_{25}	17.0	20.8	28.0	38.0	50.7	68.5	91.5
t_{50}	32.0	35.9	43.7	55.0	69.5	91.0	120.3
t_{75}	47.0	50.9	58.9	71.3	89.3	117.3	155.3
t_{95}	59.0	64.0	76.7	96.7	123.5	165.1	220.0
t_{99}	63.6	72.5	91.5	118.9	153.5	207.8	277.7

α=0.25 & β=0.80, Low External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.0	8.6	14.7	23.7	35.5	52.2	74.2
t_{25}	17.7	22.9	32.2	45.2	61.7	85.0	116.1
t_{50}	32.7	38.2	48.6	63.5	83.2	113.0	153.5
t_{75}	47.7	53.2	64.1	82.3	107.9	147.2	200.1
t_{95}	59.7	67.6	86.2	115.2	153.0	211.2	287.3
t_{99}	65.6	78.4	105.9	144.7	193.1	269.0	365.7

α=0.35 & β=0.80, Moderate External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	5.6	10.2	18.3	30.0	45.7	67.8	97.1
t_{25}	18.7	25.7	38.0	55.0	76.9	108.6	151.8
t_{50}	33.8	41.3	55.4	75.6	103.4	145.4	202.4
t_{75}	48.8	56.4	72.4	99.2	136.0	191.8	266.2
t_{95}	61.2	73.4	101.3	143.4	197.3	279.8	386.9
t_{99}	68.9	87.7	128.0	183.8	252.4	359.6	495.5

α=0.50 & β=0.80, Heavy External Friction (TRANSYT):

	500 ft.	1000 ft.	2000 ft.	3000 ft.	4000 ft.	6000 ft.	8000 ft.
t_5	6.4	12.5	23.1	38.8	59.8	89.7	130.3
t_{25}	20.2	29.6	45.8	68.5	98.7	143.7	205.2
t_{50}	35.4	45.9	64.9	93.8	134.0	194.3	275.8
t_{75}	50.5	61.3	85.8	125.5	178.9	259.2	365.9
t_{95}	63.8	82.9	125.2	186.8	264.7	383.3	536.7
t_{99}	74.1	102.5	162.4	243.5	342.4	496.3	690.9

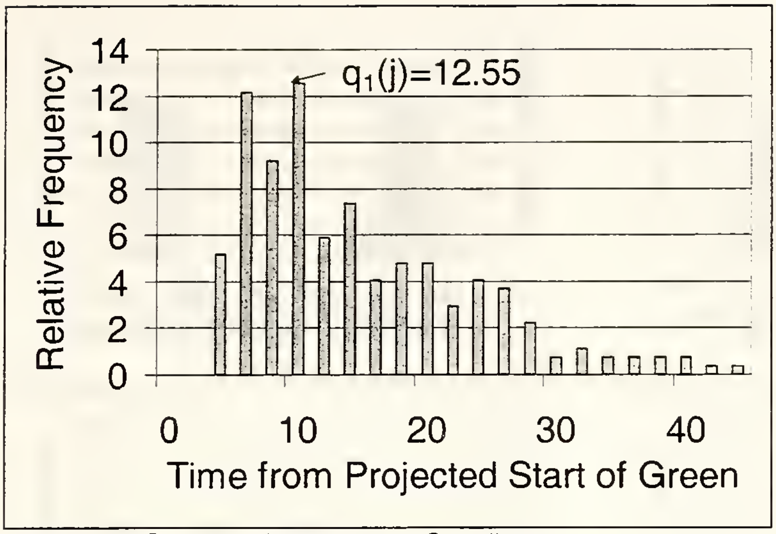


Figure B-1: Observed Histogram at Stop-line

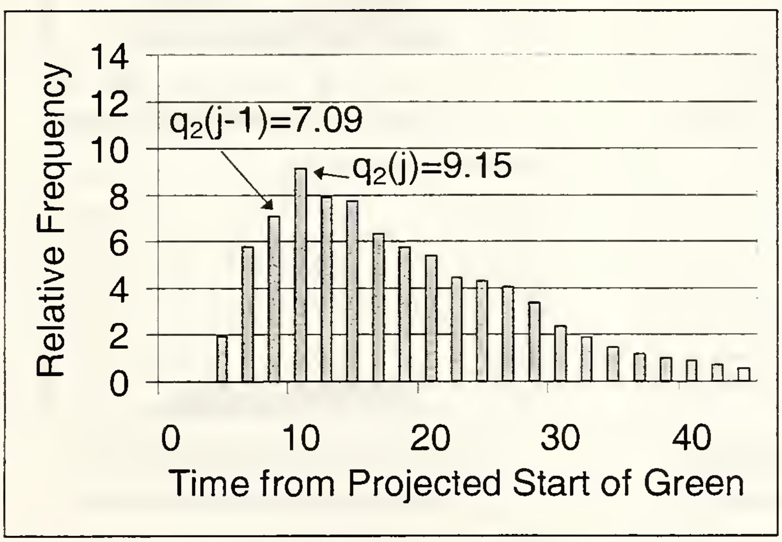
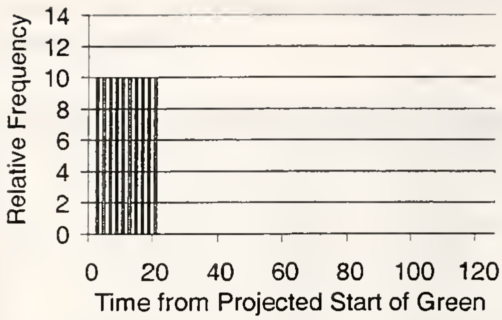
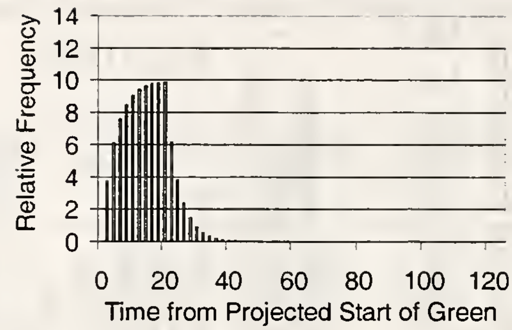


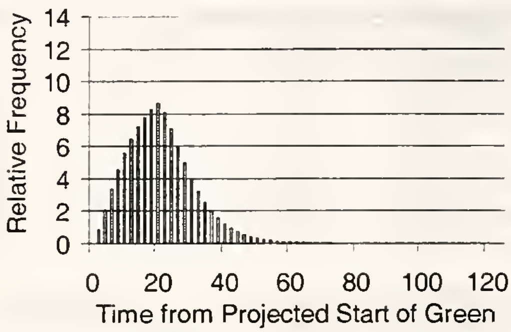
Figure B-2: Transformed Histogram at 500 ft. downstream (α=0.15 β=0.97)



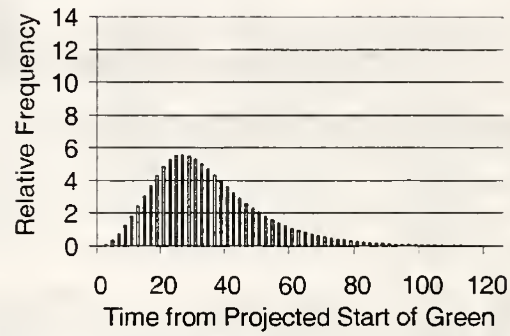
a) Platoon at Stop-line



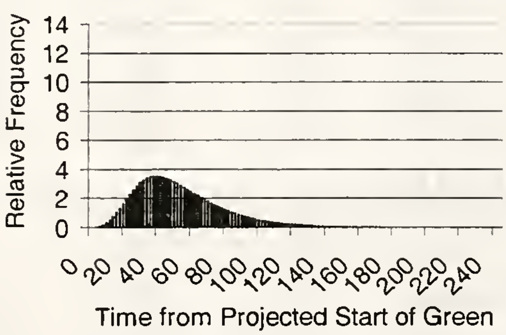
b) 500 ft Downstream



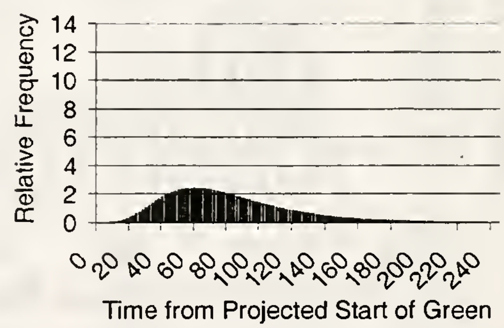
c) 1000 ft Downstream



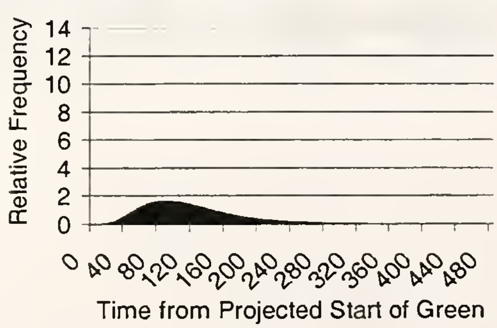
d) 2000 ft Downstream



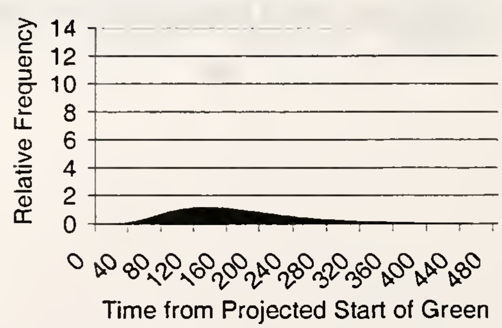
e) 3000 ft Downstream



f) 4000 ft Downstream

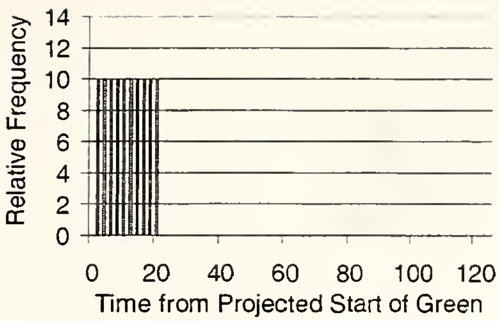


g) 6000 ft Downstream

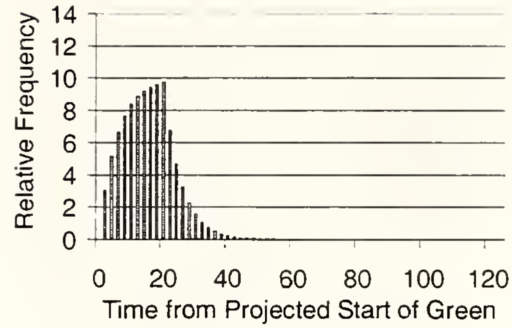


h) 8000 ft Downstream

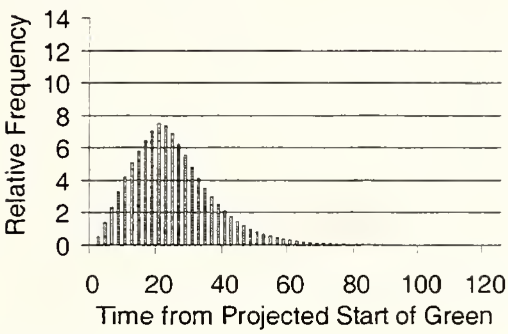
Figure B-3: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 20 second saturated platoon, Speed: 30 MPH



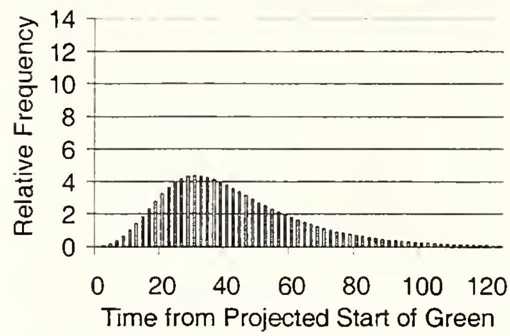
a) Platoon at Stop-line



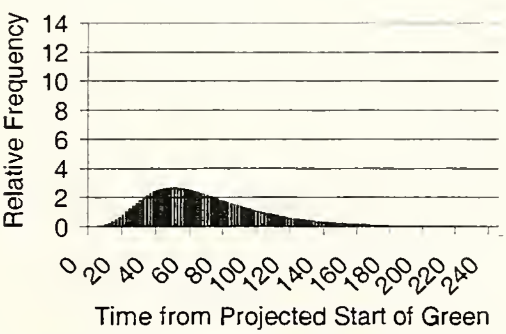
b) 500 ft Downstream



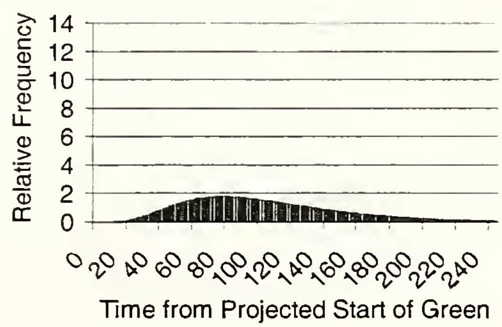
c) 1000 ft Downstream



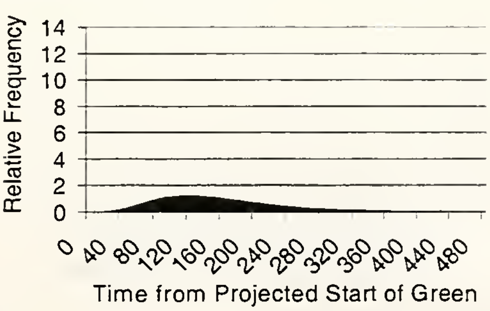
d) 2000 ft Downstream



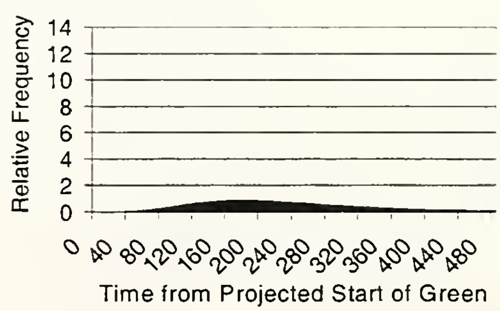
e) 3000 ft Downstream



f) 4000 ft Downstream

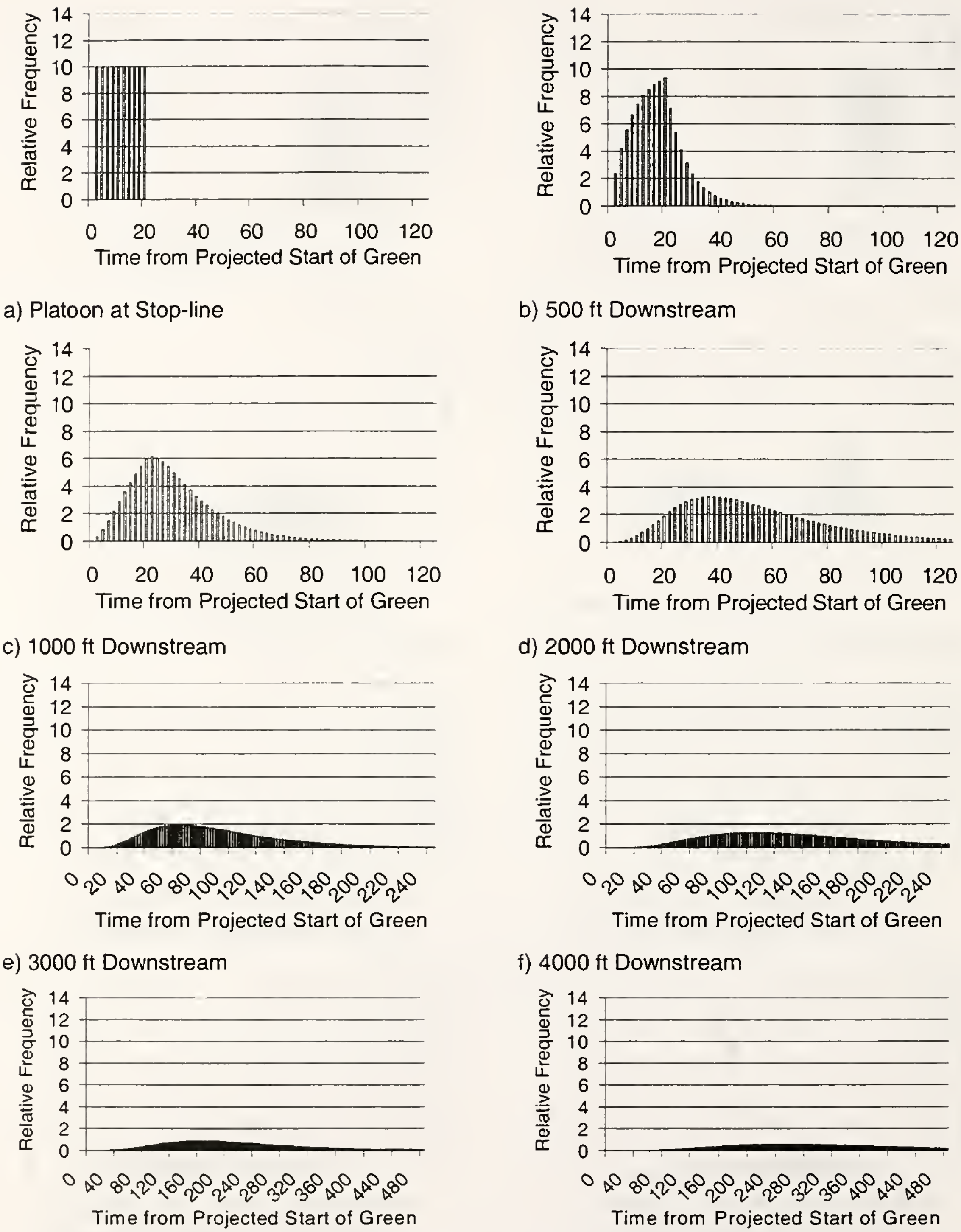


g) 6000 ft Downstream



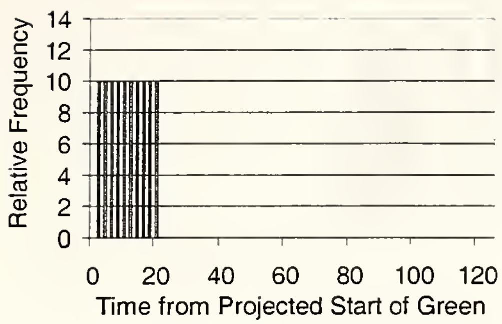
h) 8000 ft Downstream

Figure B-4: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 30 MPH

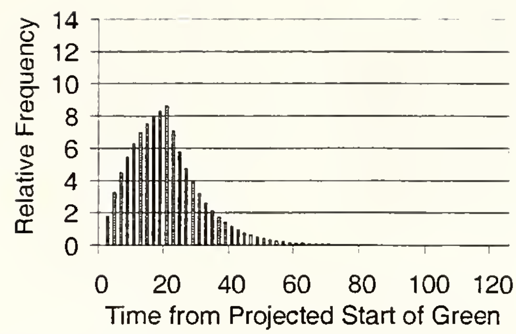


a) Platoon at Stop-line
b) 500 ft Downstream
c) 1000 ft Downstream
d) 2000 ft Downstream
e) 3000 ft Downstream
f) 4000 ft Downstream
g) 6000 ft Downstream
h) 8000 ft Downstream

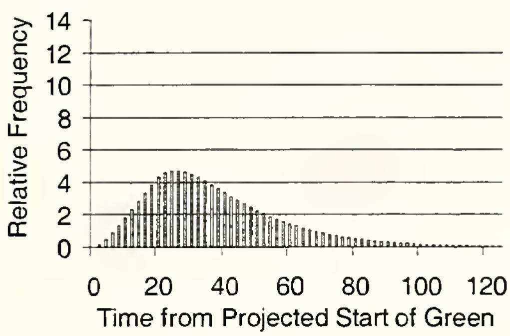
Figure B-5: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - $\alpha=0.35$ $\beta=0.80$ (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 30 MPH



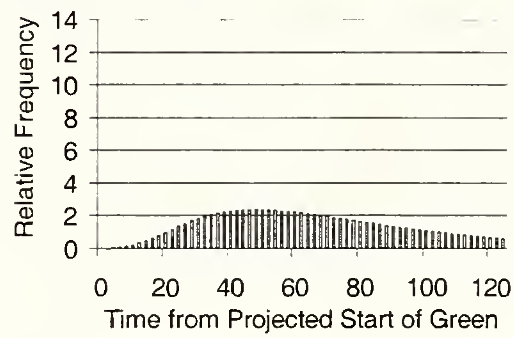
a) Platoon at Stop-line



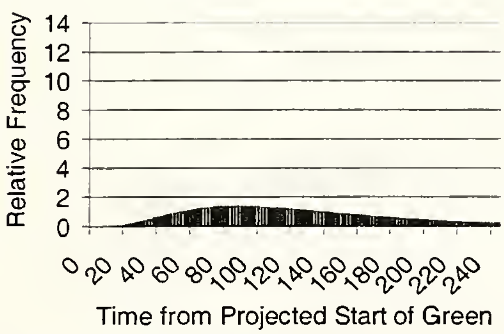
b) 500 ft Downstream



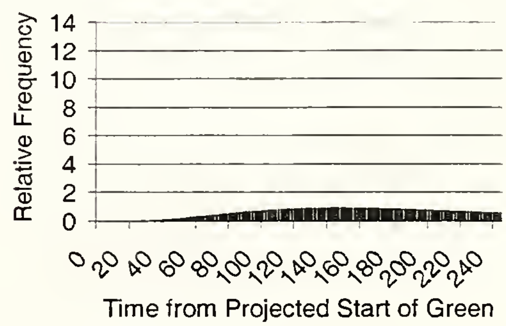
c) 1000 ft Downstream



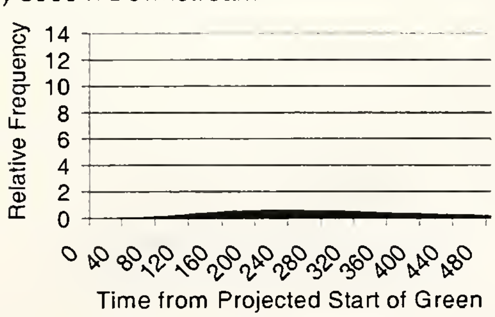
d) 2000 ft Downstream



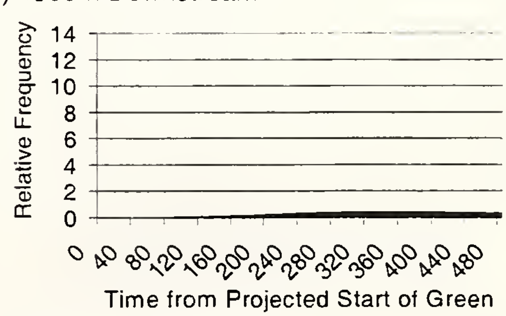
e) 3000 ft Downstream



f) 4000 ft Downstream



g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-6: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 30 MPH

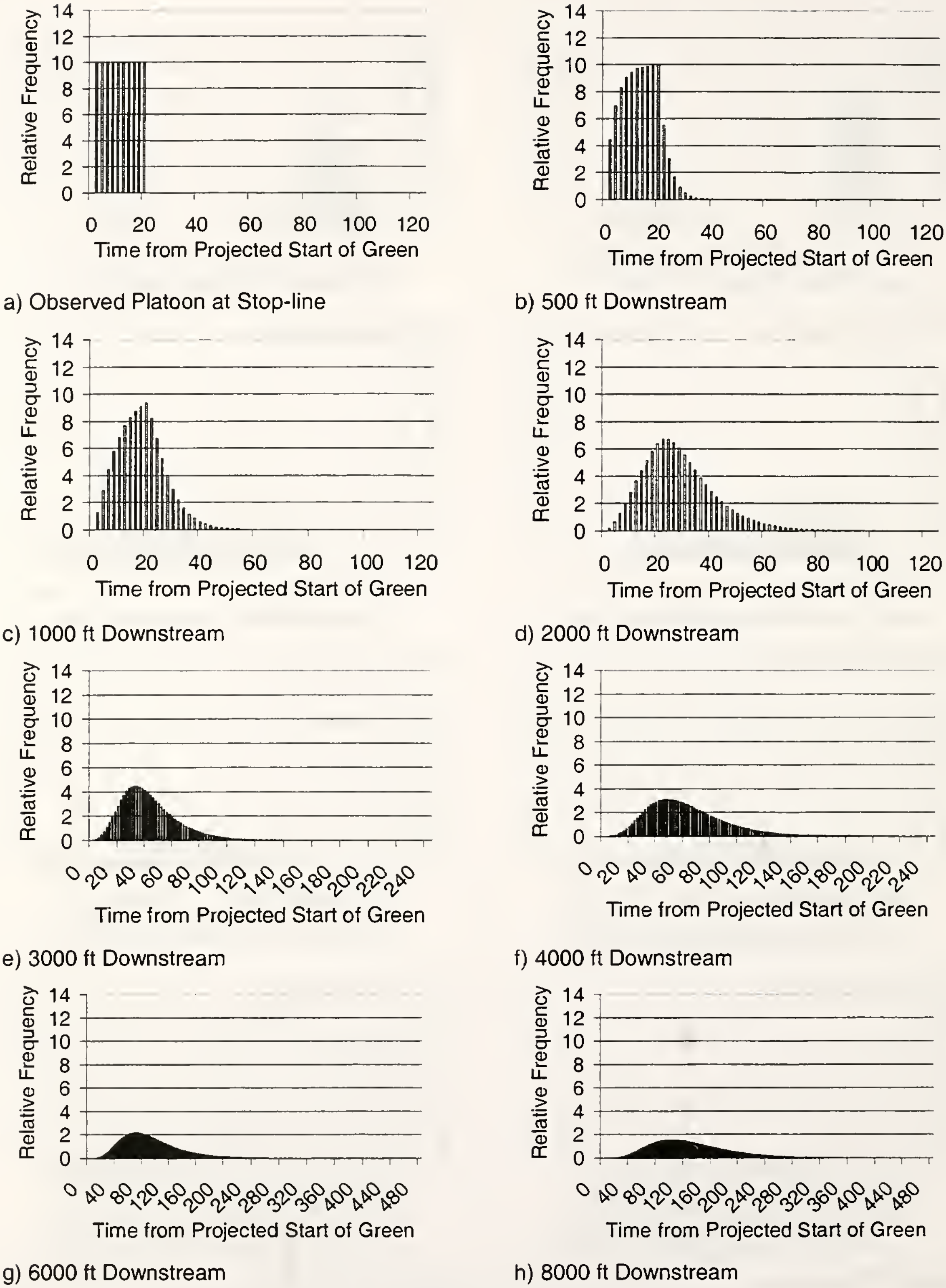
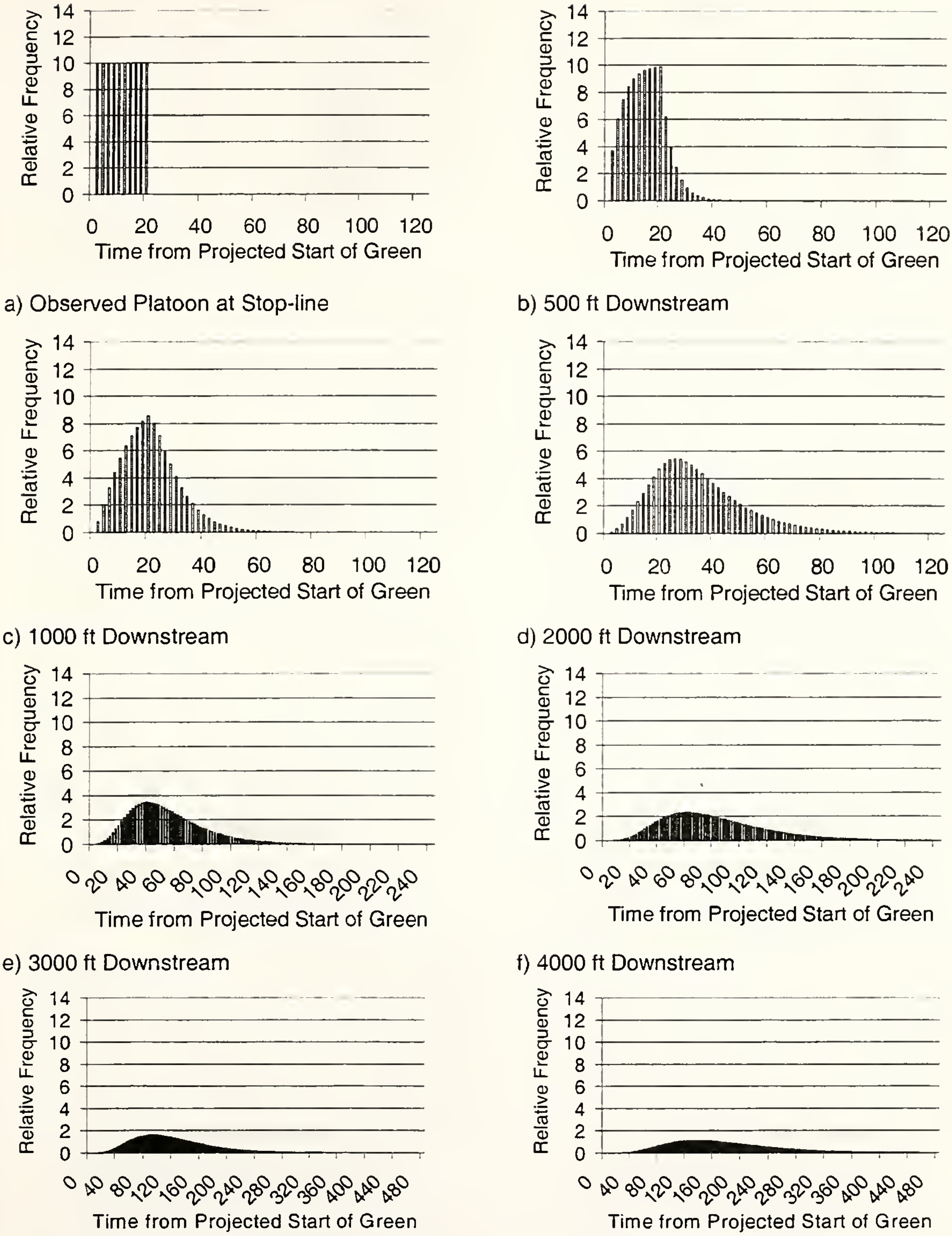


Figure B-7: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 20 second saturated platoon, Speed: 40 MPH



a) Observed Platoon at Stop-line

b) 500 ft Downstream

c) 1000 ft Downstream

d) 2000 ft Downstream

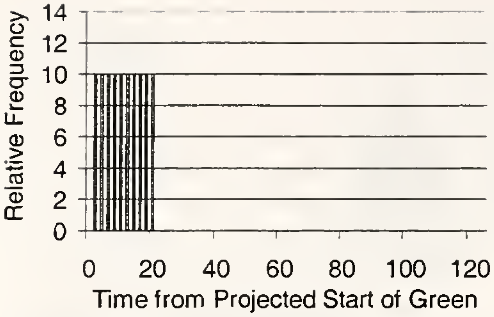
e) 3000 ft Downstream

f) 4000 ft Downstream

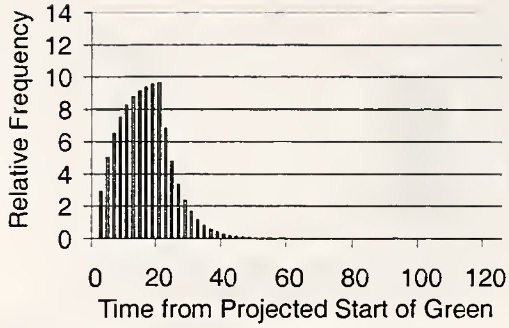
g) 6000 ft Downstream

h) 8000 ft Downstream

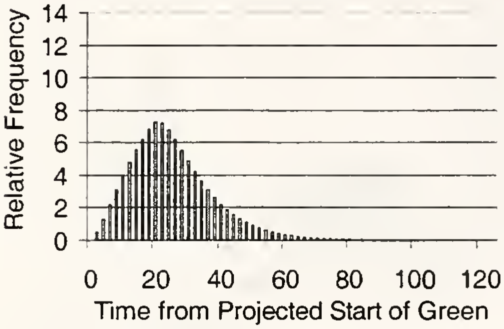
Figure B-8: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 40 MPH



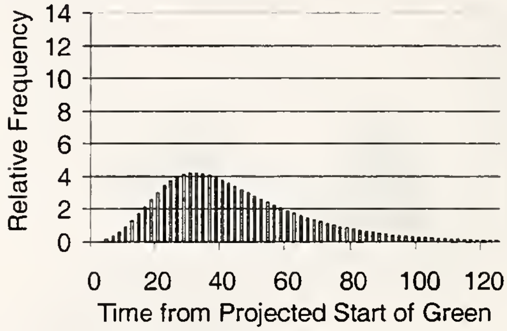
a) Observed Platoon at Stop-line



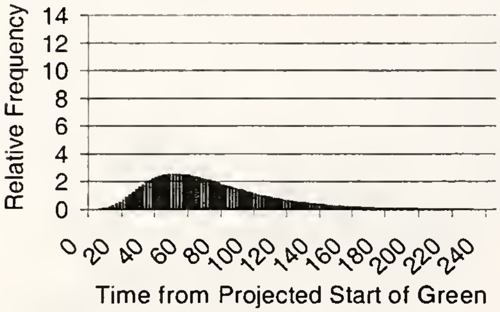
b) 500 ft Downstream



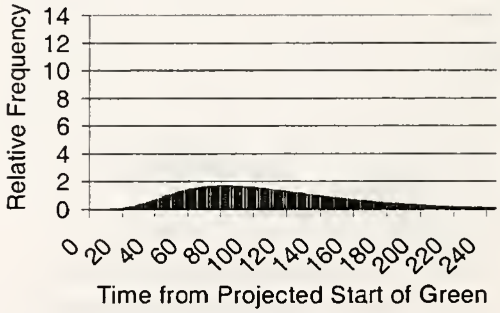
c) 1000 ft Downstream



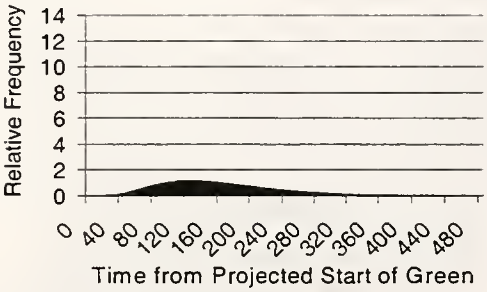
d) 2000 ft Downstream



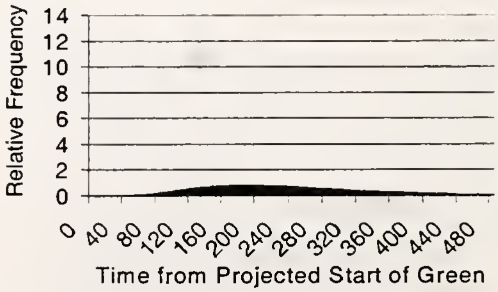
e) 3000 ft Downstream



f) 4000 ft Downstream

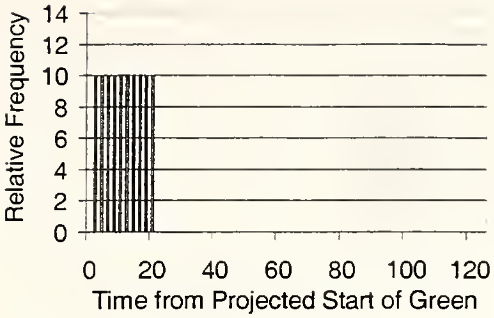


g) 6000 ft Downstream

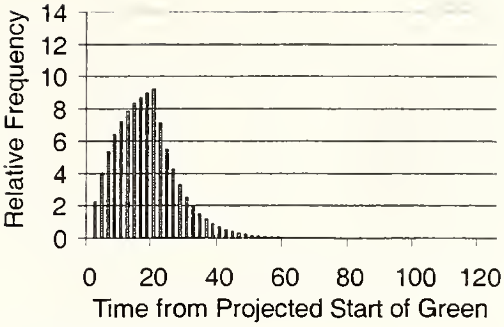


h) 8000 ft Downstream

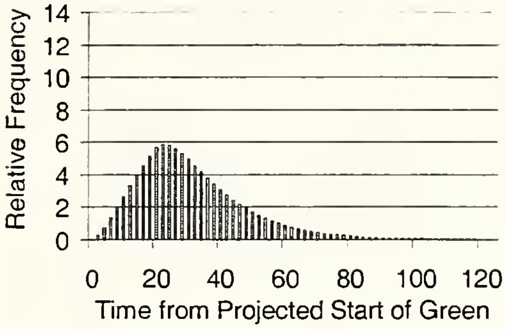
Figure B-9: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 40 MPH



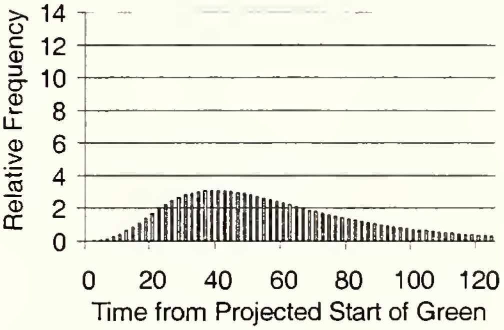
a) Observed Platoon at Stop-line



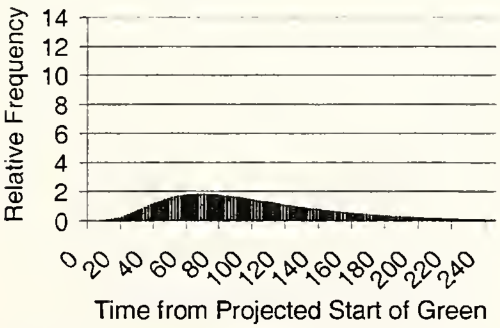
b) 500 ft Downstream



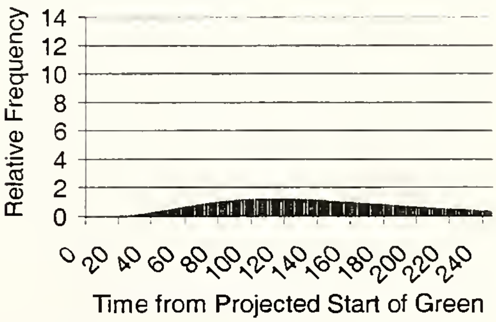
c) 1000 ft Downstream



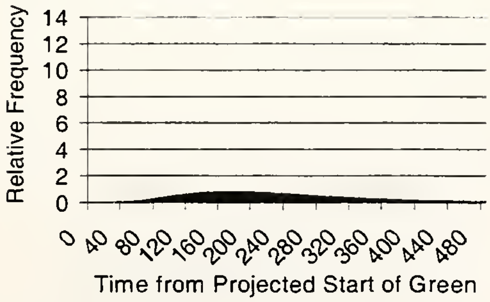
d) 2000 ft Downstream



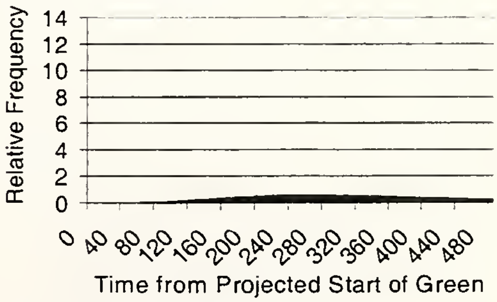
e) 3000 ft Downstream



f) 4000 ft Downstream

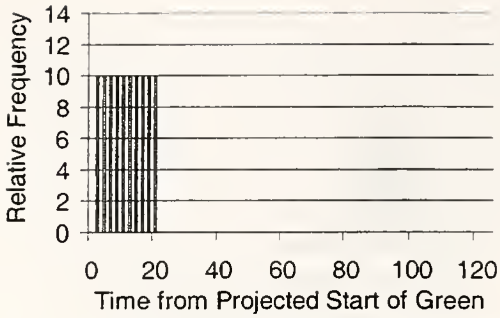


g) 6000 ft Downstream

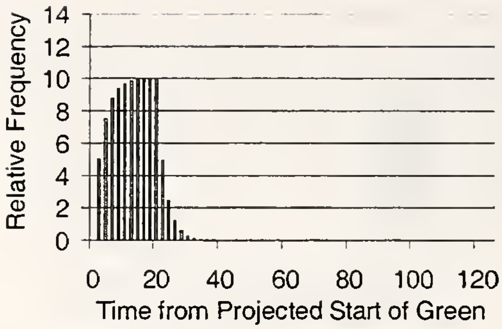


h) 8000 ft Downstream

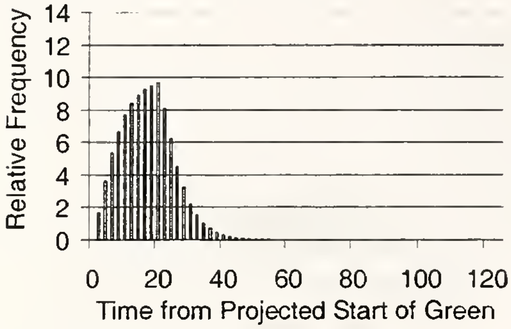
Figure B-10: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 40 MPH



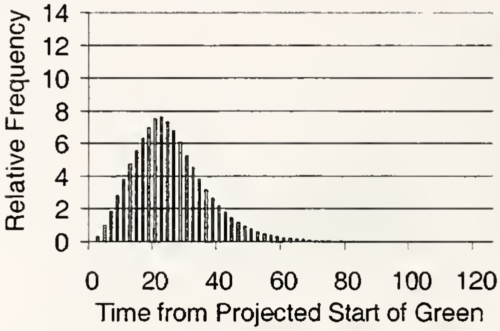
a) Observed Platoon at Stop-line



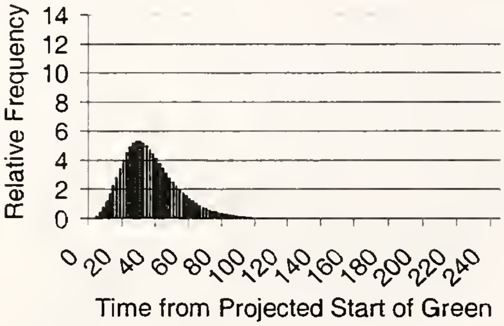
b) 500 ft Downstream



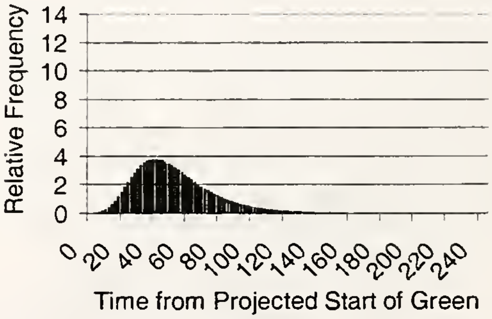
c) 1000 ft Downstream



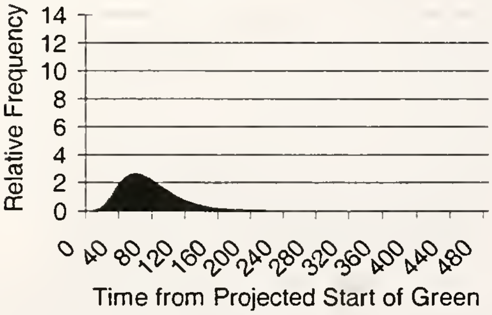
d) 2000 ft Downstream



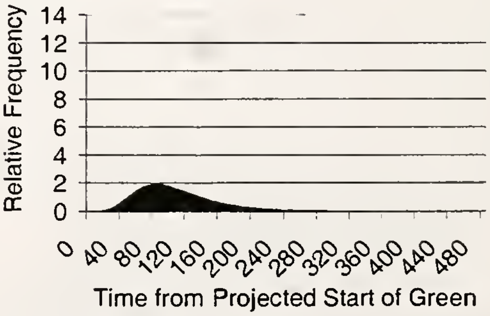
e) 3000 ft Downstream



f) 4000 ft Downstream

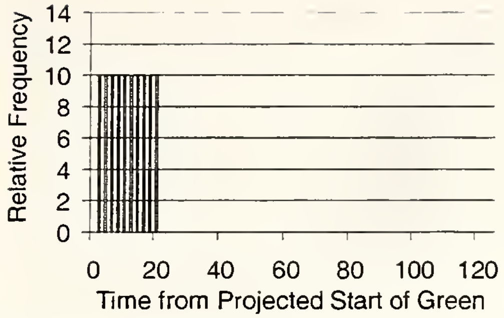


g) 6000 ft Downstream

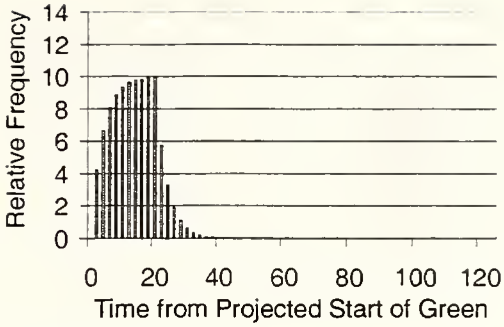


h) 8000 ft Downstream

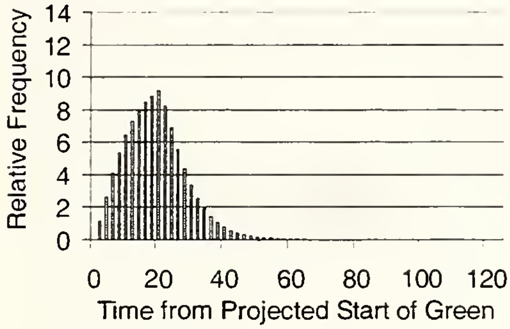
Figure B-11: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 50 MPH



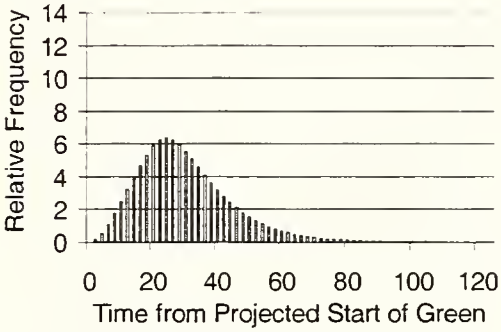
a) Observed Platoon at Stop-line



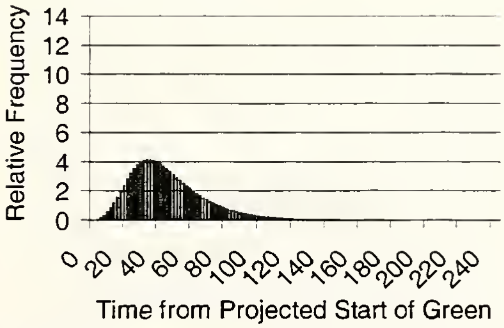
b) 500 ft Downstream



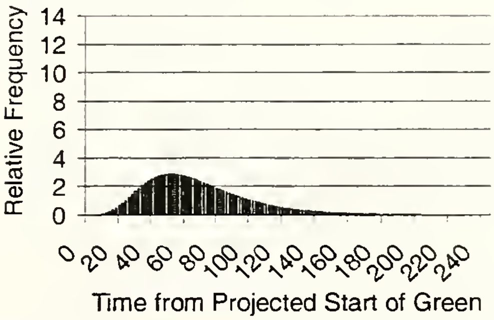
c) 1000 ft Downstream



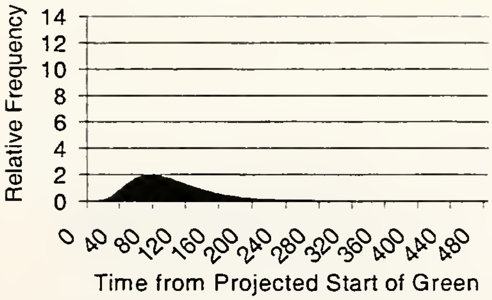
d) 2000 ft Downstream



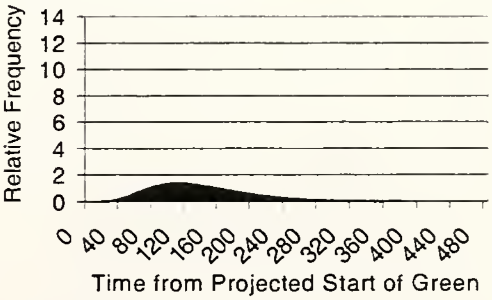
e) 3000 ft Downstream



f) 4000 ft Downstream

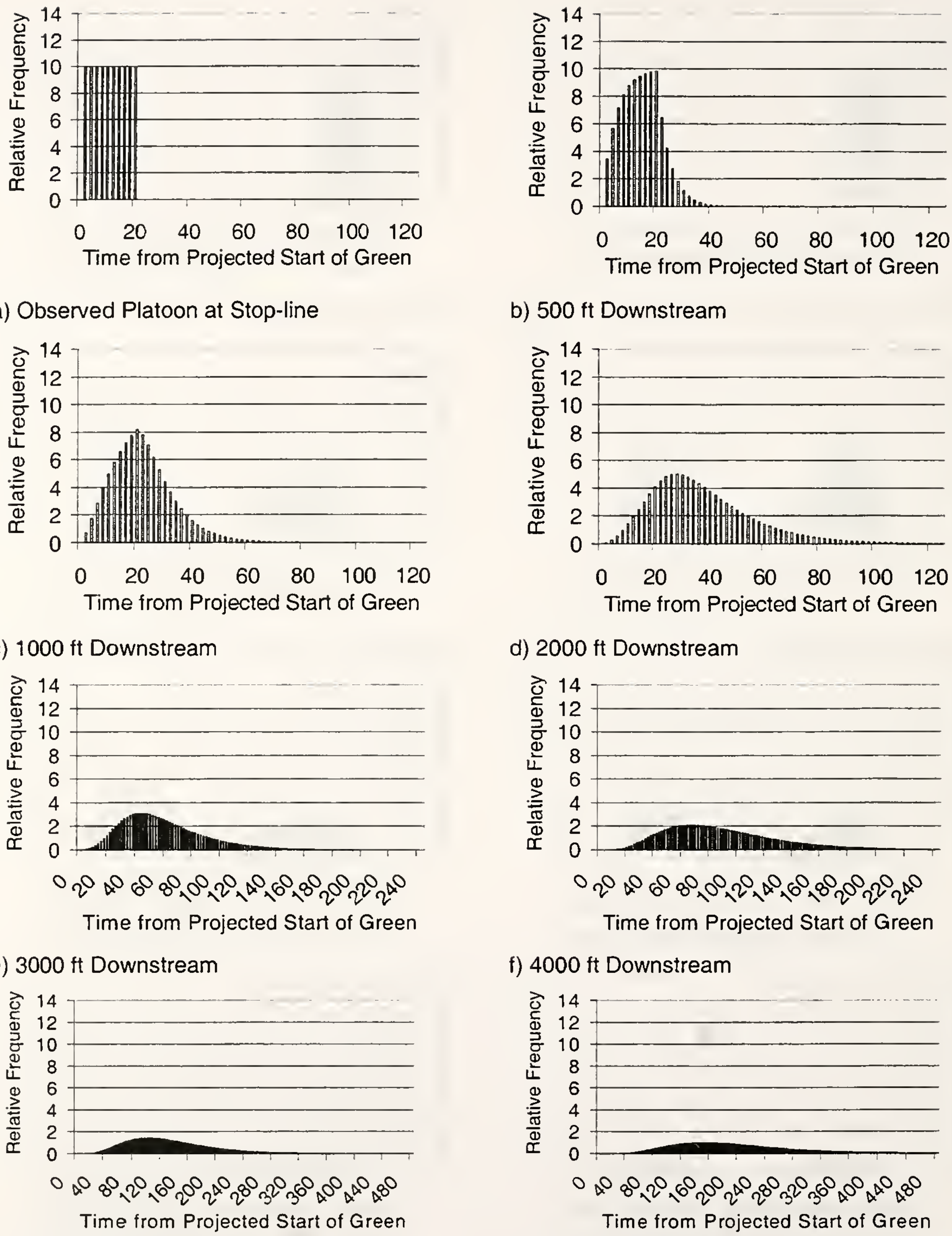


g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-12: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 50 MPH



a) Observed Platoon at Stop-line

b) 500 ft Downstream

c) 1000 ft Downstream

d) 2000 ft Downstream

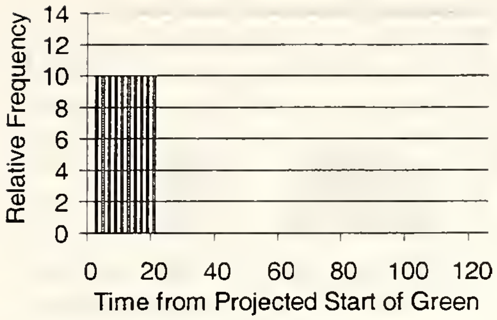
e) 3000 ft Downstream

f) 4000 ft Downstream

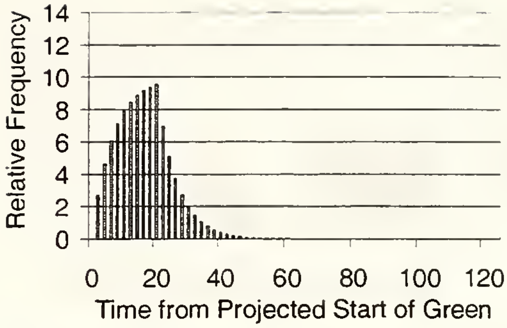
g) 6000 ft Downstream

h) 8000 ft Downstream

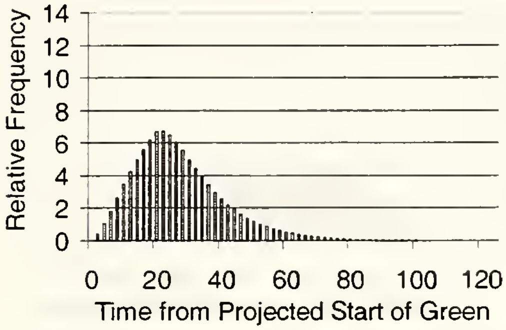
Figure B-13: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 50 MPH



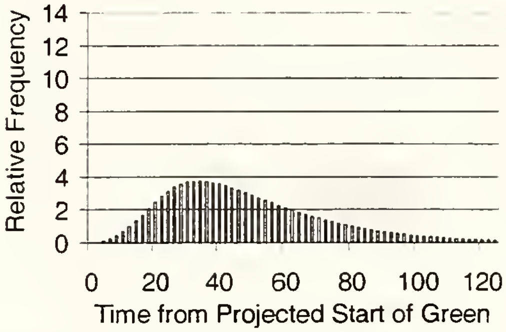
a) Observed Platoon at Stop-line



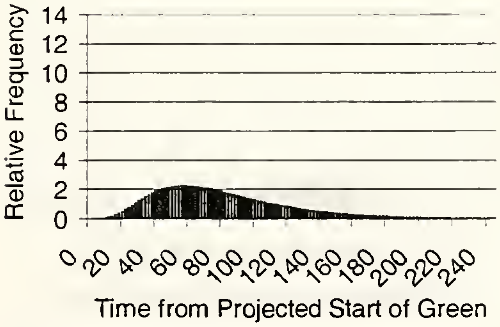
b) 500 ft Downstream



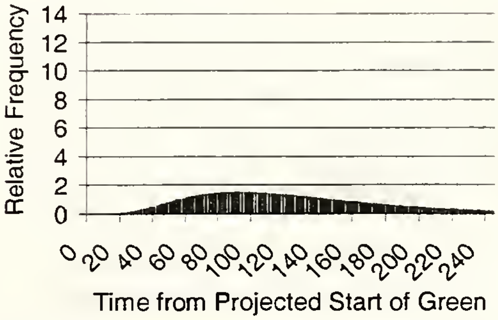
c) 1000 ft Downstream



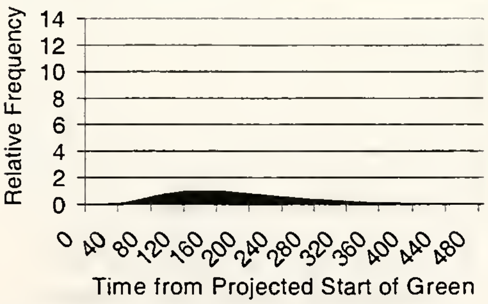
d) 2000 ft Downstream



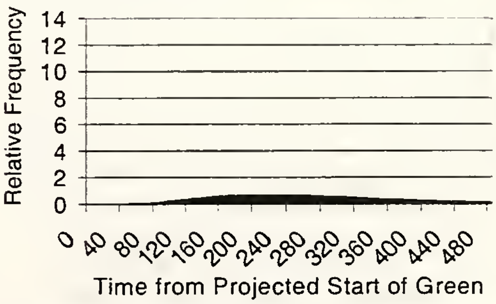
e) 3000 ft Downstream



f) 4000 ft Downstream

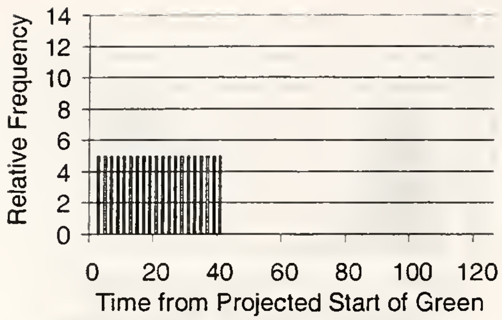


g) 6000 ft Downstream

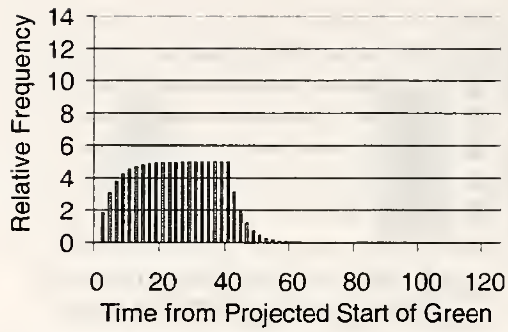


h) 8000 ft Downstream

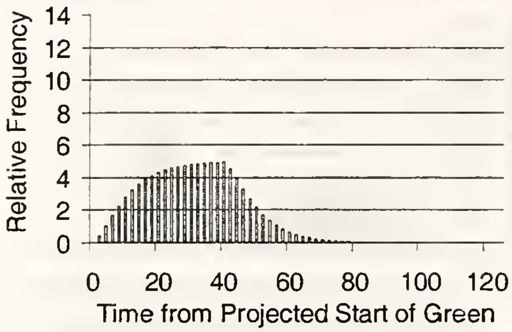
Figure B-14: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 20 second saturated platoon, Speed: 50 MPH



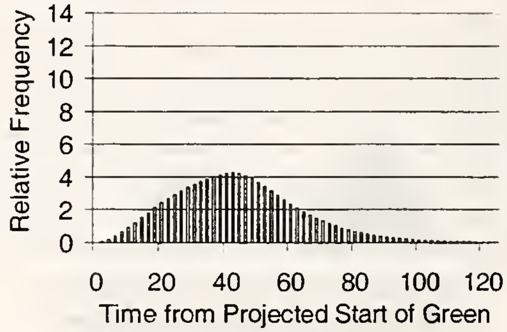
a) Platoon at Stop-line



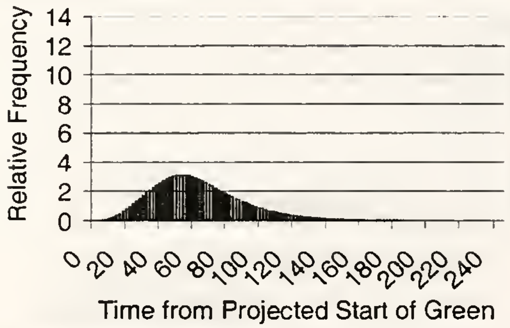
b) 500 ft Downstream



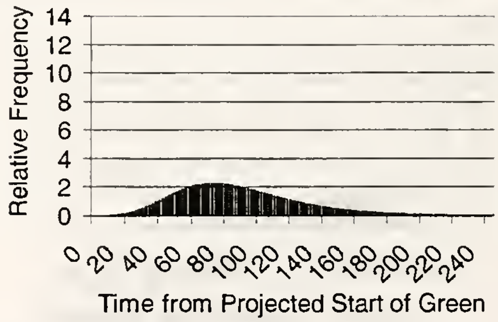
c) 1000 ft Downstream



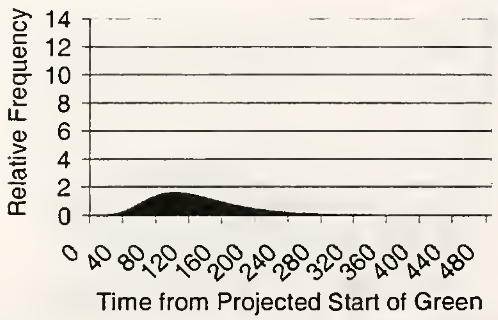
d) 2000 ft Downstream



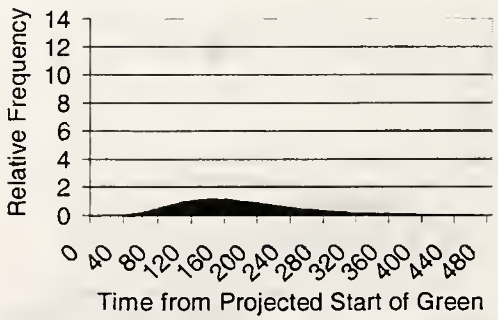
e) 3000 ft Downstream



f) 4000 ft Downstream

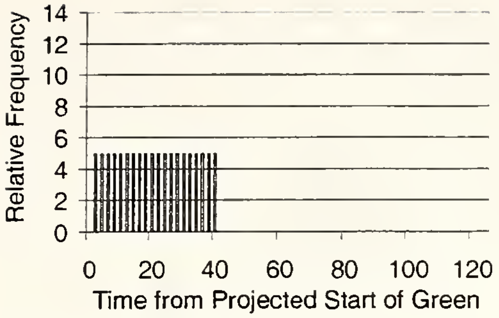


g) 6000 ft Downstream

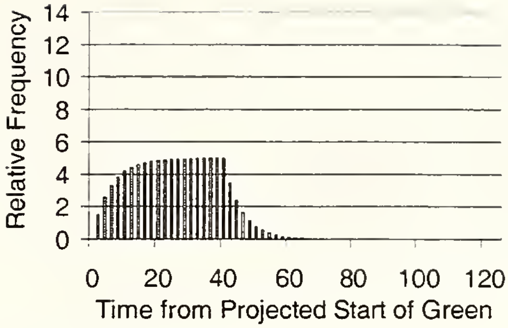


h) 8000 ft Downstream

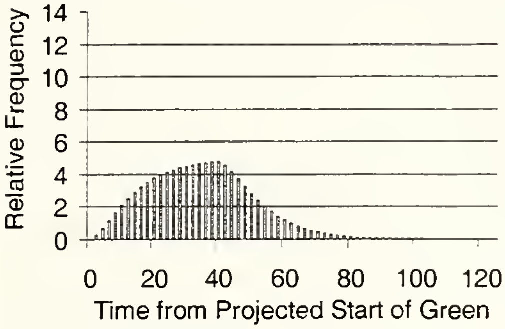
Figure B-15: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 40 second saturated platoon, Speed: 30 MPH



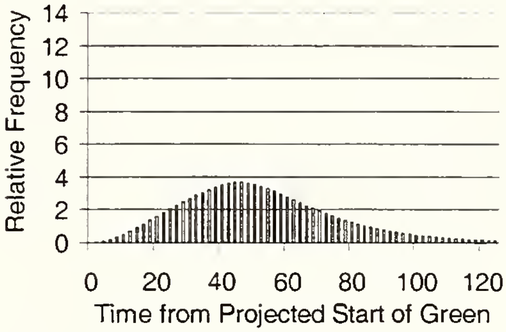
a) Platoon at Stop-line



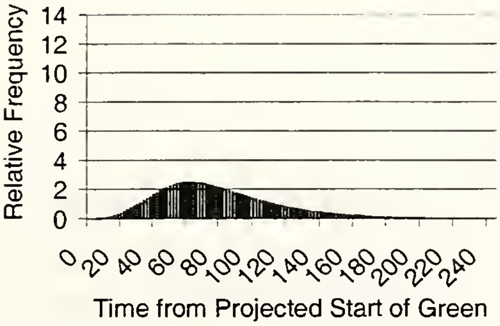
b) 500 ft Downstream



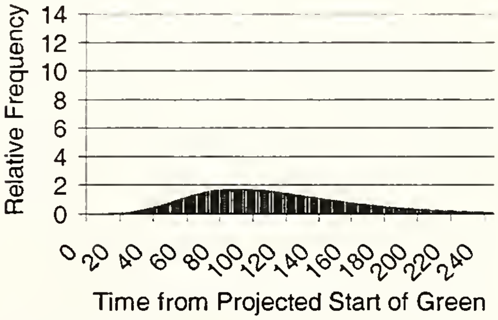
c) 1000 ft Downstream



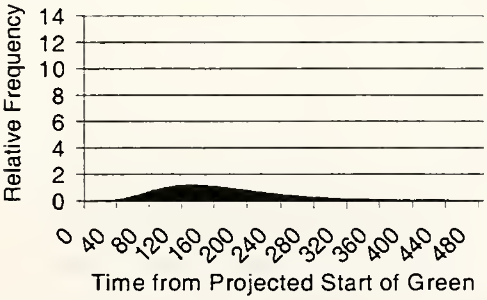
d) 2000 ft Downstream



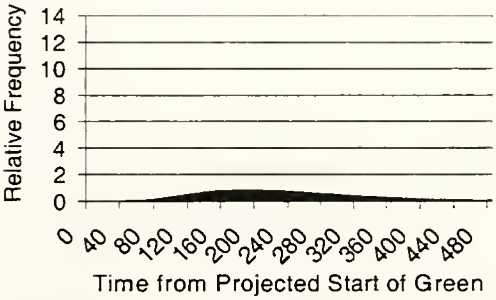
e) 3000 ft Downstream



f) 4000 ft Downstream



g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-16: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 30 MPH

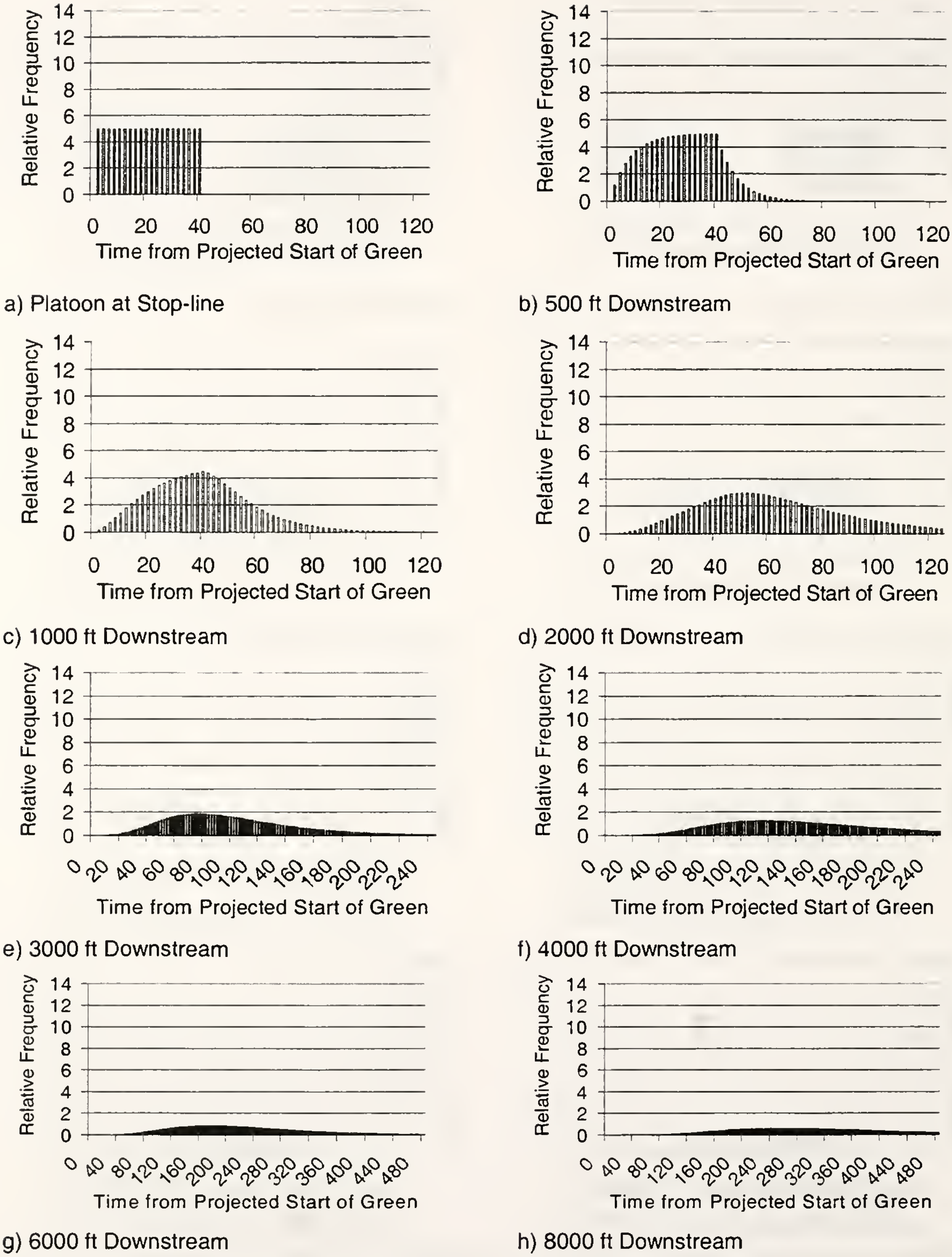


Figure B-17: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 30 MPH

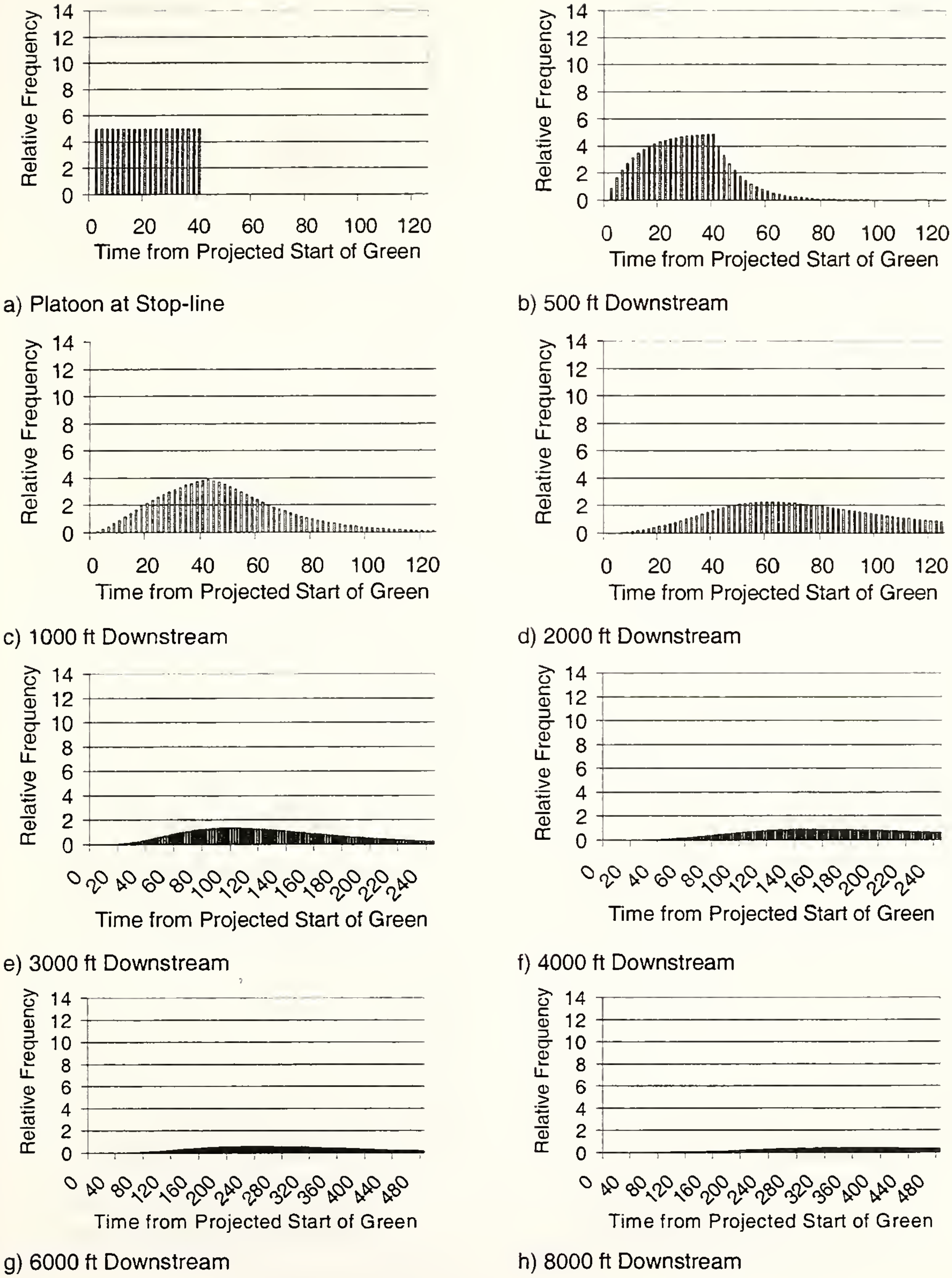


Figure B-18: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 30 MPH

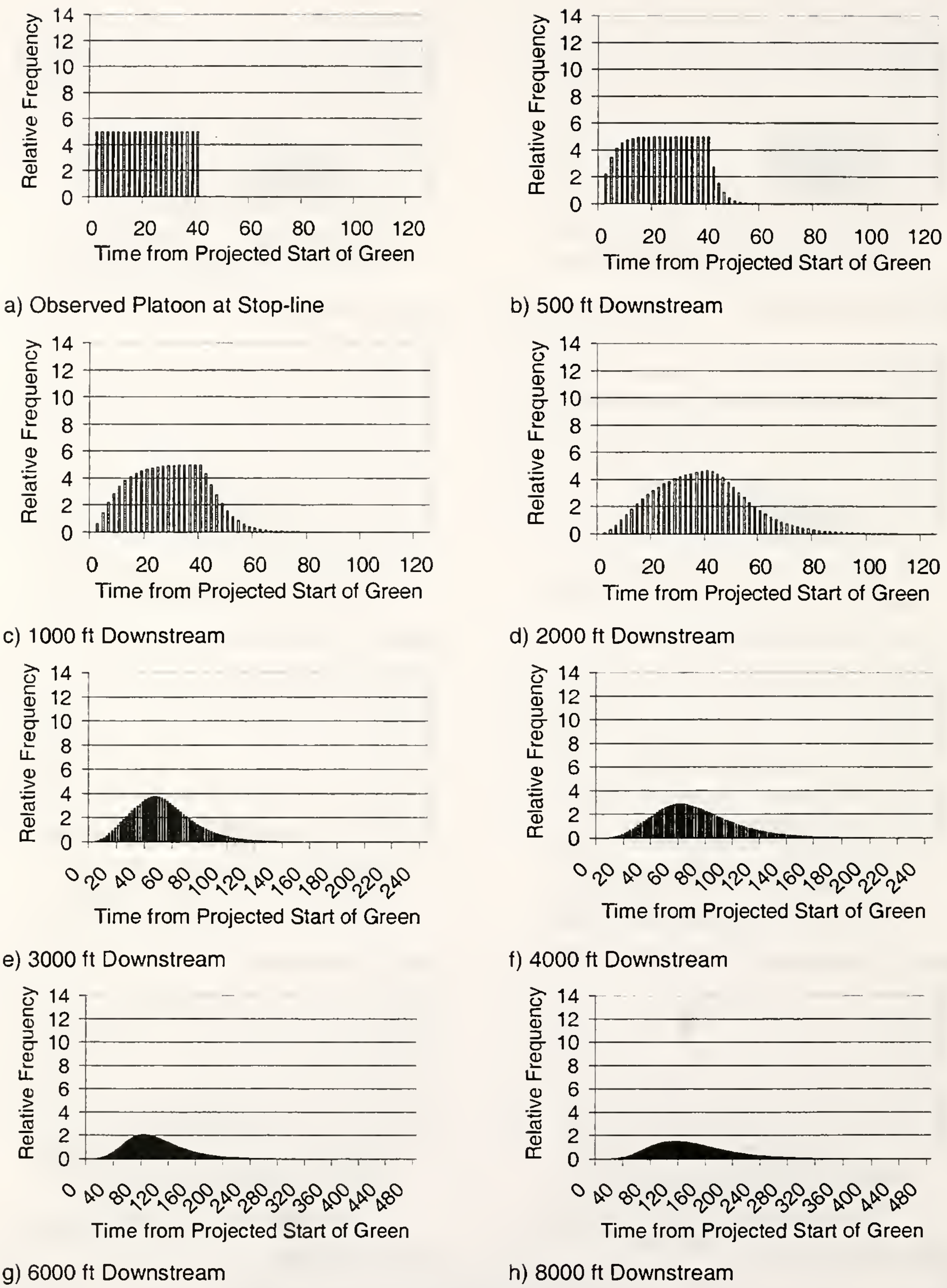
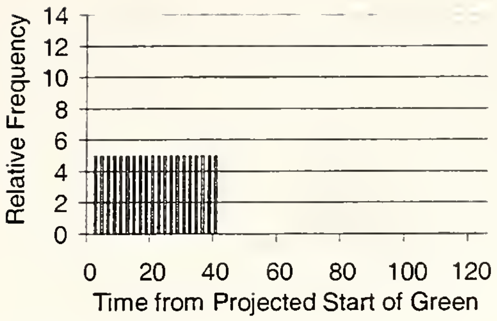
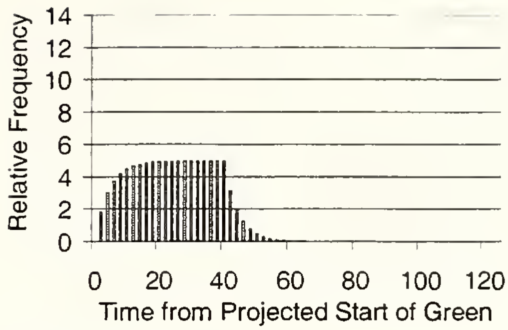


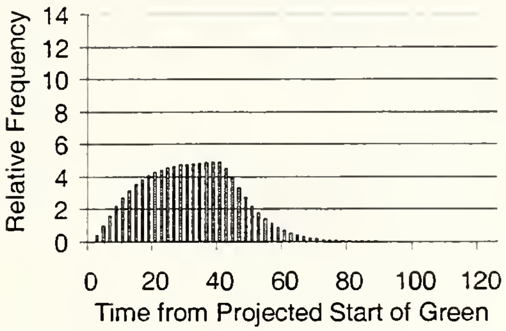
Figure B-19: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 40 second saturated platoon, Speed: 40 MPH



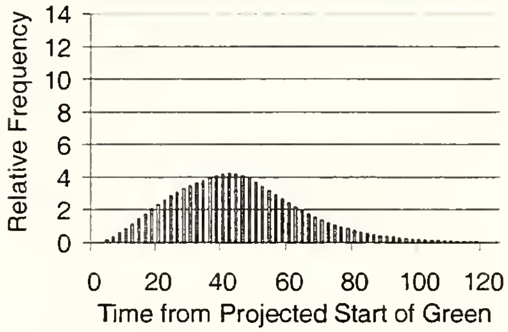
a) Observed Platoon at Stop-line



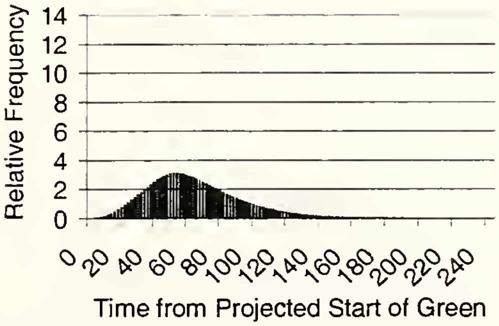
b) 500 ft Downstream



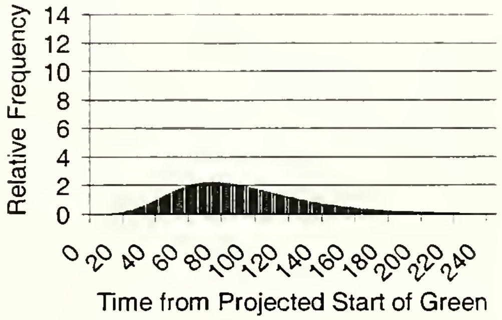
c) 1000 ft Downstream



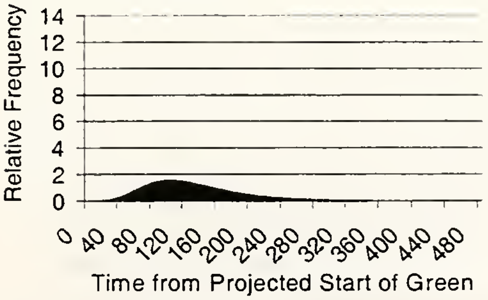
d) 2000 ft Downstream



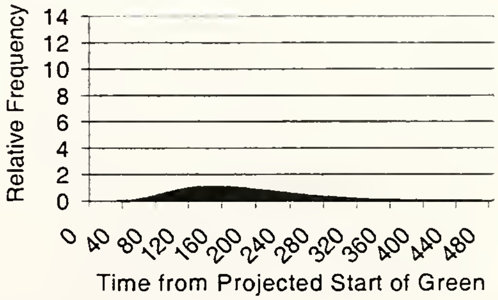
e) 3000 ft Downstream



f) 4000 ft Downstream



g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-20: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 40 MPH

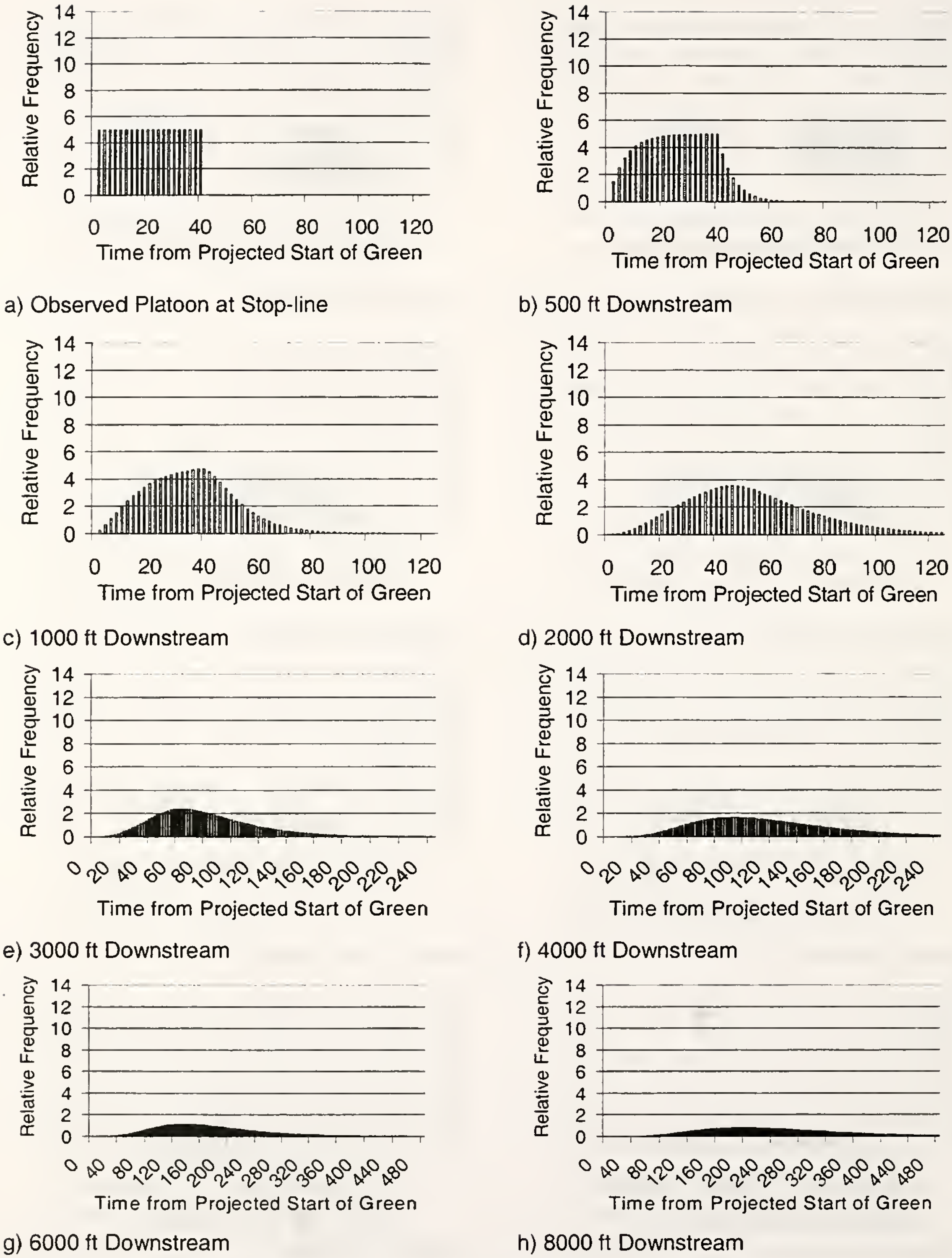
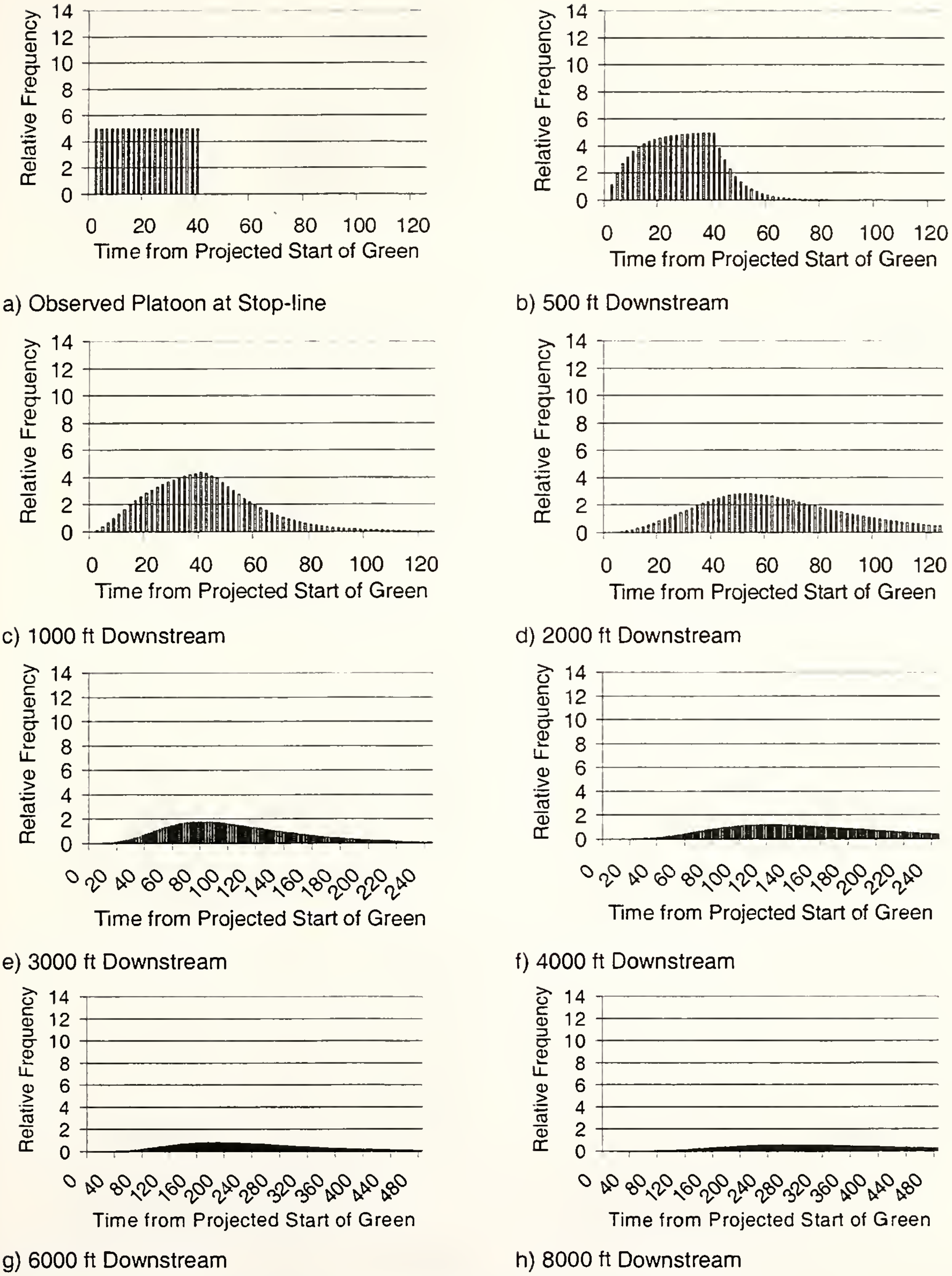
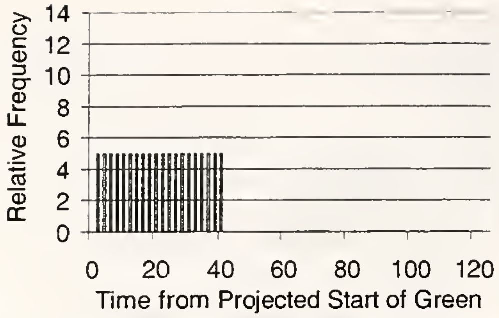


Figure B-21: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 40 MPH

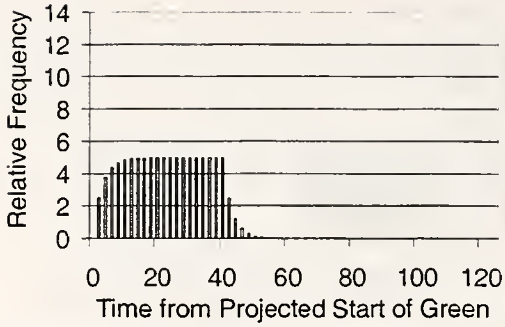


a) Observed Platoon at Stop-line
b) 500 ft Downstream
c) 1000 ft Downstream
d) 2000 ft Downstream
e) 3000 ft Downstream
f) 4000 ft Downstream
g) 6000 ft Downstream
h) 8000 ft Downstream

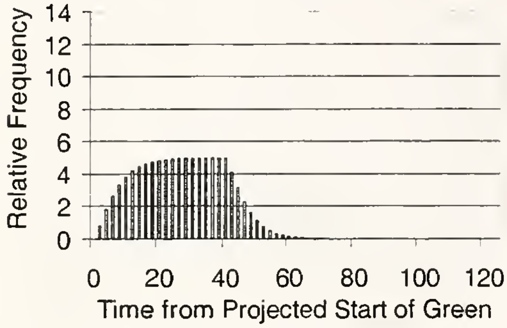
Figure B-22: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 40 MPH



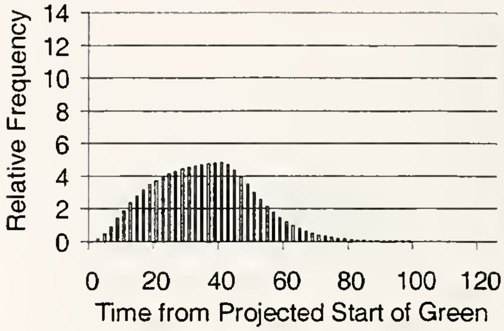
a) Observed Platoon at Stop-line



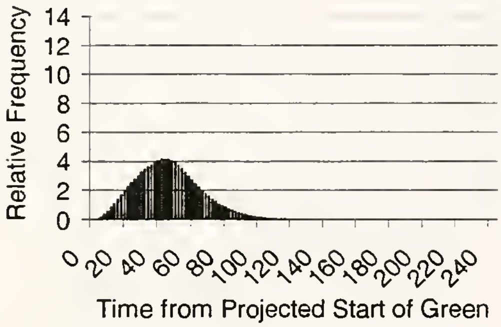
b) 500 ft Downstream



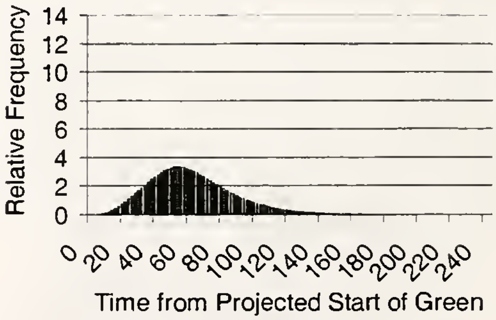
c) 1000 ft Downstream



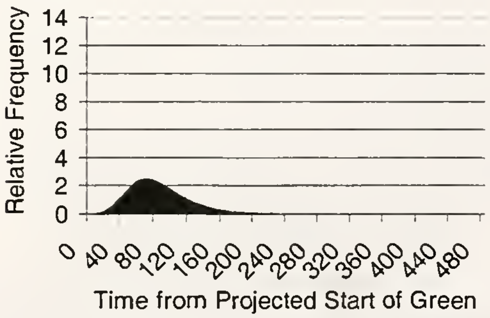
d) 2000 ft Downstream



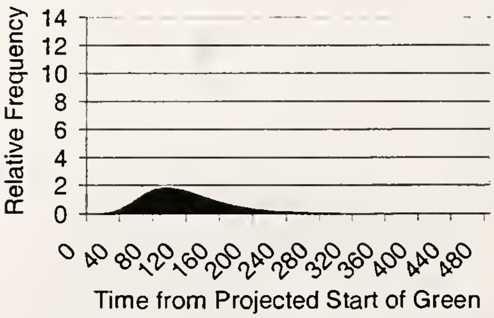
e) 3000 ft Downstream



f) 4000 ft Downstream

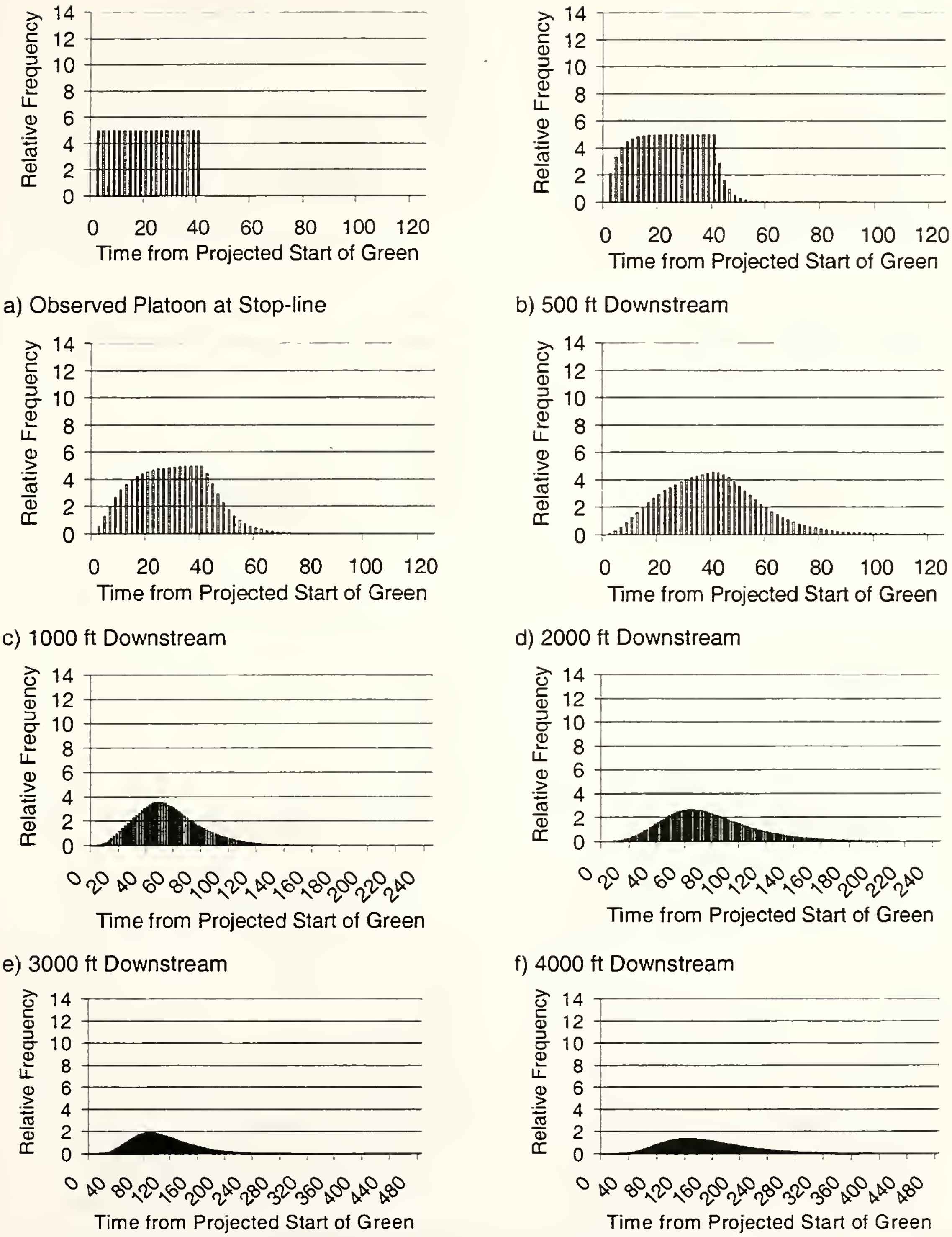


g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-23: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 40 second saturated platoon, Speed: 50 MPH



a) Observed Platoon at Stop-line

b) 500 ft Downstream

c) 1000 ft Downstream

d) 2000 ft Downstream

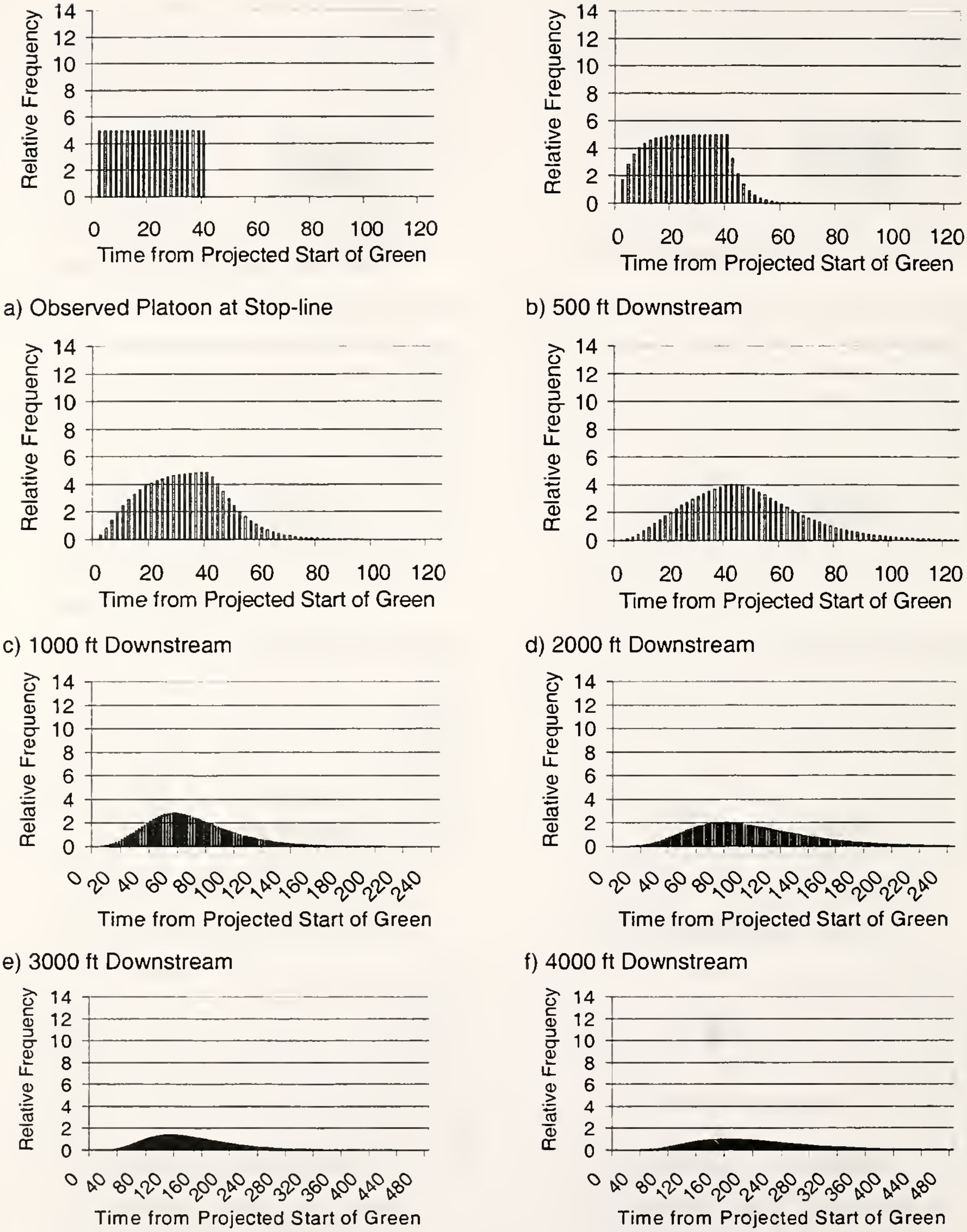
e) 3000 ft Downstream

f) 4000 ft Downstream

g) 6000 ft Downstream

h) 8000 ft Downstream

Figure B-24: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 50 MPH



a) Observed Platoon at Stop-line
b) 500 ft Downstream
c) 1000 ft Downstream
d) 2000 ft Downstream
e) 3000 ft Downstream
f) 4000 ft Downstream
g) 6000 ft Downstream
h) 8000 ft Downstream

Figure B-25: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 50 MPH

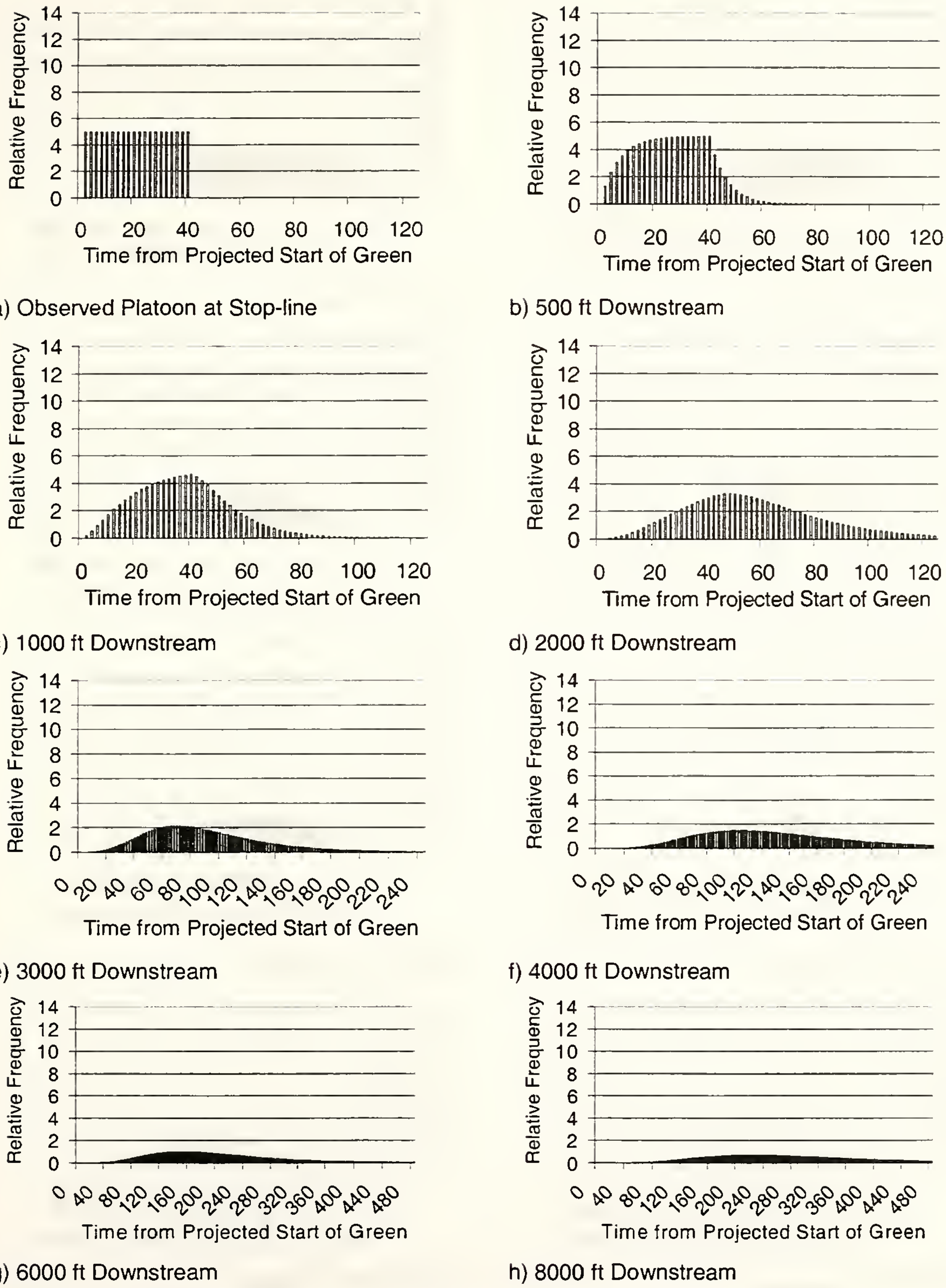
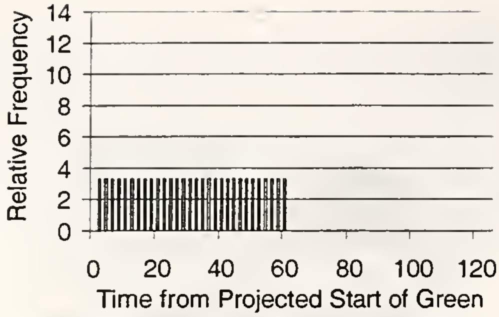
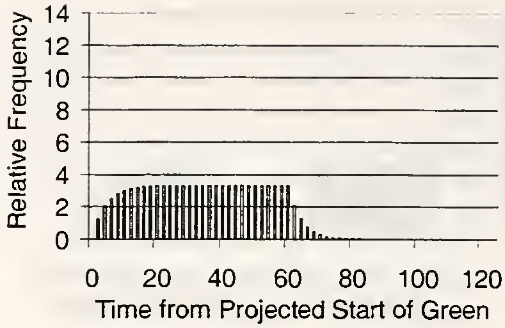


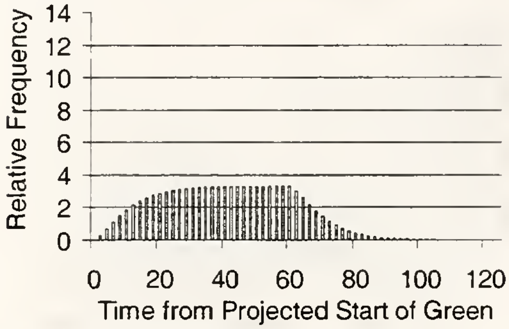
Figure B-26: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 40 second saturated platoon, Speed: 50 MPH



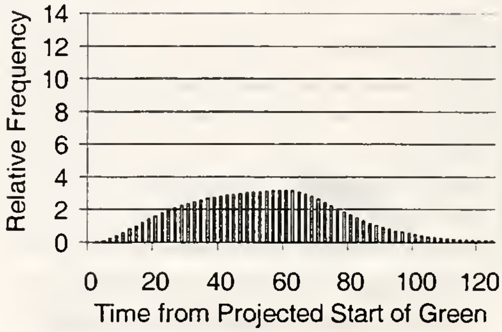
a) Platoon at Stop-line



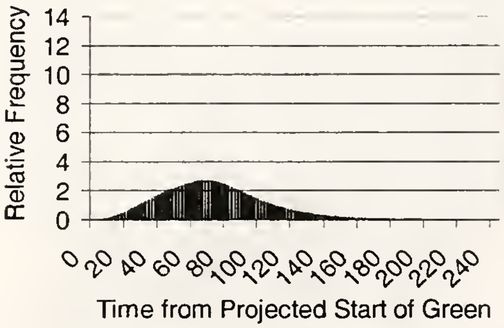
b) 500 ft Downstream



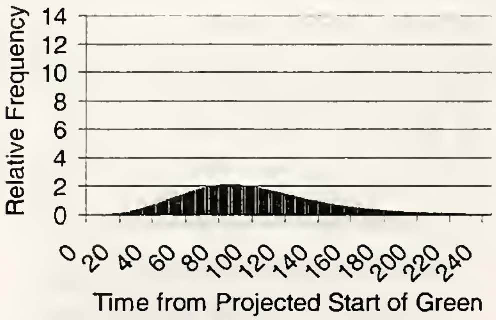
c) 1000 ft Downstream



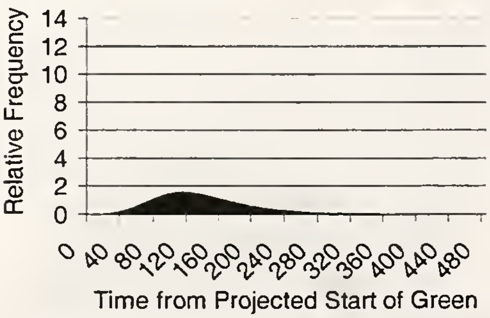
d) 2000 ft Downstream



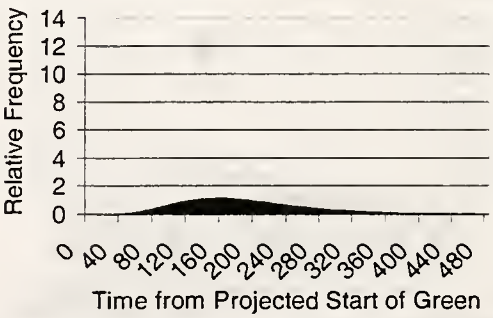
e) 3000 ft Downstream



f) 4000 ft Downstream

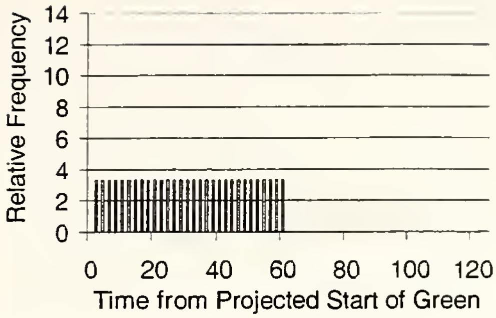


g) 6000 ft Downstream

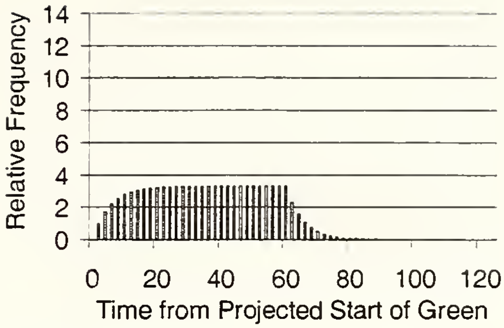


h) 8000 ft Downstream

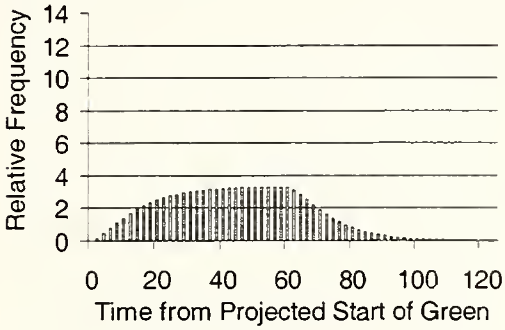
Figure B-27: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 60 second saturated platoon, Speed: 30 MPH



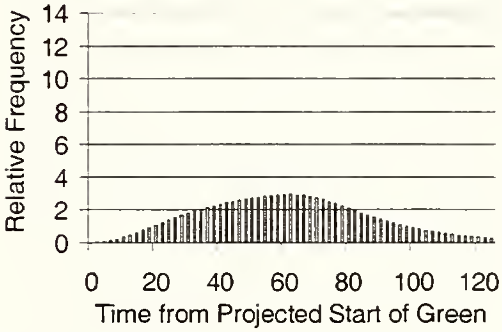
a) Platoon at Stop-line



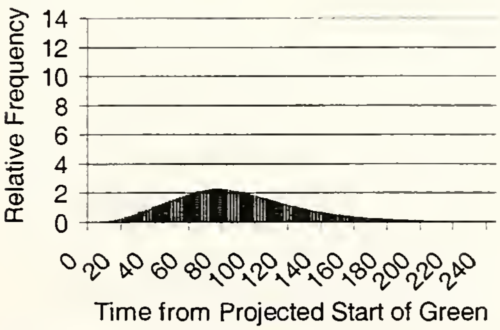
b) 500 ft Downstream



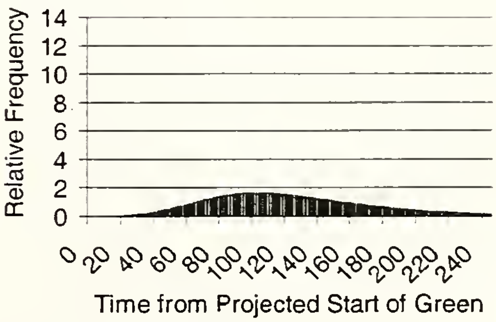
c) 1000 ft Downstream



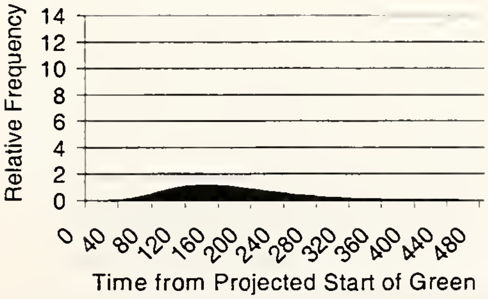
d) 2000 ft Downstream



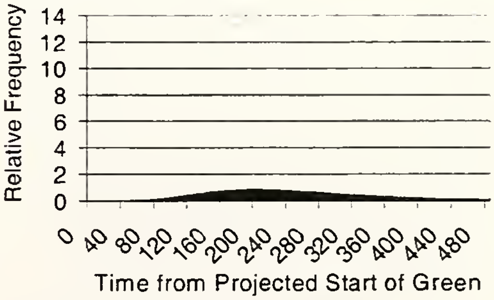
e) 3000 ft Downstream



f) 4000 ft Downstream

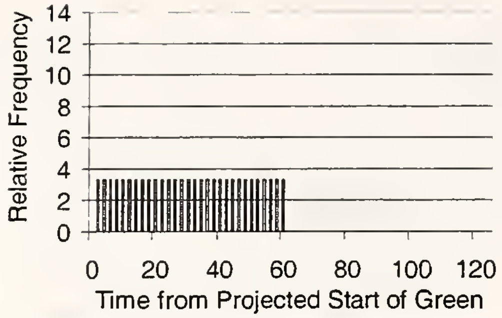


g) 6000 ft Downstream

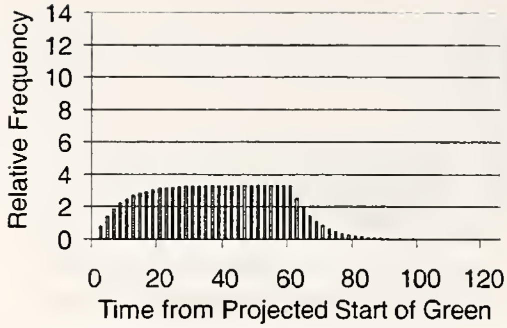


h) 8000 ft Downstream

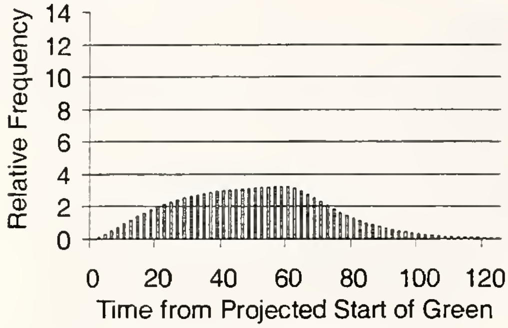
Figure B-28: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 30 MPH



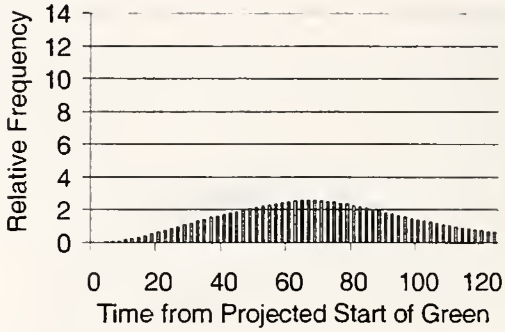
a) Platoon at Stop-line



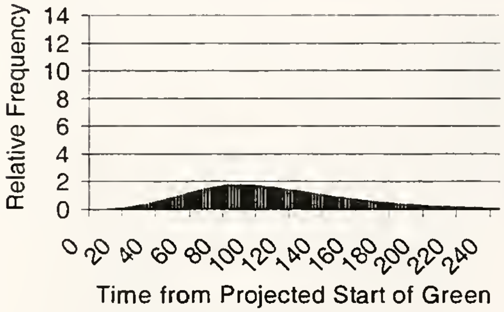
b) 500 ft Downstream



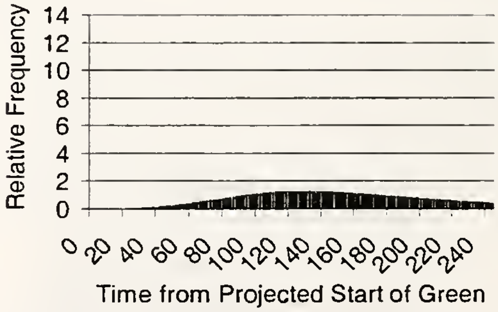
c) 1000 ft Downstream



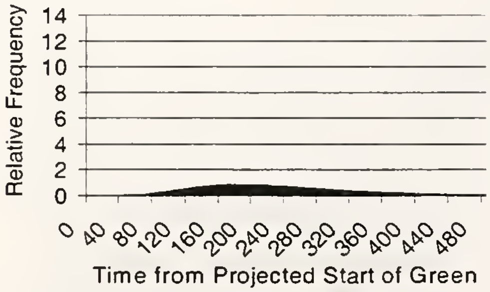
d) 2000 ft Downstream



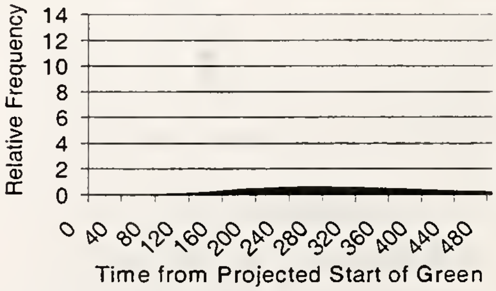
e) 3000 ft Downstream



f) 4000 ft Downstream

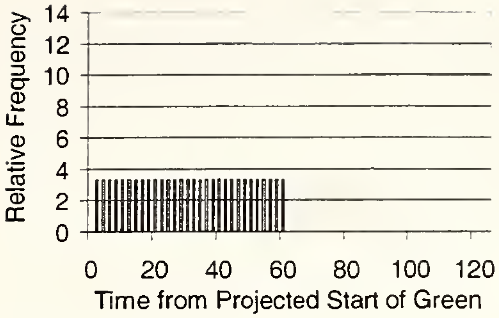


g) 6000 ft Downstream

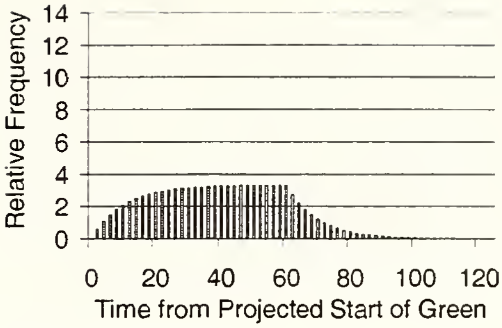


h) 8000 ft Downstream

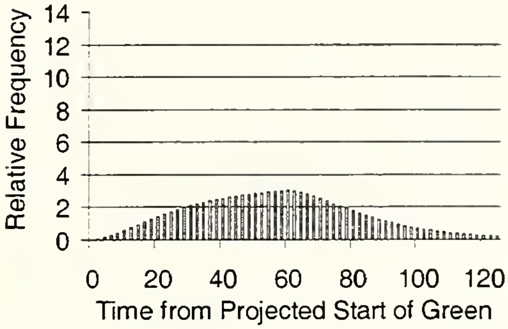
Figure B-29: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 30 MPH



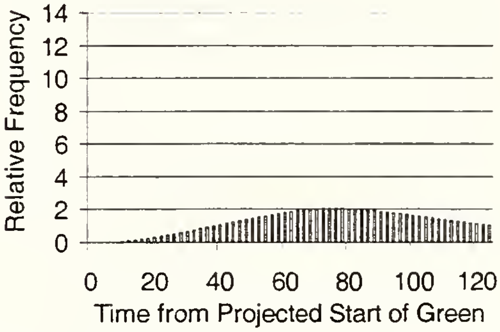
a) Platoon at Stop-line



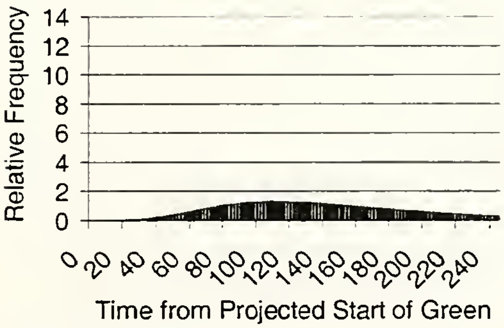
b) 500 ft Downstream



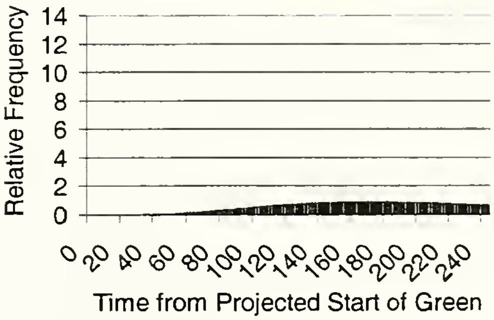
c) 1000 ft Downstream



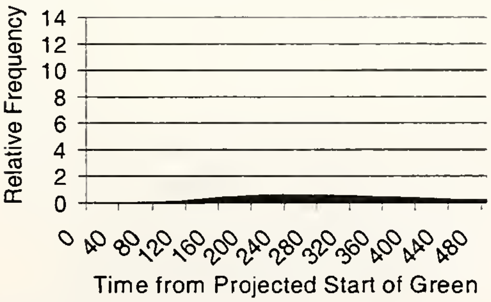
d) 2000 ft Downstream



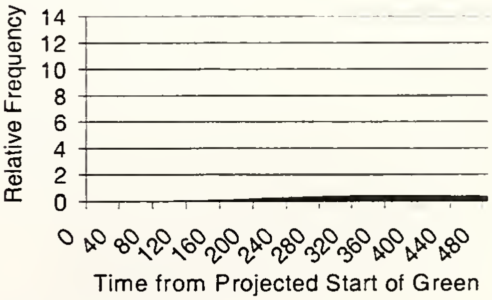
e) 3000 ft Downstream



f) 4000 ft Downstream

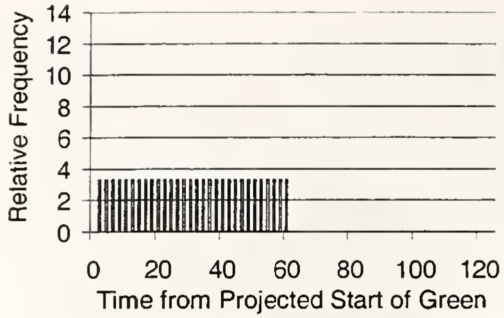


g) 6000 ft Downstream

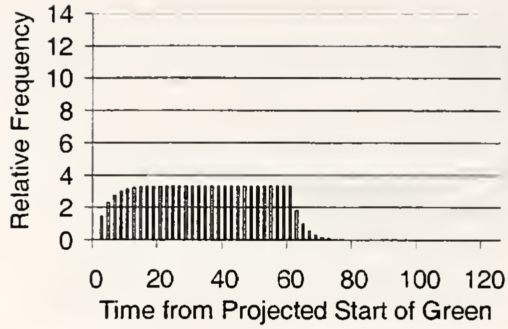


h) 8000 ft Downstream

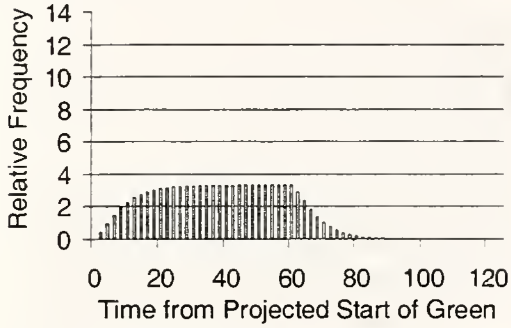
Figure B-30: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 30 MPH



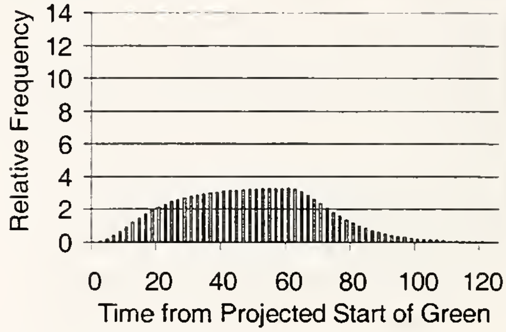
a) Platoon at Stop-line



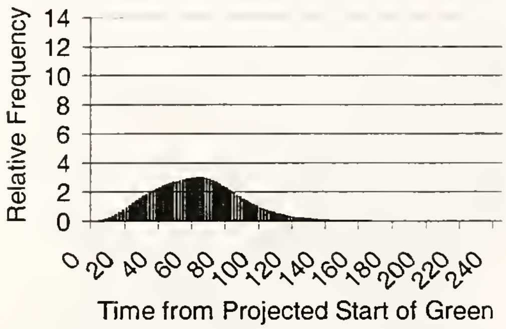
b) 500 ft Downstream



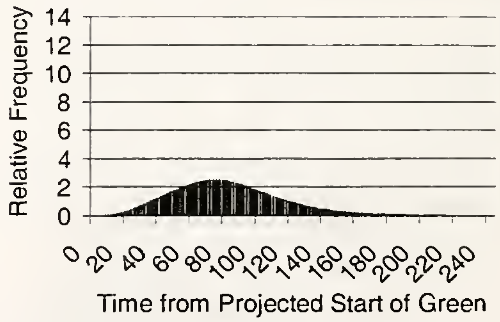
c) 1000 ft Downstream



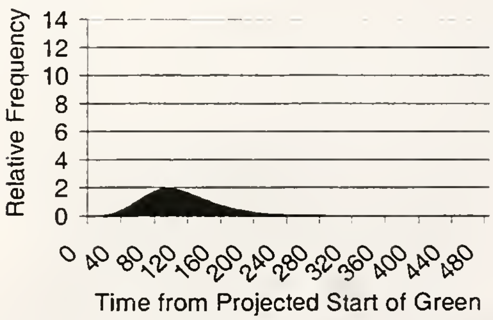
d) 2000 ft Downstream



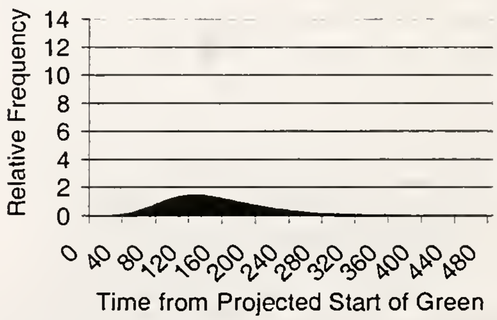
e) 3000 ft Downstream



f) 4000 ft Downstream

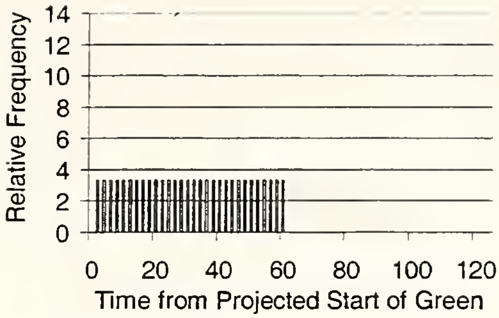


g) 6000 ft Downstream

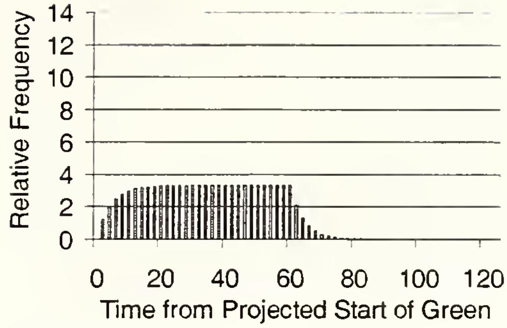


h) 8000 ft Downstream

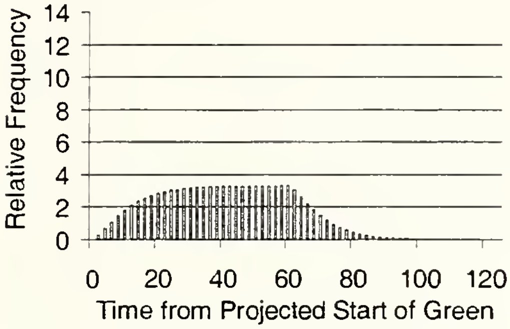
Figure B-31: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 60 second saturation, Speed: 40 MPH



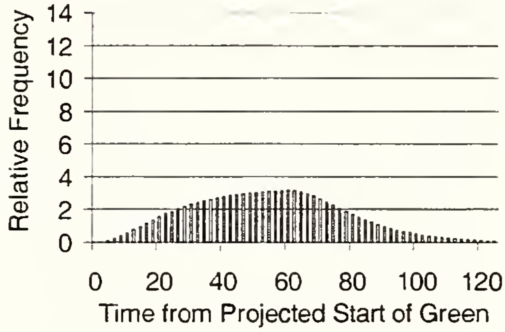
a) Platoon at Stop-line



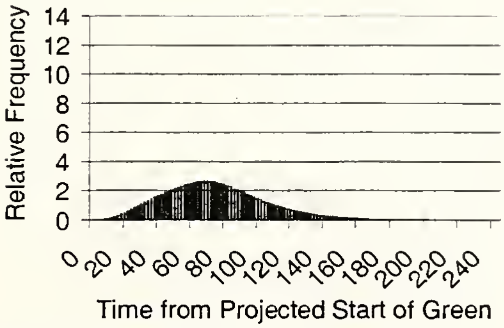
b) 500 ft Downstream



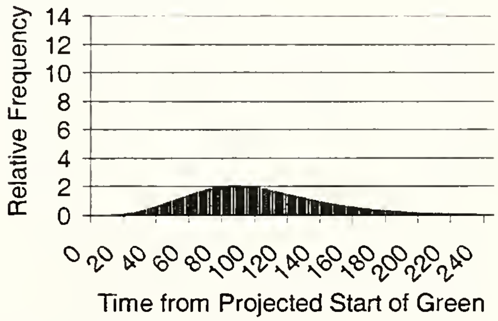
c) 1000 ft Downstream



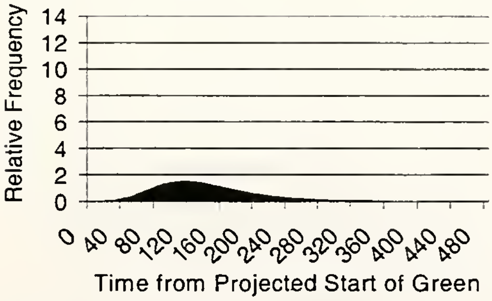
d) 2000 ft Downstream



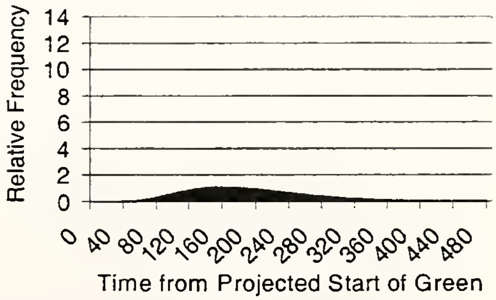
e) 3000 ft Downstream



f) 4000 ft Downstream

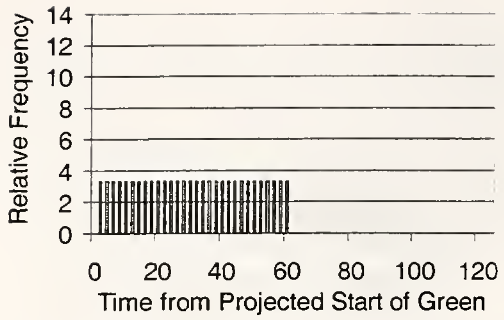


g) 6000 ft Downstream

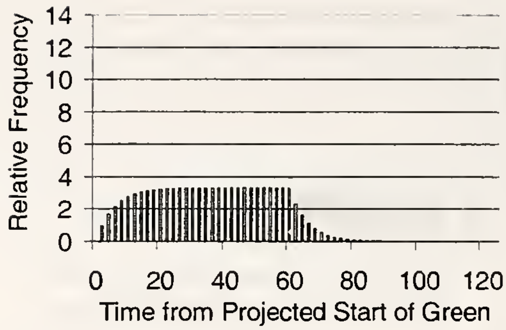


h) 8000 ft Downstream

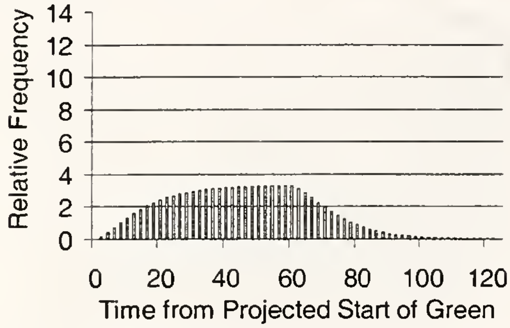
Figure B-32: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturation, Speed: 40 MPH



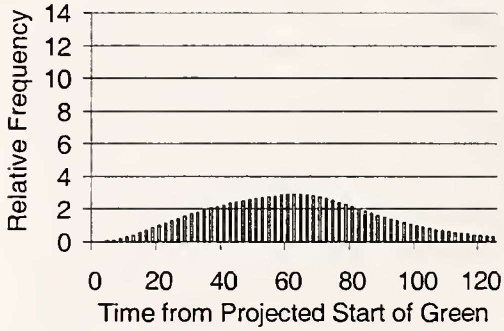
a) Platoon at Stop-line



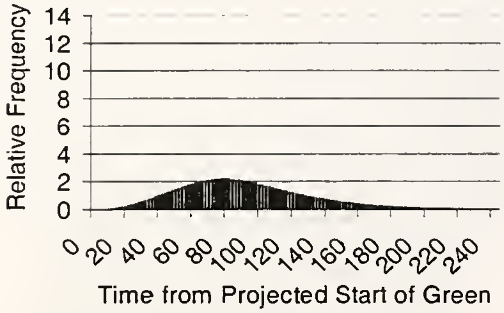
b) 500 ft Downstream



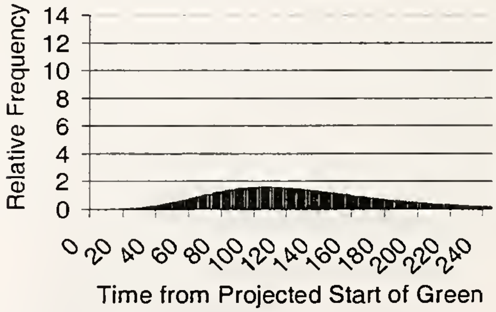
c) 1000 ft Downstream



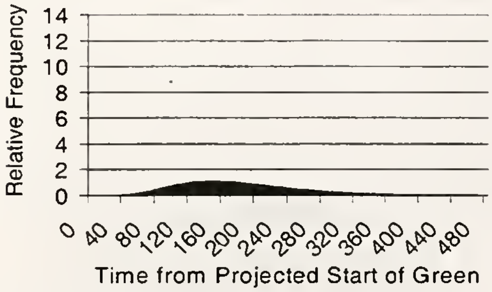
d) 2000 ft Downstream



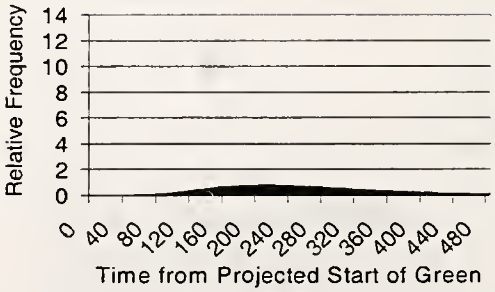
e) 3000 ft Downstream



f) 4000 ft Downstream

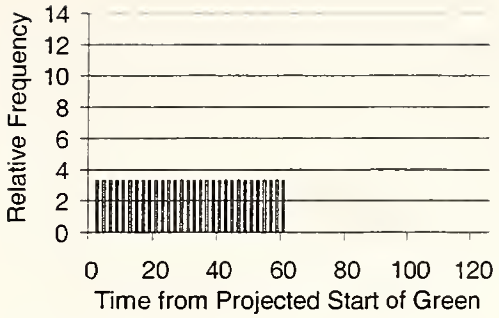


g) 6000 ft Downstream

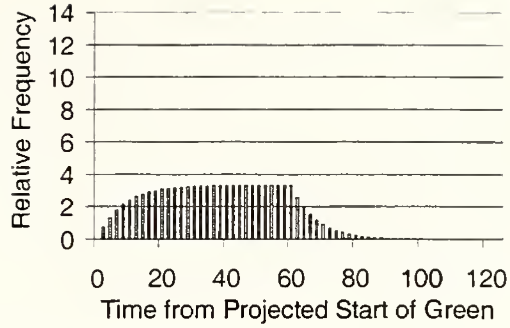


h) 8000 ft Downstream

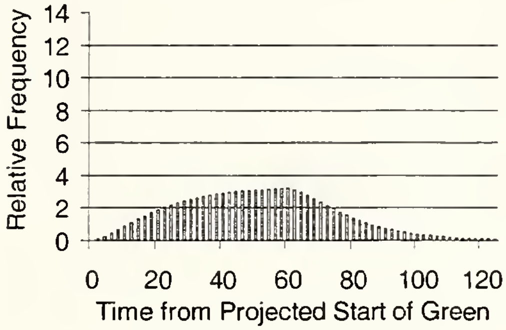
Figure B-33: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturation, Speed: 40 MPH



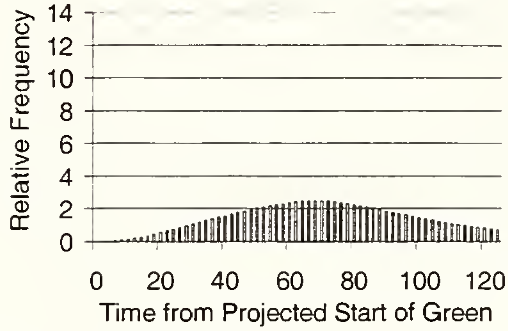
a) Platoon at Stop-line



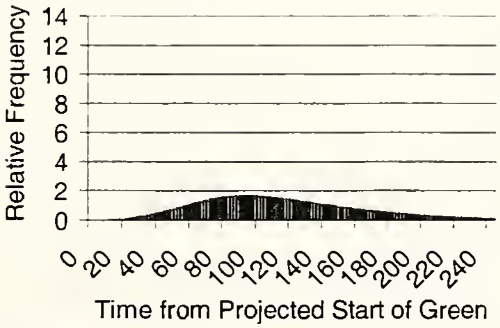
b) 500 ft Downstream



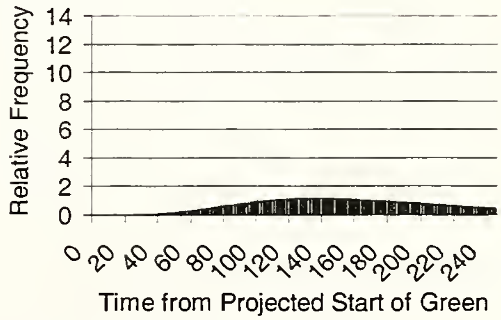
c) 1000 ft Downstream



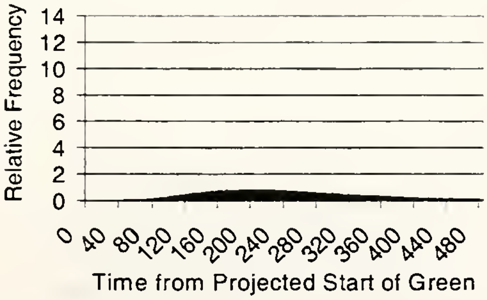
d) 2000 ft Downstream



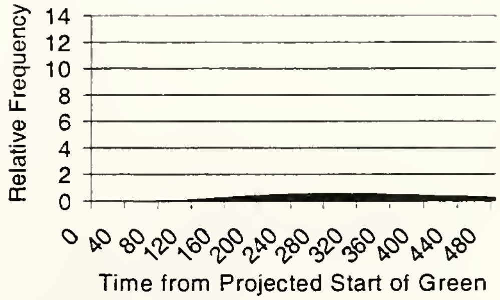
e) 3000 ft Downstream



f) 4000 ft Downstream

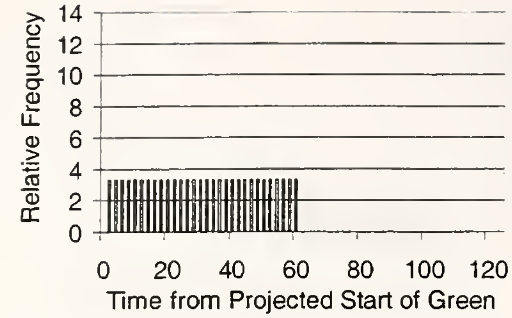


g) 6000 ft Downstream

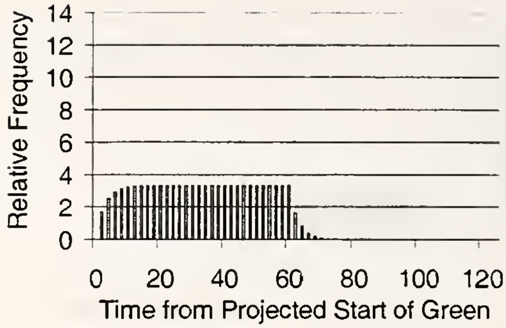


h) 8000 ft Downstream

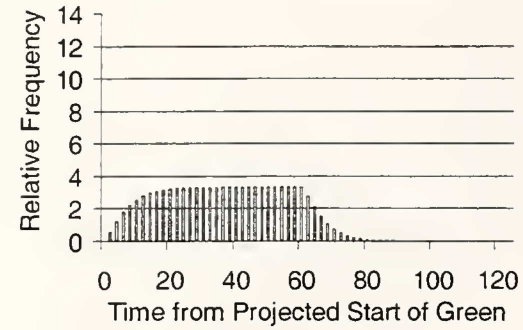
Figure B-34: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 40 MPH



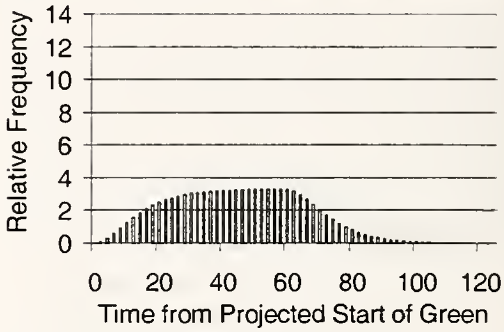
a) Platoon at Stop-line



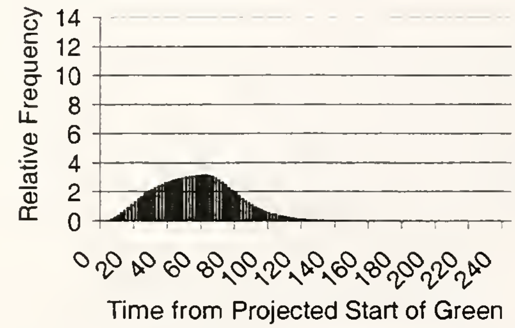
b) 500 ft Downstream



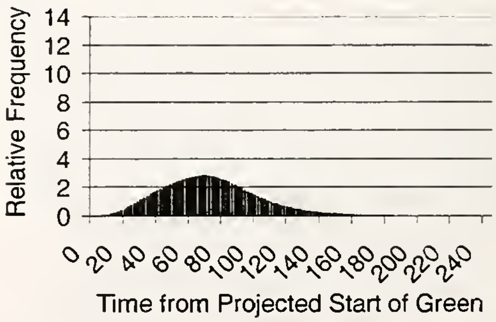
c) 1000 ft Downstream



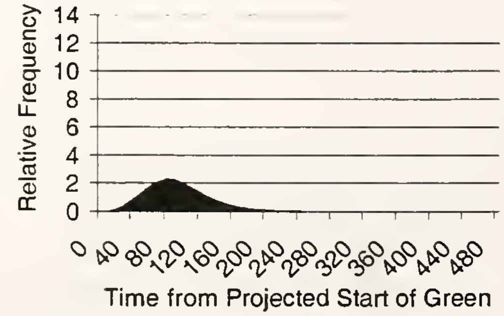
d) 2000 ft Downstream



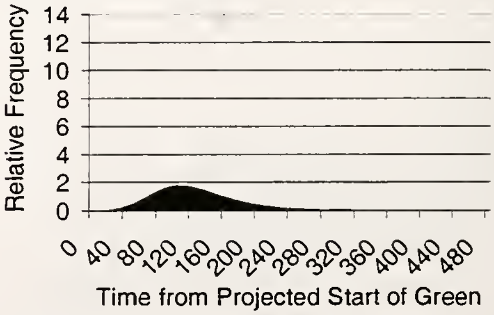
e) 3000 ft Downstream



f) 4000 ft Downstream



g) 6000 ft Downstream



h) 8000 ft Downstream

Figure B-35: Platoon Distribution at Various Downstream Observation Points
Parameters: Four-Lane Divided - α=0.15 β=0.97 (McCoy)
Arterial Characteristics: 60 second saturated platoon, Speed: 50 MPH

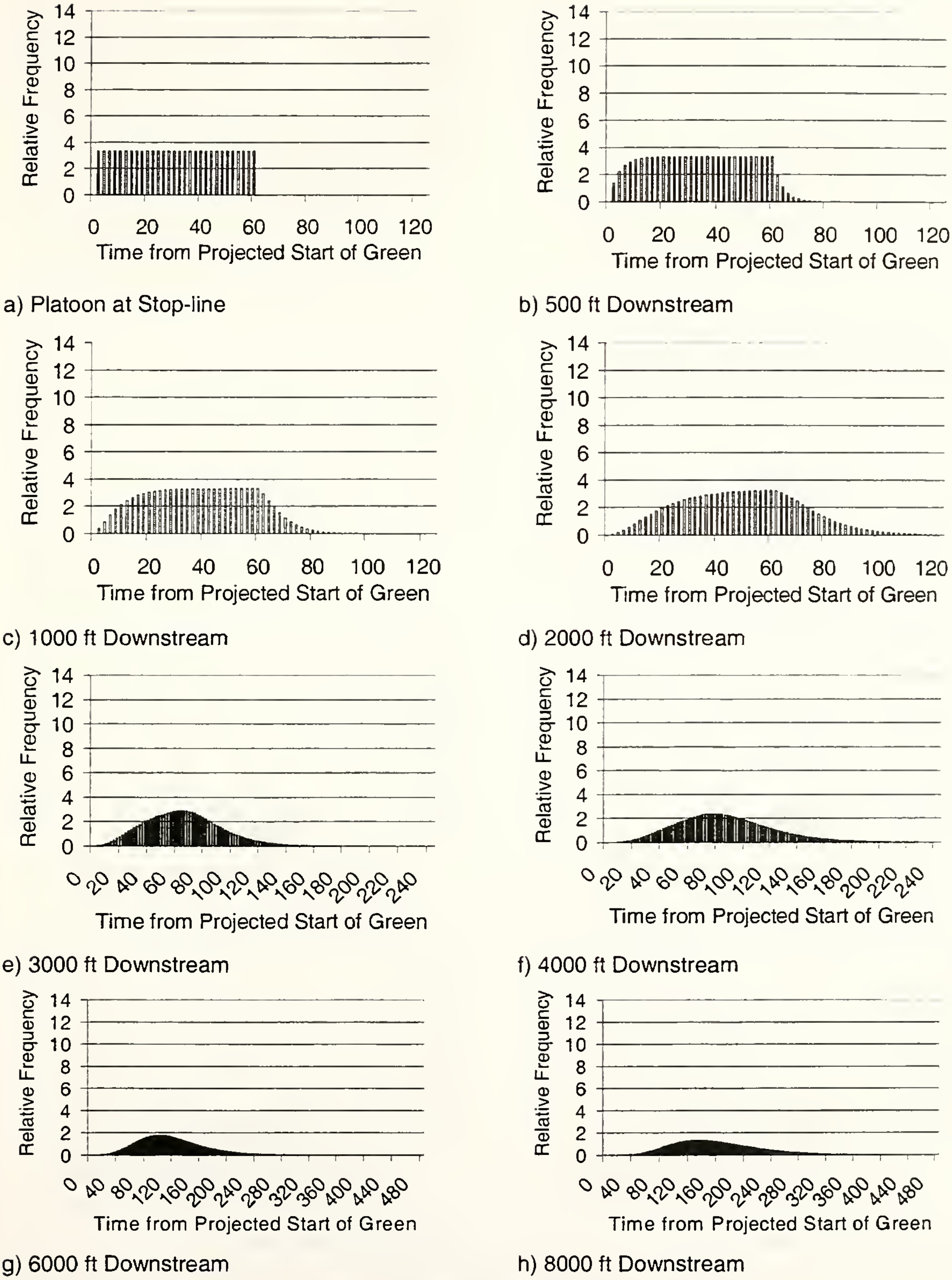
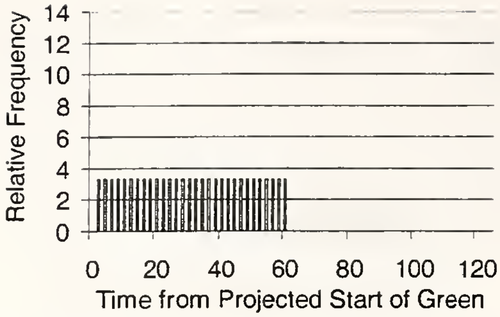
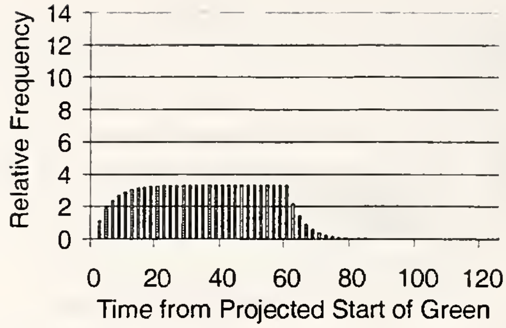


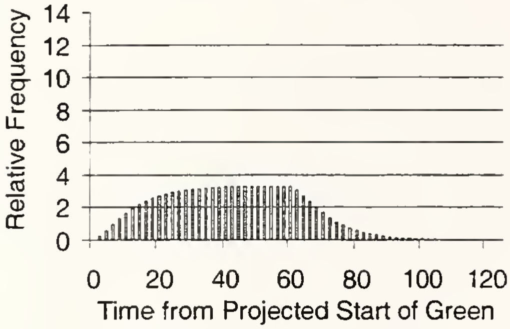
Figure B-36: Platoon Distribution at Various Downstream Observation Points
Parameters: Low External Friction - α=0.25 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 50 MPH



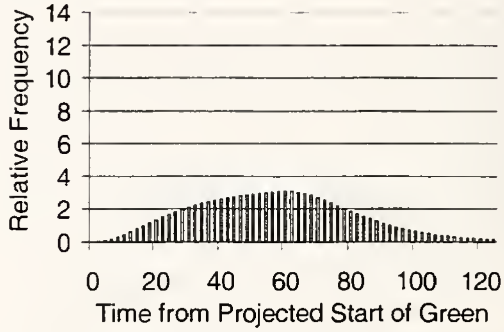
a) Platoon at Stop-line



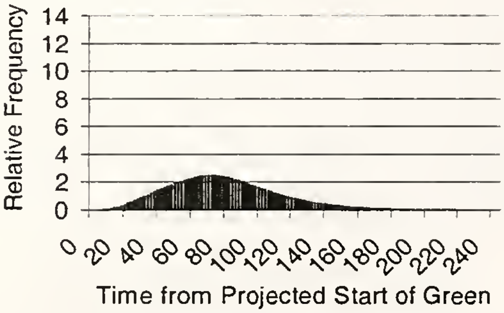
b) 500 ft Downstream



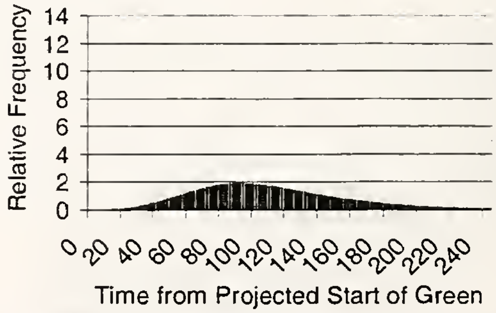
c) 1000 ft Downstream



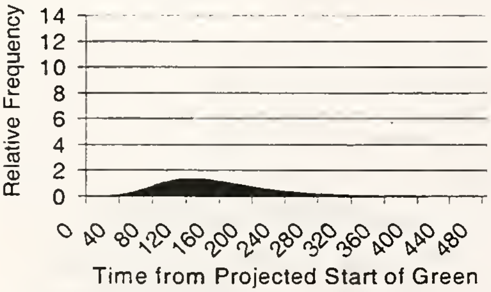
d) 2000 ft Downstream



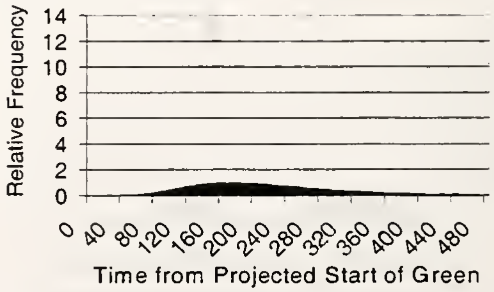
e) 3000 ft Downstream



f) 4000 ft Downstream

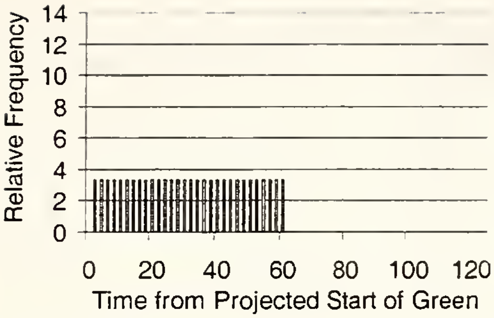


g) 6000 ft Downstream

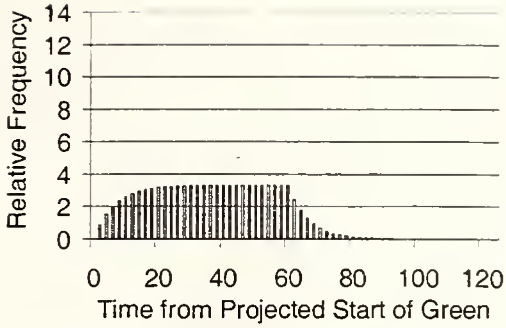


h) 8000 ft Downstream

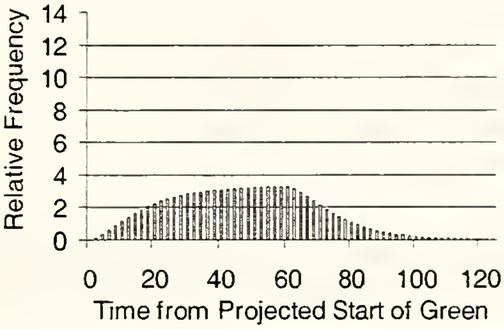
Figure B-37: Platoon Distribution at Various Downstream Observation Points
Parameters: Moderate External Friction - α=0.35 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 50 MPH



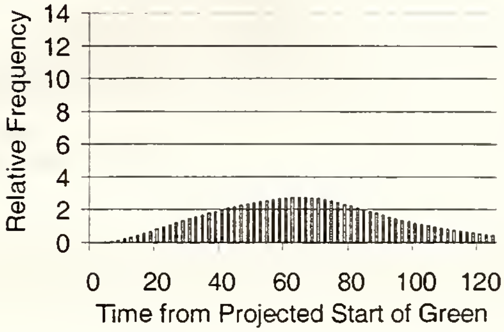
a) Platoon at Stop-line



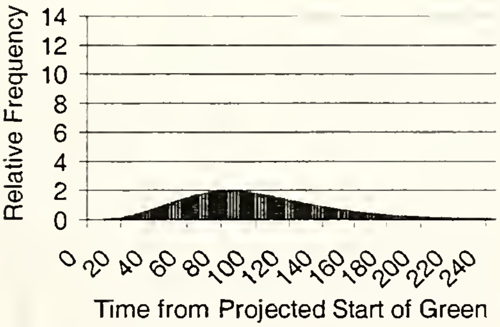
b) 500 ft Downstream



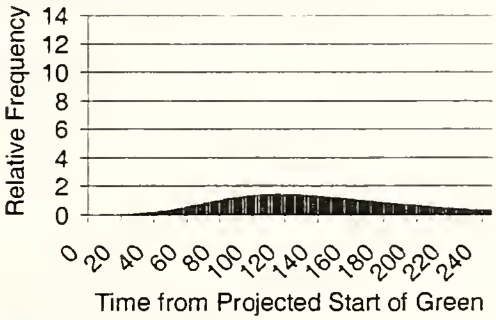
c) 1000 ft Downstream



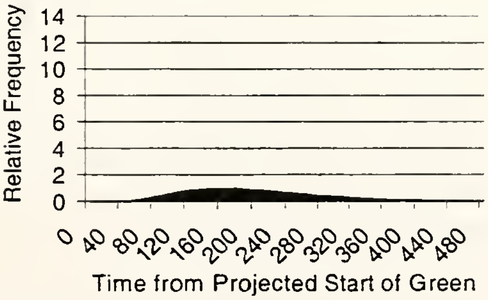
d) 2000 ft Downstream



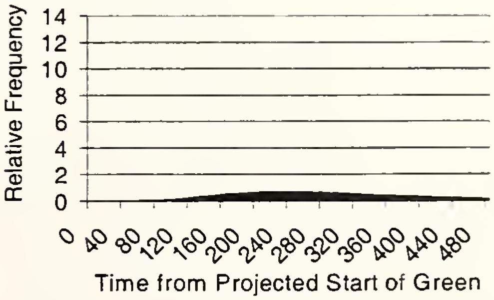
e) 3000 ft Downstream



f) 4000 ft Downstream

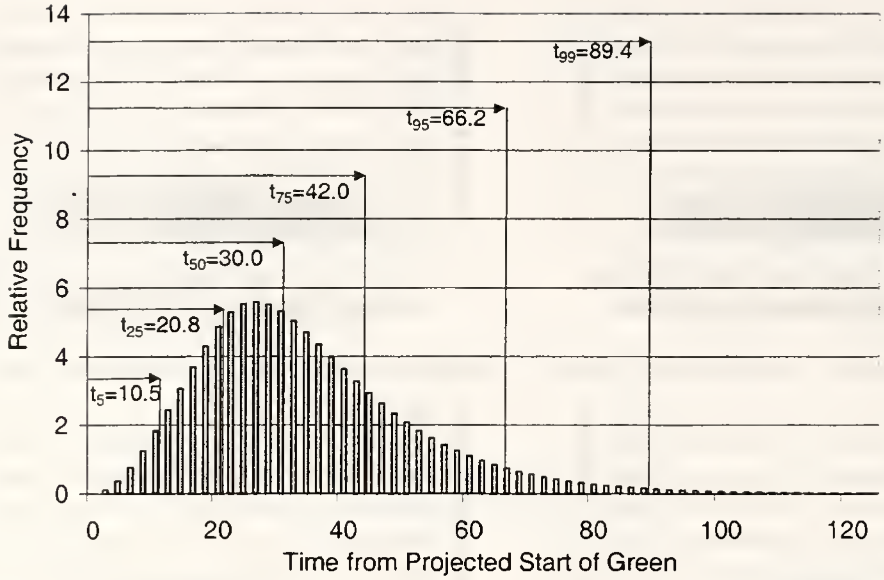


g) 6000 ft Downstream



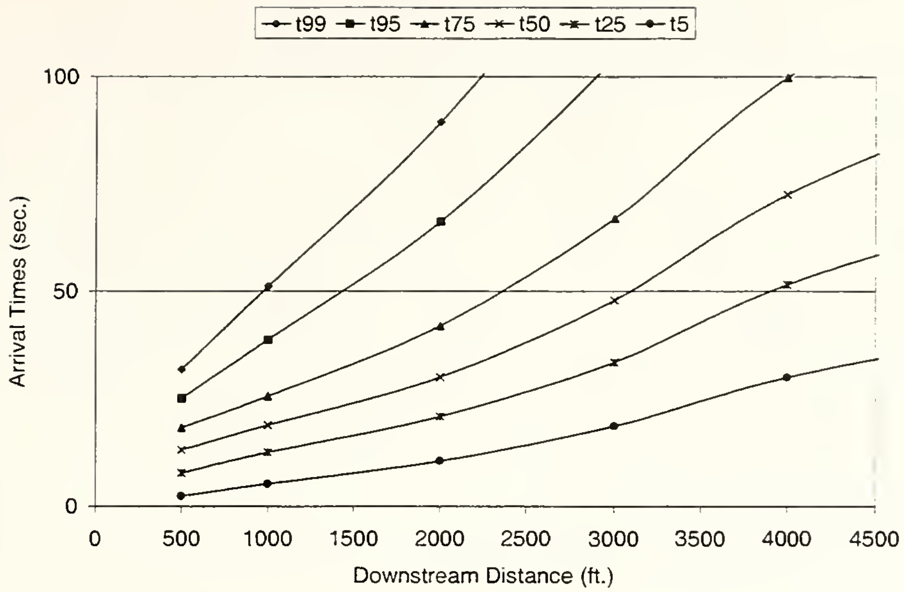
h) 8000 ft Downstream

Figure B-38: Platoon Distribution at Various Downstream Observation Points
Parameters: Heavy External Friction - α=0.50 β=0.80 (TRANSYT)
Arterial Characteristics: 60 second saturated platoon, Speed: 50 MPH



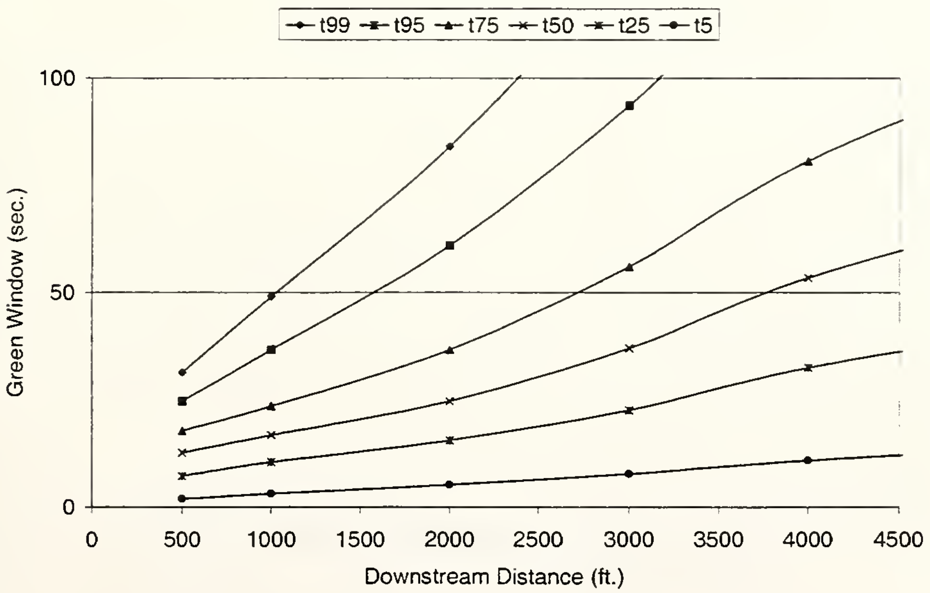
2000 ft. Downstream, 20-second saturated platoon, Speed: 30 MPH
Platoon Dispersion Parameters: α=0.15 and β=0.97

Figure B-39: Example Arrival Times (Theoretical Model)



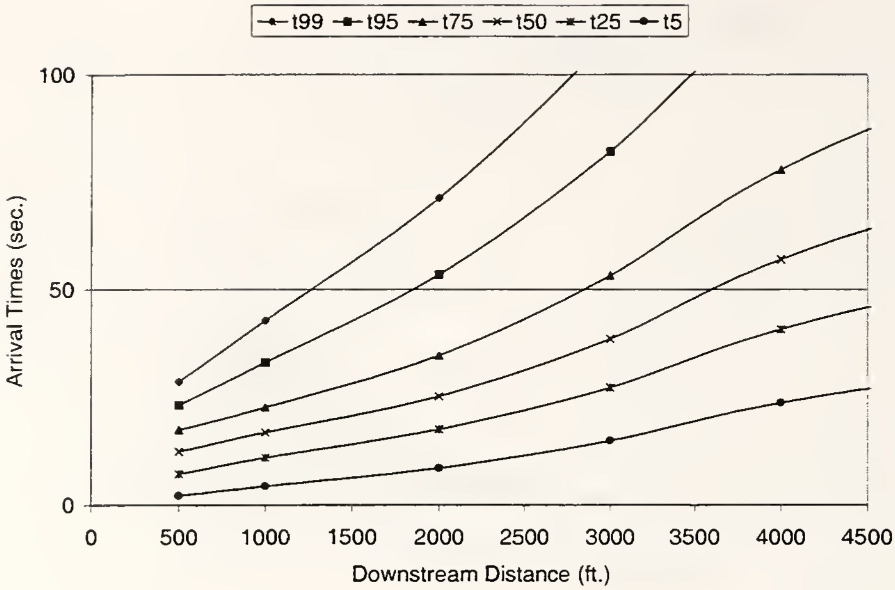
20-second saturated platoon, Speed: 30 MPH
Platoon Dispersion Parameters: α=0.15 and β=0.97

Figure B-40: Theoretical Arrival Times



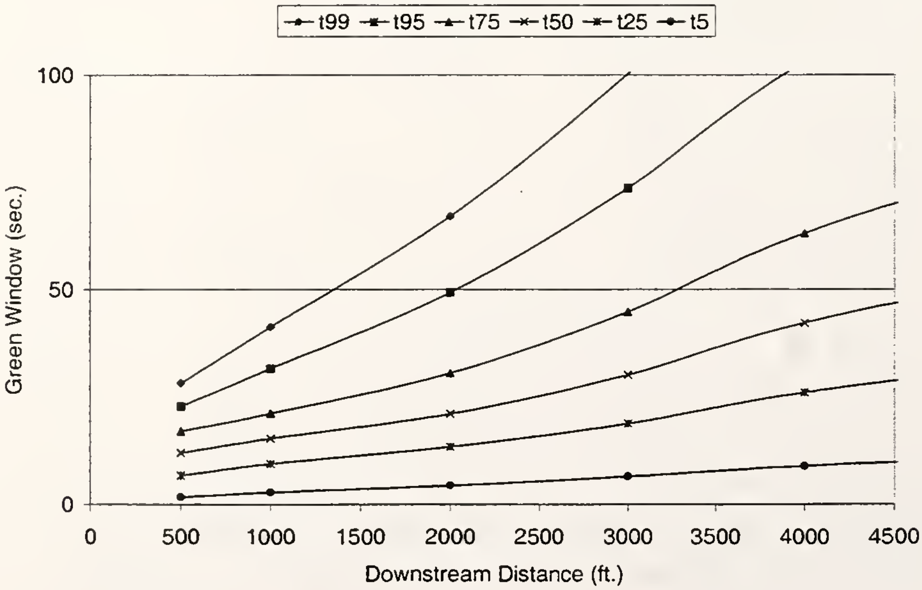
20-second saturated platoon, Speed: 30 MPH
Platoon Dispersion Parameters: α=0.15 and β=0.97

Figure B-41: Theoretical Green Window (Adjusted Arrival Times)



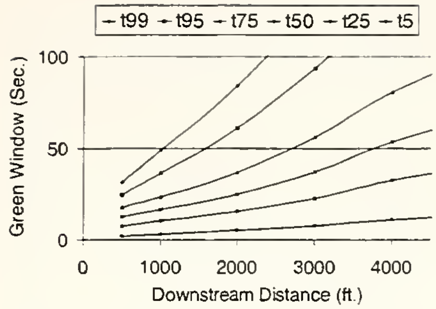
20-second saturated platoon, Speed: 40 MPH
Platoon Dispersion Parameters: α=0.15 and β=0.97

Figure B-42: Theoretical Arrival Times

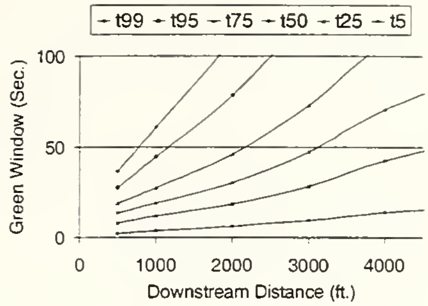


20-second saturated platoon, Speed: 40 MPH
Platoon Dispersion Parameters: α=0.15 and β=0.97

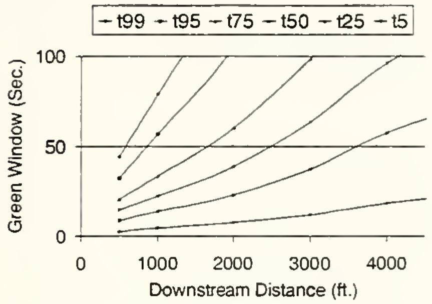
Figure B-43: Theoretical Green Window (Adjusted Arrival Times)



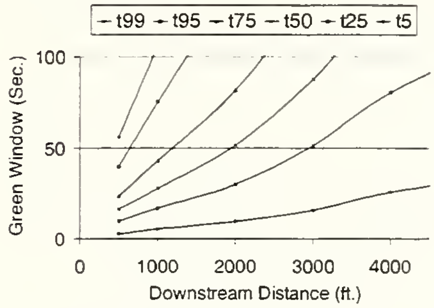
a) α=0.15, β=0.97



b) α=0.25, β=0.80

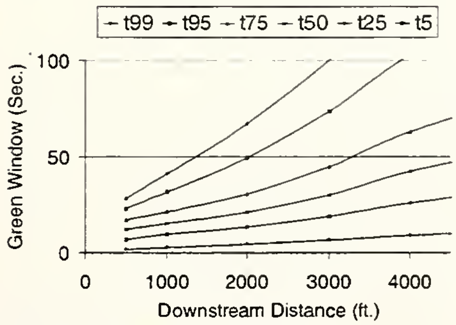


c) α=0.35, β=0.80

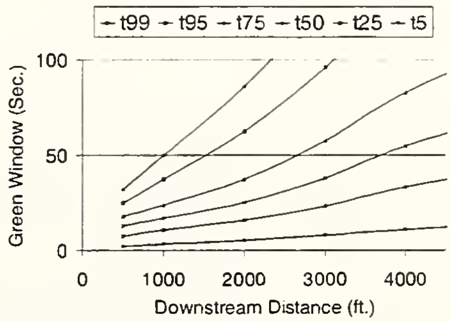


d) α=0.50, β=0.80

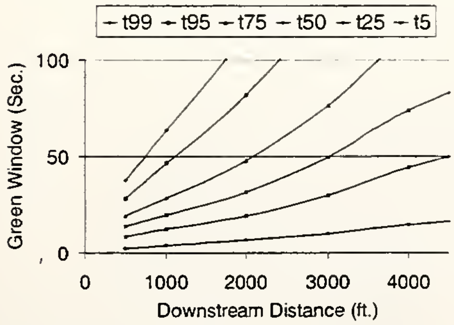
Figure B-44: Theoretical Green Window (20 second saturated platoon, Speed: 30 MPH)



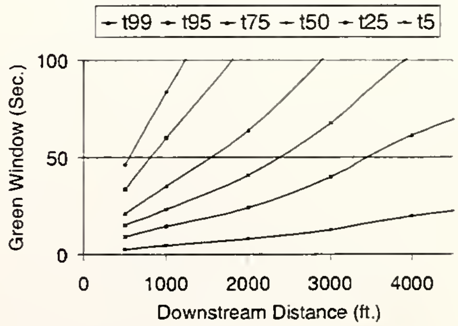
a) α=0.15, β=0.97



b) α=0.25, β=0.80

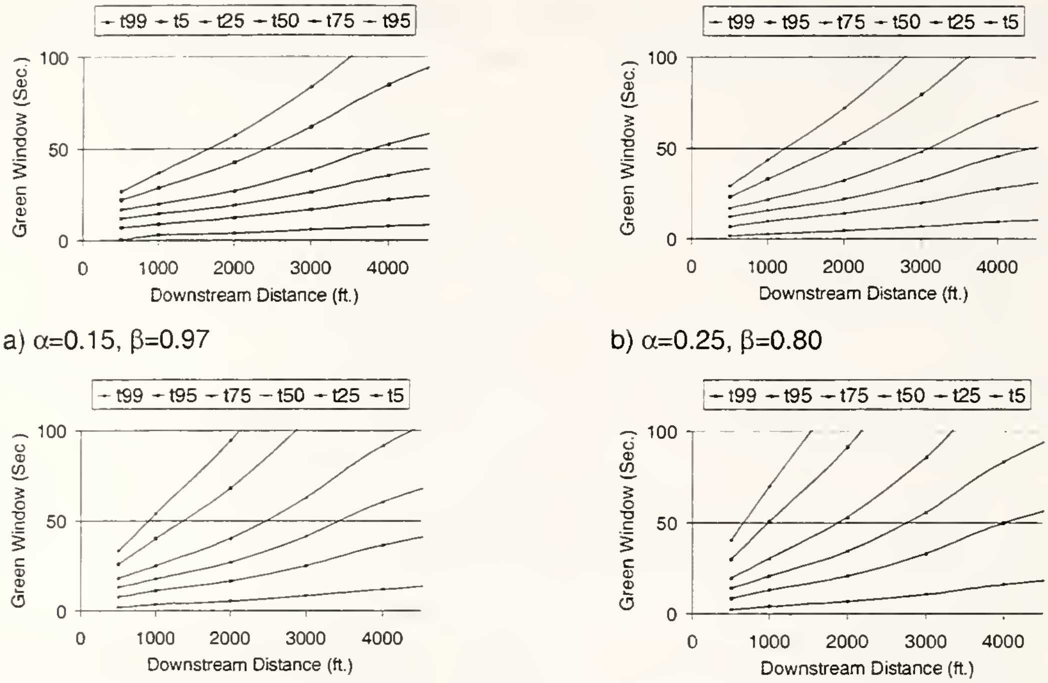


c) α=0.35, β=0.80



d) α=0.50, β=0.80

Figure B-45: Theoretical Green Window (20 second saturated platoon, Speed: 40 MPH)



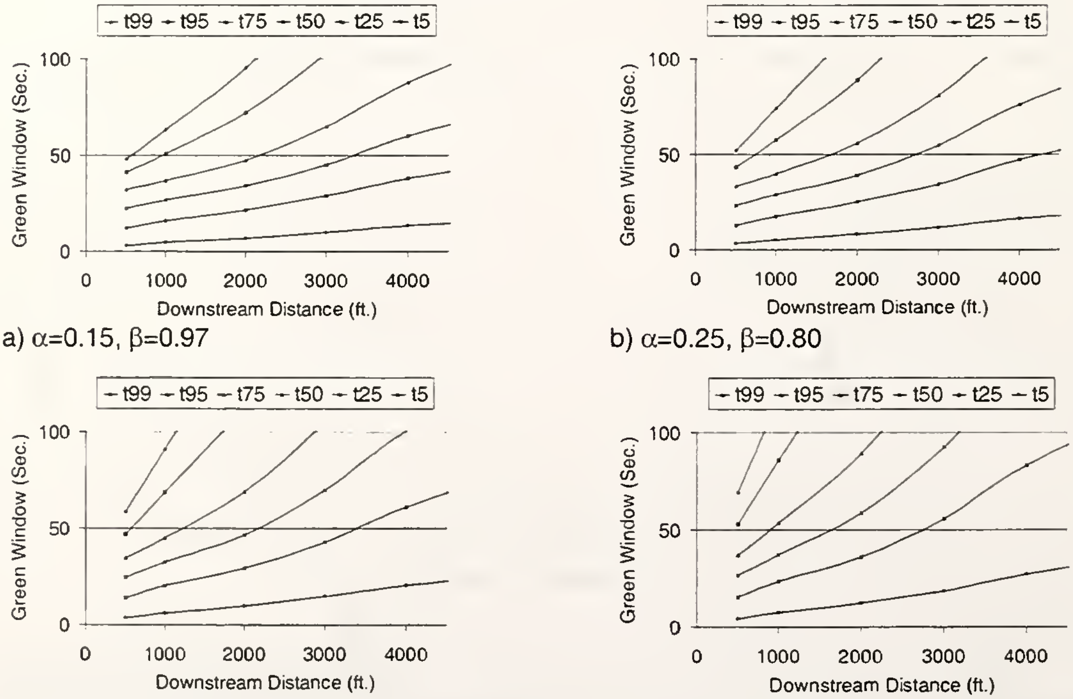
a) α=0.15, β=0.97

b) α=0.25, β=0.80

c) α=0.35, β=0.80

d) α=0.50, β=0.80

Figure B-46: Theoretical Green Window (20 second saturated platoon, Speed: 50 MPH)



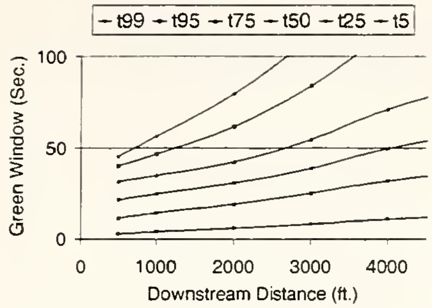
a) α=0.15, β=0.97

b) α=0.25, β=0.80

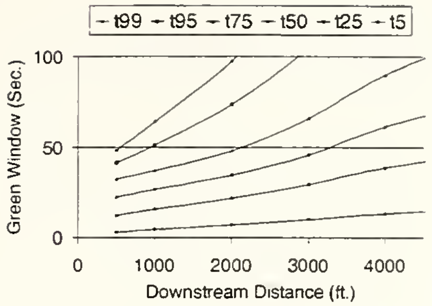
c) α=0.35, β=0.80

d) α=0.50, β=0.80

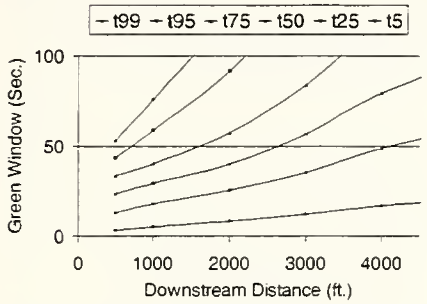
Figure B-47: Theoretical Green Window (40 second saturated platoon, Speed: 30 MPH)



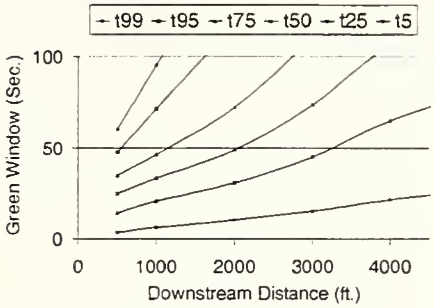
a) α=0.15, β=0.97



b) α=0.25, β=0.80

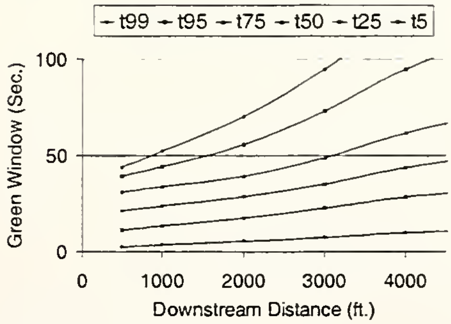


c) α=0.35, β=0.80

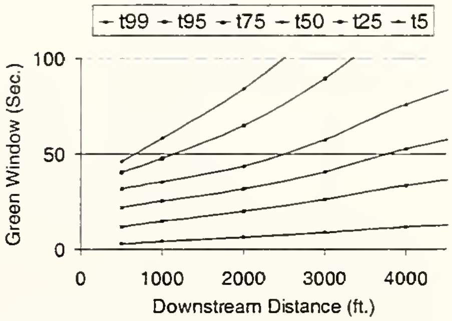


d) α=0.50, β=0.80

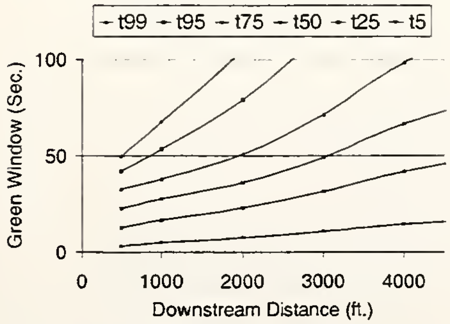
Figure B-48: Theoretical Green Window (40 second saturated platoon, Speed: 40 MPH)



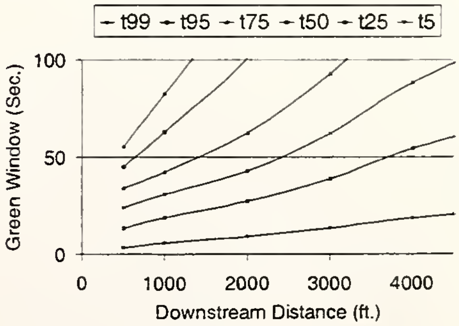
a) α=0.15, β=0.97



b) α=0.25, β=0.80

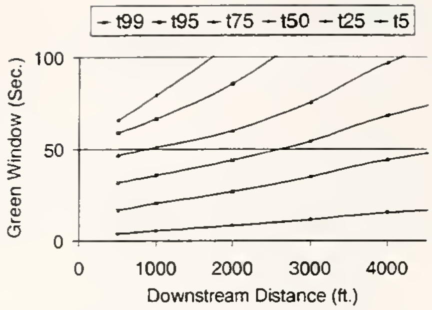


c) α=0.35, β=0.80

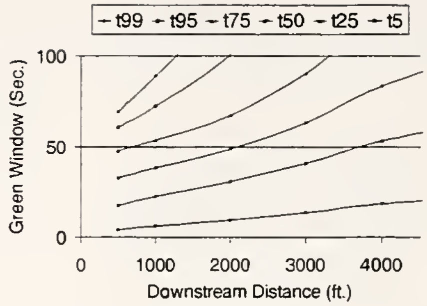


d) α=0.50, β=0.80

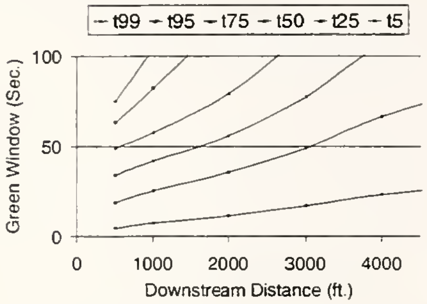
Figure B-49: Theoretical Green Window (40 second saturated platoon, Speed: 50 MPH)



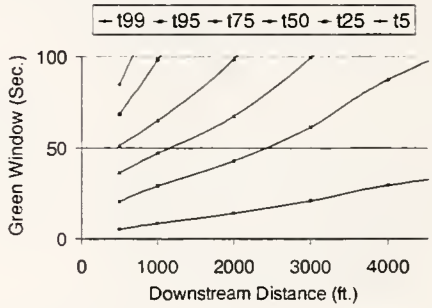
a) α=0.15, β=0.97



b) α=0.25, β=0.80

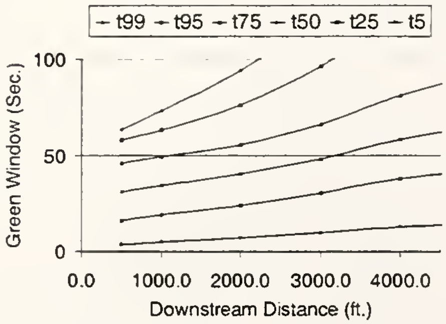


c) α=0.35, β=0.80

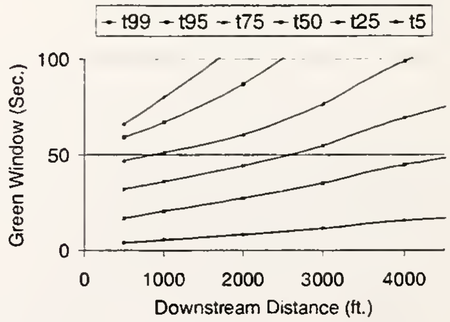


d) α=0.50, β=0.80

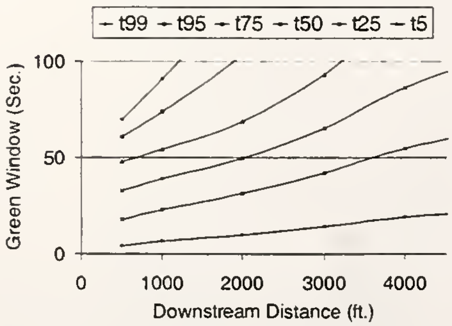
Figure B-50: Theoretical Green Window (60 second saturated platoon, Speed: 30 MPH)



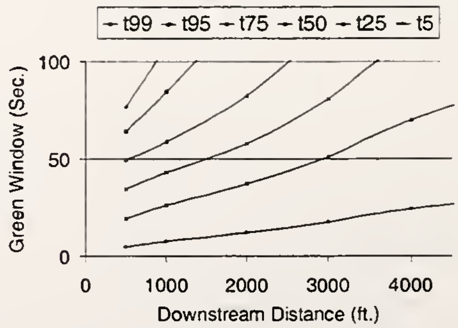
a) α=0.15, β=0.97



b) α=0.25, β=0.80

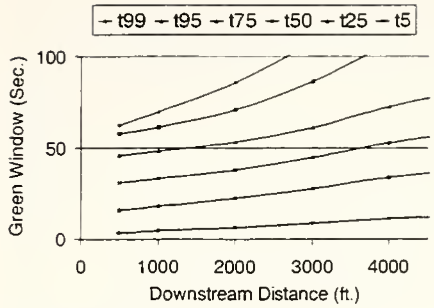


c) α=0.35, β=0.80

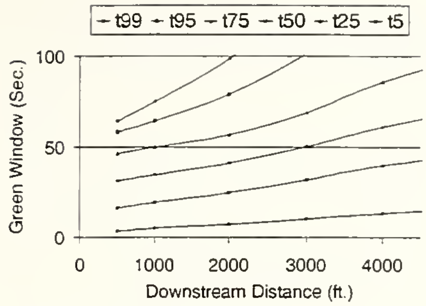


d) α=0.50, β=0.80

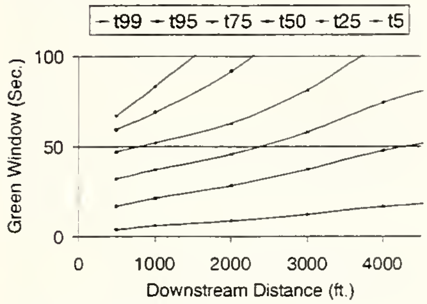
Figure B-51: Theoretical Green Window (60 second saturated platoon, Speed: 40 MPH)



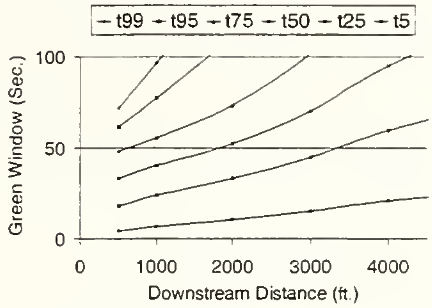
a) α=0.15, β=0.97



b) α=0.25, β=0.80



c) α=0.35, β=0.80



d) α=0.50, β=0.80

Figure B-52: Theoretical Green Window (60 second saturated platoon, Speed: 50 MPH)

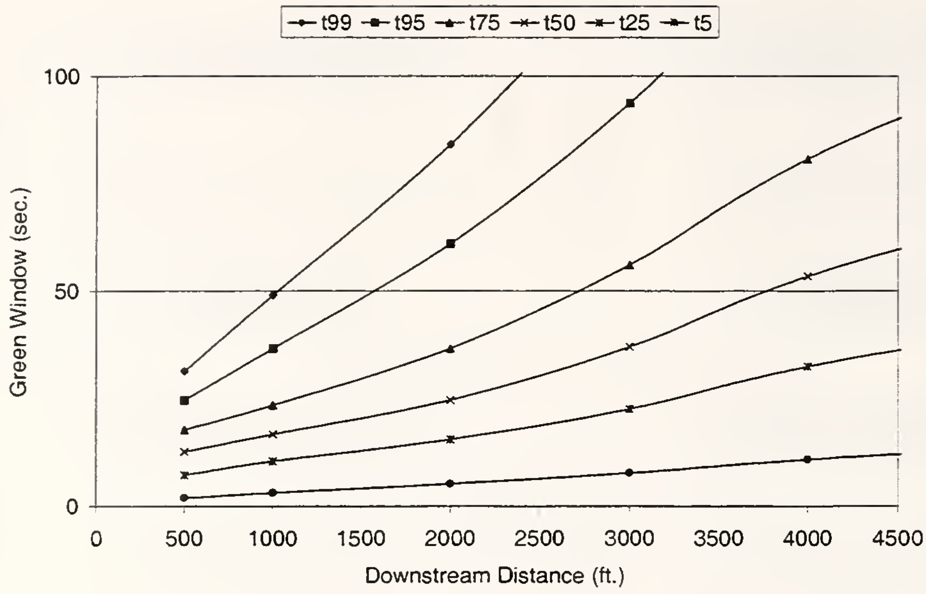


Figure B-53: Theoretical Green Window (20 second saturated platoon, Speed: 30 MPH)

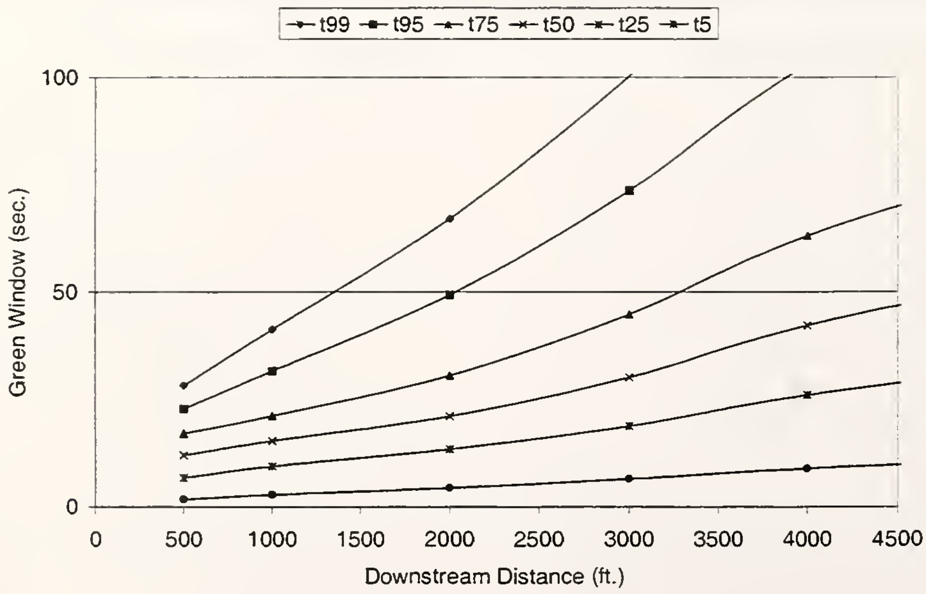


Figure B-54 Theoretical Green Window (20 second saturated platoon, Speed: 40 MPH)

APPENDIX C

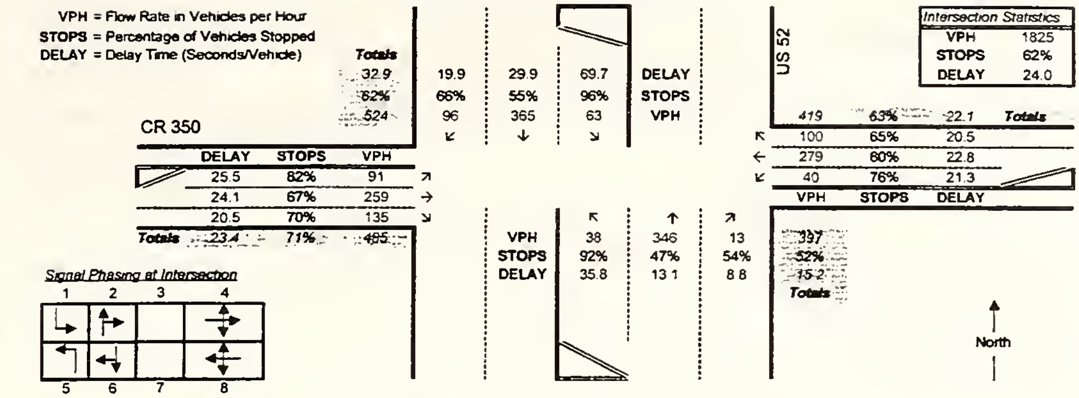
SIMULATION RANDOM NUMBER SEEDS

Table C-1 Random Number Seeds Used in CORSIM Simulations

Run Number	Seed 1	Seed 2	Seed 3
1	2431	4879	6153
2	2851	5647	2189
3	1027	8347	9723
4	7353	8753	3451
5	3873	2851	4369
6	8327	6841	3753
7	4789	7257	5817
8	6751	3783	4449
9	1279	7357	9371
10	8743	4153	7853
11	9459	7847	6349
12	8351	3279	4821
13	8953	2469	5837
14	9243	4683	3979
15	2857	8241	5973
16	3473	8621	3497
17	6871	2597	3497
18	2343	7891	3631
19	8979	3741	2357
20	4697	6783	2859

APPENDIX D

SIMULATION RESULTS

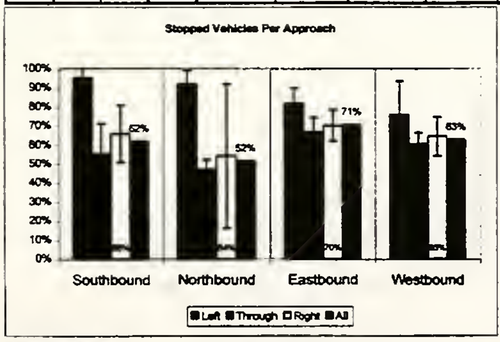


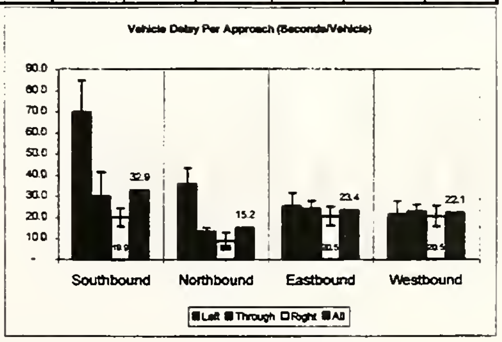
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	8.51	9.30	7.07	5.44	12.51	0.56	81.48	35.84	4.50	4.48	91.85	31.16
2	8	1	Thru ↑	60.48	86.40	65.70	18.86	84.38	0.78	58.78	13.15	12.58	12.25	47.00	42.93
2	6	1	Right ↗	2.21	3.15	2.39	0.50	2.89	0.84	54.37	8.77	0.16	0.18	54.17	46.62
1	6	1	Left ↘	8.36	15.60	10.17	18.01	28.17	0.37	108.63	69.73	14.16	13.77	95.58	20.21
6	6	1	Thru ↓	54.67	91.15	59.40	45.18	104.59	0.58	69.01	28.91	24.76	23.14	55.38	31.97
8	8	1	Right ↙	14.31	23.85	15.54	7.96	23.50	0.67	58.98	19.86	2.50	2.23	86.03	36.81
4	2	1	Left ↗	3.38	22.56	4.51	9.64	14.15	0.33	37.47	25.47	7.43	7.30	81.95	14.78
4	2	1	Thru →	8.68	64.55	12.91	26.00	38.91	0.34	36.09	24.09	16.44	17.29	66.65	15.11
4	2	1	Right ↘	5.03	33.55	6.71	11.38	18.09	0.37	32.55	20.55	6.82	6.25	70.19	16.89
8	4	1	Left ↙	4.43	9.85	5.91	3.61	9.51	0.64	57.30	21.32	2.27	2.23	75.93	28.59
8	4	1	Thru ←	31.29	69.55	41.71	26.52	68.23	0.61	58.60	22.82	15.16	14.27	60.38	27.60
8	4	1	Right ↖	11.20	24.90	14.90	8.43	23.36	0.64	58.49	20.49	4.36	4.07	64.59	28.87

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.03	2.90	2.21	1.79	3.82	0.05	7.59	7.59	1.67	1.66	7.58	2.90
2	6	1	Thru ↑	2.89	4.12	3.13	2.11	3.55	0.02	1.70	1.70	1.68	1.58	5.52	1.23
2	8	1	Right ↗	1.27	1.61	1.38	0.44	1.77	0.08	4.12	4.02	0.19	0.19	37.60	3.69
1	6	1	Left ↘	2.28	3.80	2.48	5.18	7.17	0.05	15.07	15.07	4.34	4.18	8.79	2.86
6	6	1	Thru ↓	3.33	5.56	3.62	16.48	16.44	0.08	11.41	11.41	11.80	11.24	16.12	4.45
6	6	1	Right ↙	1.81	3.01	1.96	2.23	3.67	0.05	4.33	4.33	1.44	1.26	15.06	2.66
4	2	1	Left ↗	0.63	5.55	1.11	3.55	4.41	0.05	6.08	6.09	3.03	2.93	7.89	2.41
4	2	1	Thru →	0.86	5.88	1.16	4.94	5.79	0.03	3.56	3.56	4.02	3.87	7.57	1.55
4	2	1	Right ↘	0.76	5.21	1.04	2.52	3.08	0.05	4.49	4.49	2.03	1.88	6.07	2.19
8	4	1	Left ↙	1.31	2.91	1.74	1.84	3.24	0.07	6.33	6.34	1.23	1.21	17.69	3.20
8	4	1	Thru ←	3.02	8.72	4.03	4.97	8.27	0.03	3.22	3.23	3.43	3.26	6.29	1.53
8	4	1	Right ↖	2.52	5.81	3.36	2.49	5.28	0.05	4.96	4.88	1.71	1.64	10.29	2.44



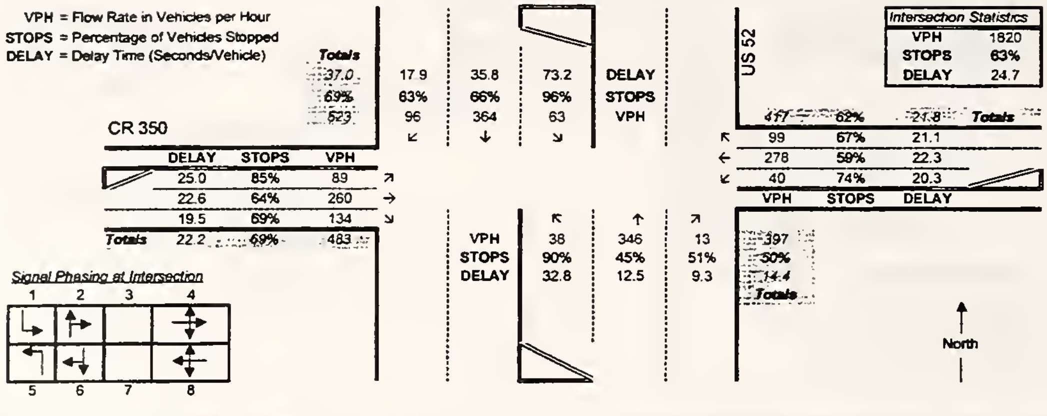


Additional Notes:

Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings - > 11 Vehicles in 10 seconds

F:\Jay\Research\Excel Files\Period3\100%\00-45-60-25-13_11-10\

Figure D-1 Period 3 Configuration A-100

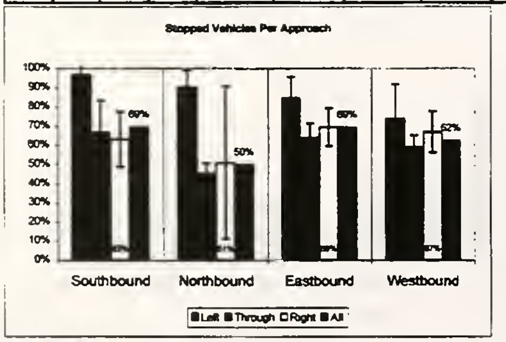


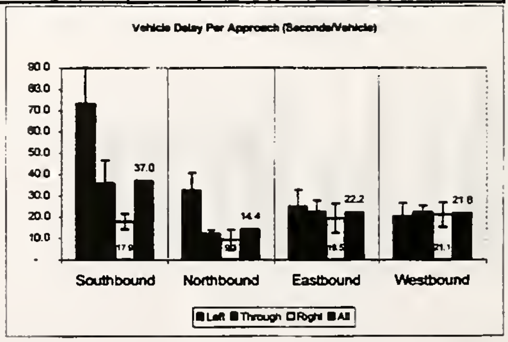
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	6.58	9.40	7.15	5.08	12.23	0.59	78.44	32.61	4.06	4.01	90.28	32.40
2	8	1	Thru ↑	60.45	88.35	65.67	18.02	83.66	0.78	58.19	12.55	11.99	11.65	45.28	43.34
2	8	1	Right ↗	2.21	3.15	2.39	0.52	2.92	0.84	54.92	9.33	0.21	0.20	50.88	48.23
1	6	1	Left ↘	9.36	15.60	10.17	19.15	29.32	0.36	112.27	73.17	15.11	14.62	96.44	18.88
6	6	1	Thru ↓	34.58	91.00	59.30	54.43	113.73	0.53	74.94	35.84	31.33	29.41	66.42	29.39
6	6	1	Right ↙	14.37	23.95	15.61	7.22	22.83	0.69	57.03	17.93	1.97	1.72	63.03	38.01
4	2	1	Left ↗	3.34	22.25	4.45	9.13	13.58	0.34	36.99	24.99	7.17	7.01	84.59	15.13
4	2	1	Thru →	9.73	64.85	12.97	24.49	37.46	0.35	34.60	22.80	17.19	16.16	63.96	15.93
4	2	1	Right ↘	5.02	33.45	6.89	10.95	17.84	0.40	31.50	19.50	6.50	5.96	69.45	17.78
8	4	1	Left ↙	4.46	9.90	5.94	3.47	9.40	0.65	58.31	20.34	2.11	2.07	73.79	29.08
8	4	1	Thru ←	31.22	69.40	41.62	25.78	67.40	0.62	58.30	22.31	14.44	13.54	58.84	27.84
8	4	1	Right ↖	11.09	24.65	14.78	8.84	23.43	0.64	57.08	21.07	4.64	4.28	66.83	28.64

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.10	3.00	2.28	1.95	3.98	0.05	7.65	7.65	1.75	1.75	8.62	2.98
2	8	1	Thru ↑	3.21	4.58	3.48	1.91	4.24	0.02	1.41	1.41	1.95	1.91	5.16	1.06
2	8	1	Right ↗	1.27	1.81	1.38	0.45	1.77	0.07	4.94	4.86	0.24	0.22	39.60	3.99
1	9	1	Left ↘	2.27	3.79	2.47	6.69	8.76	0.06	16.77	16.77	5.79	5.81	7.16	3.16
6	6	1	Thru ↓	3.36	5.61	3.66	16.71	18.16	0.06	10.78	10.79	11.72	11.18	16.90	4.27
6	6	1	Right ↙	1.86	3.14	2.04	2.09	3.85	0.04	3.67	3.67	1.16	1.01	14.41	2.37
4	2	1	Left ↗	0.60	5.33	1.07	2.69	3.49	0.06	7.71	7.71	2.43	2.35	10.95	2.66
4	2	1	Thru →	0.90	6.00	1.20	6.58	7.22	0.06	5.28	5.28	5.02	4.65	7.40	2.25
4	2	1	Right ↘	0.75	5.01	1.00	4.36	4.95	0.07	6.74	6.74	3.36	3.14	9.62	3.22
8	4	1	Left ↙	1.31	2.90	1.74	1.62	3.23	0.07	6.15	6.15	1.16	1.14	17.79	3.06
8	4	1	Thru ←	3.15	7.00	4.20	4.15	7.42	0.03	3.00	3.00	2.54	2.42	6.26	1.40
8	4	1	Right ↖	2.51	5.58	3.35	3.01	5.73	0.06	5.72	5.72	1.94	1.62	10.72	2.78





Additional Notes:

Period 3 Premption Settings - >00 Min, 45 Max, 60 Reservice, 20 Delay, 13 Inhibit

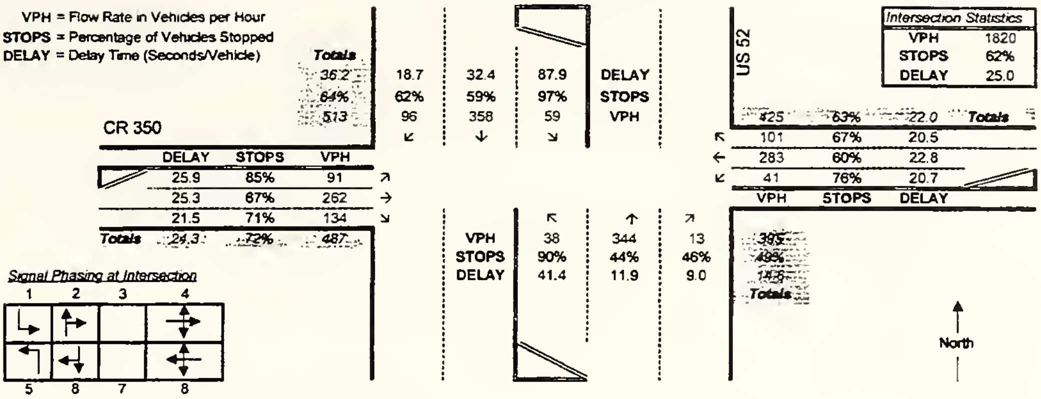
Platoon Settings - > 16 Vehicles in 15 seconds

F:\Jay\Research\Excel Files\Period3\100%\00-45-60-20-13_16-15\

P3b-100.xls School of Civil Engineering - Purdue University Printed on 7/15/98 at 11:19 AM

Figure D-2 Period 3 Configuration B-100

VPH = Flow Rate in Vehicles per Hour
STOPS = Percentage of Vehicles Stopped
DELAY = Delay Time (Seconds/Vehicle)

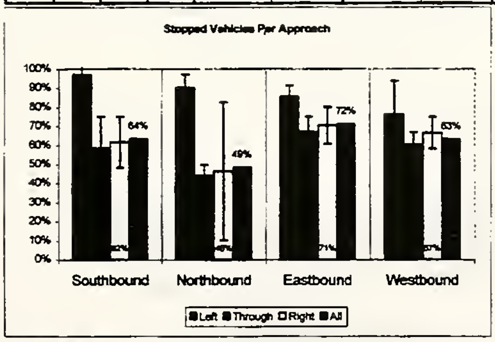


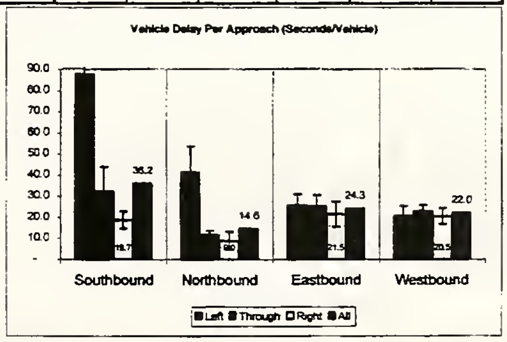
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	6.55	9.35	7.11	6.47	13.58	0.53	87.08	41.45	5.44	5.39	90.41	29.42
2	8	1	Thru ↑	60.17	85.95	65.36	16.94	82.30	0.79	57.48	11.87	10.97	10.64	44.13	43.88
2	8	1	Right ↗	2.24	3.20	2.43	0.51	2.95	0.84	54.59	8.99	0.18	0.16	46.42	46.48
1	6	1	Left ↘	8.73	14.55	9.48	20.93	30.41	0.32	126.99	87.89	19.09	18.60	97.17	17.92
6	8	1	Thru ↓	53.85	89.45	58.29	48.19	106.46	0.56	71.46	32.36	28.30	26.44	58.62	30.91
6	6	1	Right ↙	14.37	23.95	15.61	7.50	23.10	0.68	57.85	16.75	2.24	1.95	81.79	37.51
4	2	1	Left ↗	3.38	22.56	4.51	9.58	14.09	0.32	37.85	25.85	7.40	7.25	85.44	14.53
4	2	1	Thru →	9.83	65.50	13.10	27.74	40.84	0.33	37.30	25.30	19.38	18.14	67.16	14.78
4	2	1	Right ↘	5.00	33.35	6.67	11.92	18.59	0.37	33.46	21.47	7.34	8.77	70.56	16.59
8	4	1	Left ↙	4.52	10.05	6.03	3.56	9.58	0.64	56.71	20.73	2.13	2.10	76.16	28.72
6	4	1	Thru ←	31.78	70.60	42.34	26.65	69.20	0.61	58.76	22.78	14.90	13.96	60.43	27.64
8	4	1	Right ↖	11.29	25.10	15.05	8.50	23.55	0.64	56.50	20.50	4.27	3.84	66.52	28.79

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	2.08	2.94	2.24	3.09	4.89	0.06	12.24	12.23	2.90	2.88	7.01	3.59
2	8	1	Thru ↑	3.33	4.75	3.61	2.25	4.26	0.02	1.78	1.78	1.79	1.73	5.63	1.36
2	8	1	Right ↗	1.26	1.78	1.36	0.44	1.75	0.07	4.32	4.25	0.21	0.21	36.16	3.93
1	6	1	Left ↘	1.78	2.83	1.91	7.53	8.31	0.07	31.88	31.88	11.11	10.65	5.03	3.91
6	8	1	Thru ↓	3.82	6.37	4.15	17.14	16.43	0.06	11.32	11.32	13.51	12.84	16.51	4.50
8	8	1	Right ↙	1.78	2.96	1.92	1.98	3.42	0.05	4.16	4.16	1.26	1.09	13.45	2.65
4	2	1	Left ↗	0.86	5.71	1.14	2.63	3.51	0.04	5.30	5.30	2.18	2.11	5.88	1.94
4	2	1	Thru →	0.81	5.42	1.06	6.81	7.45	0.05	5.26	5.28	5.75	5.48	7.98	2.12
4	2	1	Right ↘	0.78	5.20	1.04	3.51	4.10	0.08	5.85	5.96	3.04	2.78	9.72	2.70
6	4	1	Left ↙	1.31	2.91	1.75	1.42	3.07	0.05	4.53	4.53	0.99	0.95	17.59	2.27
8	4	1	Thru ←	3.00	8.67	4.00	4.67	6.02	0.03	2.92	2.91	3.35	3.27	6.78	1.34
6	4	1	Right ↖	2.58	5.75	3.45	2.21	5.28	0.04	3.76	3.75	1.41	1.30	6.34	1.88

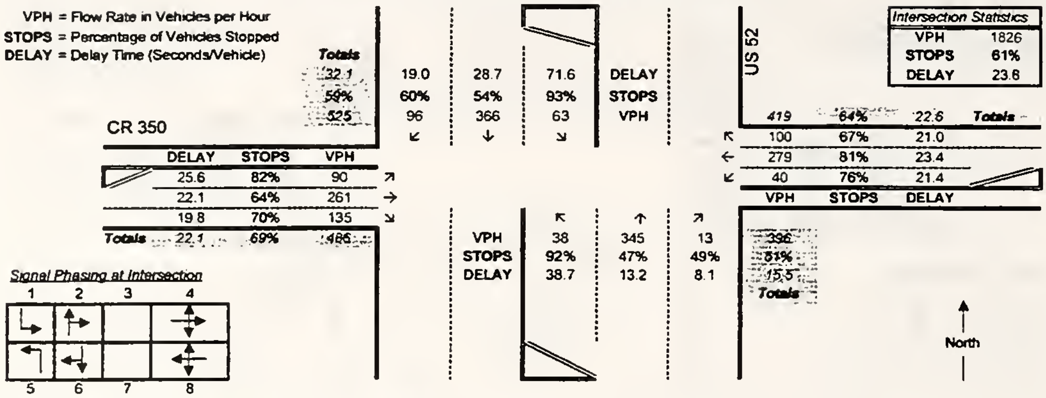




Additional Notes:
Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings - > 6 Vehicles in 10 seconds
F:\Jay\Research\Excel Files\Period3\100%\00-45-60-25-13_6-10\

P3c-100.xls School of Civil Engineering - Purdue University Printed on 7/15/98 at 11:17 AM

Figure D-3 Period 3 Configuration C-100

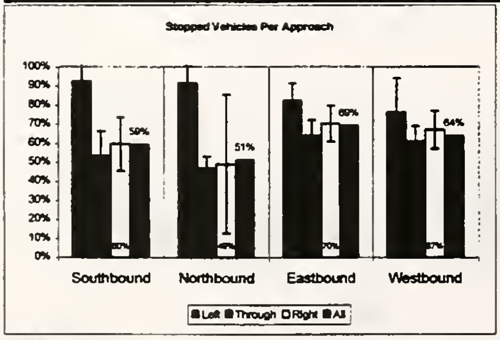


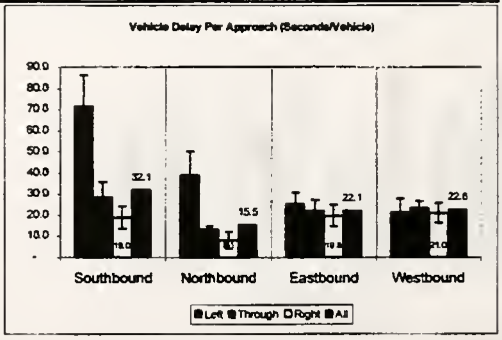
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	8.51	8.30	7.07	5.80	12.87	0.55	84.36	38.73	4.63	4.78	91.52	30.35
2	8	1	Thru ↑	60.34	86.20	65.56	18.68	84.54	0.78	58.63	13.23	12.74	12.37	46.93	42.84
2	8	1	Right ↗	2.21	3.15	2.39	0.47	2.86	0.85	53.84	8.06	0.13	0.12	49.08	47.25
1	8	1	Left ↘	9.45	15.75	10.28	18.78	29.04	0.36	110.72	71.62	14.62	14.14	92.54	19.86
6	8	1	Thru ↓	54.78	91.30	59.49	43.67	103.18	0.58	67.79	28.69	23.44	21.81	53.56	32.17
8	8	1	Right ↙	14.31	23.85	15.54	7.53	23.07	0.68	58.11	19.01	2.28	2.02	59.53	37.42
4	2	1	Left ↗	3.38	22.40	4.48	9.49	13.97	0.32	37.58	25.56	7.55	7.40	82.48	14.63
4	2	1	Thru →	9.77	65.10	13.02	24.05	37.07	0.36	34.07	22.07	18.84	15.50	64.23	16.20
4	2	1	Right ↘	3.06	33.75	6.75	11.15	17.90	0.39	31.78	19.76	6.65	8.09	70.38	17.41
8	4	1	Left ↙	4.48	9.95	5.97	3.66	9.62	0.64	57.35	21.37	2.27	2.23	78.23	28.59
8	4	1	Thru ←	31.38	69.75	41.83	27.22	69.06	0.61	59.34	23.36	15.77	14.84	81.06	27.37
8	4	1	Right ↖	11.20	24.90	14.93	9.75	23.69	0.64	57.01	21.03	4.59	4.19	68.98	28.59

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.08	2.94	2.24	2.13	3.98	0.07	11.38	11.37	1.92	1.91	8.72	3.83
2	8	1	Thru ↑	3.18	4.56	3.47	2.28	4.82	0.02	1.46	1.44	1.85	1.78	5.91	1.04
2	8	1	Right ↗	1.27	1.81	1.38	0.42	1.74	0.07	4.04	3.86	0.14	0.13	36.56	3.78
1	8	1	Left ↘	2.32	3.66	2.52	5.84	7.89	0.06	14.63	14.83	4.87	4.70	9.34	2.59
6	8	1	Thru ↓	3.30	5.51	3.59	11.04	12.41	0.06	7.13	7.13	8.14	7.85	12.66	3.29
8	8	1	Right ↙	1.82	3.03	1.97	2.11	3.38	0.05	5.34	5.34	1.34	1.11	14.06	2.86
4	2	1	Left ↗	0.84	5.60	1.12	2.89	3.60	0.04	5.33	5.33	2.27	2.19	8.89	1.85
4	2	1	Thru →	0.86	5.75	1.15	6.30	7.02	0.08	5.03	5.03	5.21	4.97	8.02	2.67
4	2	1	Right ↘	0.78	5.21	1.04	3.48	4.12	0.08	5.18	5.18	2.81	2.88	9.40	2.68
8	4	1	Left ↙	1.27	2.62	1.89	1.81	3.15	0.07	6.56	8.56	1.19	1.16	17.65	3.28
8	4	1	Thru ←	2.69	8.42	3.65	5.15	8.22	0.04	3.42	3.43	3.74	3.57	8.01	1.81
8	4	1	Right ↖	2.81	5.80	3.48	3.14	8.17	0.06	4.75	4.78	1.98	1.81	9.69	2.37





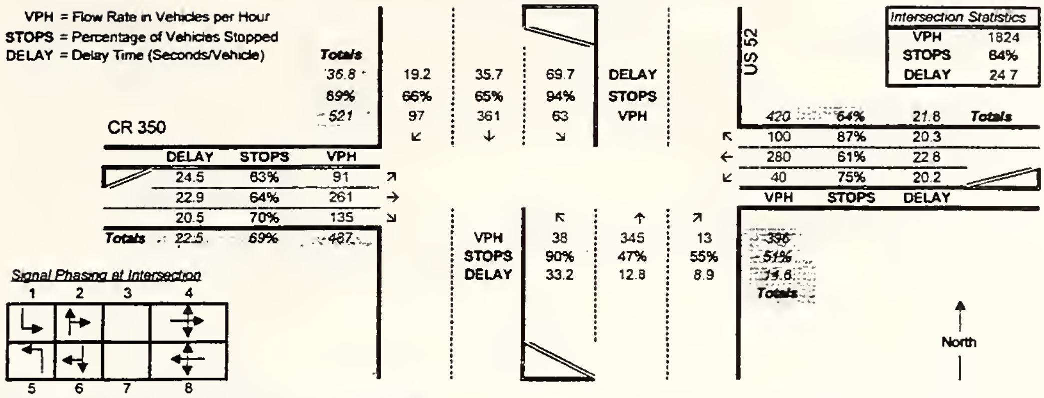
Additional Notes:

Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 30 Delay, 13 Inhibit

Platoon Settings - > 6 Vehicles in 5 seconds

F:\Jay\Research\Excel Files\Period3\100%\00-45-60-30-13_6-05\

Figure D-4 Period 3 Configuration D-100

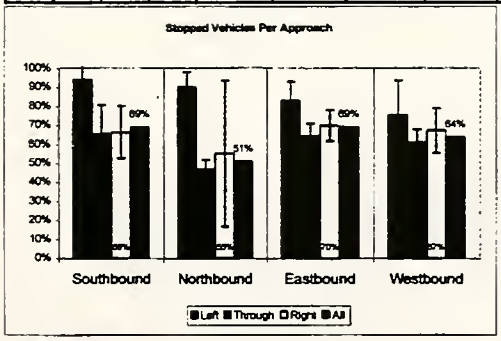


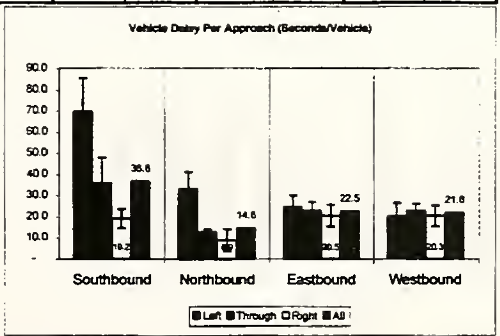
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	6.51	9.30	7.07	5.02	12.09	0.58	78.87	33.23	4.11	4.07	90.17	32.23
2	8	1	Thru ↑	80.34	86.20	85.55	18.40	83.96	0.78	58.44	12.82	12.23	11.87	46.89	43.14
2	8	1	Right ↗	2.21	3.15	2.39	0.51	2.91	0.84	54.32	8.86	0.19	0.19	56.22	46.87
1	8	1	Left ↘	9.38	15.60	10.17	18.00	28.17	0.37	108.78	69.68	13.96	13.44	94.21	20.25
6	8	1	Thru ↓	54.13	90.25	58.81	53.89	112.70	0.53	74.85	36.75	31.68	29.67	85.48	29.54
6	8	1	Right ↙	14.49	24.15	15.74	7.77	23.51	0.68	58.25	19.15	2.42	2.16	66.43	37.28
4	2	1	Left ↗	3.38	22.56	4.51	8.11	13.82	0.34	36.51	24.51	8.86	8.86	82.89	15.12
4	2	1	Thru →	9.77	85.10	13.02	24.91	37.93	0.36	34.90	22.90	17.43	16.40	64.05	15.70
4	2	1	Right ↘	5.06	33.70	8.74	11.57	18.31	0.38	32.52	20.52	6.92	6.38	69.88	17.04
8	4	1	Left ↙	4.48	9.96	5.97	3.45	9.41	0.65	56.21	20.23	2.08	2.02	75.47	29.14
8	4	1	Thru ←	31.44	69.90	41.92	26.36	68.28	0.62	58.59	22.80	14.75	13.80	60.91	27.73
8	4	1	Right ↖	11.25	25.00	14.99	8.44	23.44	0.64	58.34	20.35	4.33	3.98	67.36	28.94

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.07	2.98	2.25	1.81	3.67	0.08	7.79	7.80	1.50	1.51	7.96	2.89
2	8	1	Thru ↑	3.47	4.98	3.77	2.00	5.04	0.02	1.22	1.22	2.06	2.02	5.10	0.91
2	8	1	Right ↗	1.27	1.61	1.38	0.48	1.77	0.08	5.65	5.35	0.21	0.20	38.49	4.92
1	8	1	Left ↘	2.30	3.83	2.50	5.58	7.57	0.06	15.87	15.87	4.90	4.73	6.39	2.97
6	8	1	Thru ↓	3.61	8.03	3.93	18.93	20.47	0.08	12.16	12.18	14.13	13.35	15.18	4.52
6	8	1	Right ↙	1.90	3.17	2.08	2.32	4.03	0.05	4.48	4.48	1.47	1.30	13.70	2.74
4	2	1	Left ↗	0.83	5.50	1.10	2.64	3.43	0.05	5.84	5.84	2.14	2.06	10.13	2.23
4	2	1	Thru →	0.94	6.29	1.28	5.62	6.46	0.05	4.13	4.13	4.16	4.03	6.73	2.04
4	2	1	Right ↘	0.78	5.07	1.01	3.56	4.25	0.08	5.12	5.12	2.78	2.61	8.15	2.82
8	4	1	Left ↙	1.33	2.95	1.77	1.56	3.19	0.07	6.12	8.13	1.12	1.08	16.18	3.19
8	4	1	Thru ←	2.94	6.54	3.93	4.81	7.58	0.03	3.32	3.32	3.21	3.12	7.00	1.55
8	4	1	Right ↖	2.53	5.64	3.38	2.62	5.47	0.05	4.89	4.89	1.65	1.55	11.62	2.37





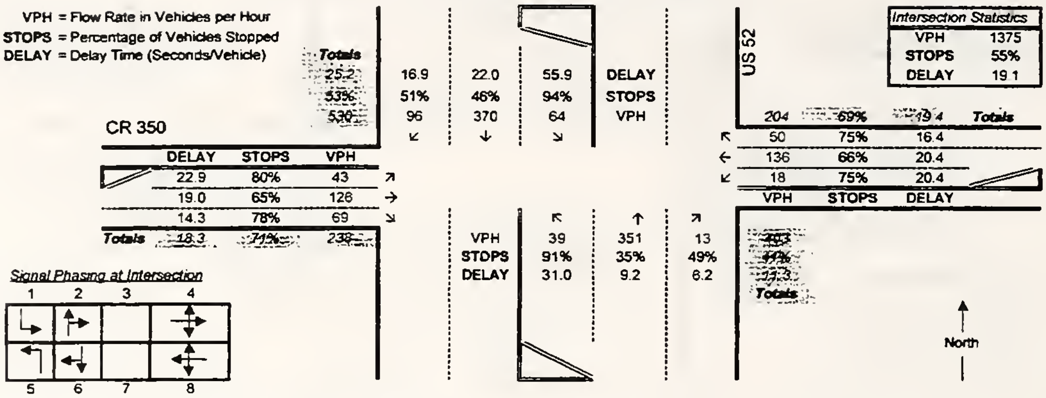
Additional Notes:

Period 3 Existing Conditions with 100% Side Street Volume and CID interface control

F:\Jay\Research\Excel Files\Period3\100%\Existing\

E3-100.xls School of Civil Engineering - Purdue University Printed on 7/10/98 at 9:05 AM

Figure D-5 Period 3 Configuration E-100

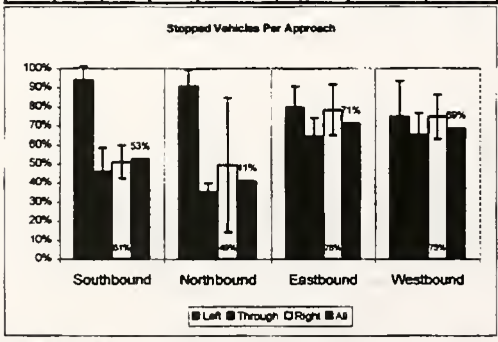


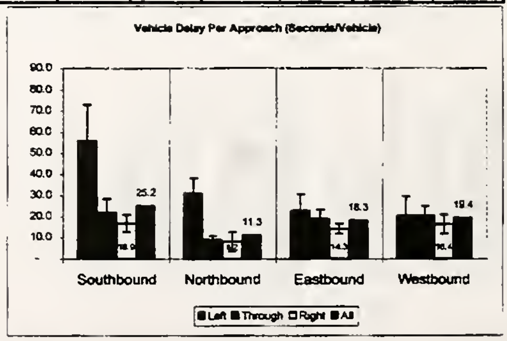
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	6.72	9.60	7.30	4.92	12.22	0.60	78.62	30.98	3.92	3.87	90.72	33.16
2	6	1	Thru ↑	61.32	87.60	66.62	13.44	80.06	0.83	34.88	9.24	7.92	7.70	35.34	45.97
2	8	1	Right ↗	2.21	3.15	2.39	0.47	2.86	0.80	51.58	8.22	0.12	0.12	49.39	44.37
1	8	1	Left ↘	9.54	15.90	10.36	15.07	25.43	0.42	95.00	56.90	11.10	10.73	94.21	23.36
6	6	1	Thru ↓	55.48	92.50	60.28	33.97	94.24	0.66	61.12	22.02	15.76	14.29	45.95	35.69
6	6	1	Right ↙	14.34	23.90	15.57	6.81	22.39	0.70	56.01	16.91	1.55	1.39	51.18	38.74
4	2	1	Left ↗	1.56	10.55	2.11	3.69	6.00	0.36	34.94	22.94	3.32	3.29	79.61	16.09
4	2	1	Thru →	4.70	31.30	6.26	9.90	16.16	0.40	30.97	16.97	7.79	7.50	84.51	17.74
4	2	1	Right ↘	2.58	17.25	3.45	4.13	7.58	0.46	26.25	14.26	2.44	2.26	78.47	20.75
8	4	1	Left ↙	1.94	4.30	2.58	1.42	4.00	0.65	56.39	20.39	1.02	1.02	74.63	29.38
8	4	1	Thru ←	15.22	33.85	20.30	11.66	31.96	0.64	56.43	20.44	8.19	7.91	65.60	28.87
8	4	1	Right ↖	5.56	12.35	7.41	3.25	10.66	0.69	52.38	16.38	1.80	1.70	74.74	31.13

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.23	3.16	2.42	2.01	4.15	0.05	7.27	7.27	1.77	1.76	8.87	2.98
2	8	1	Thru ↑	3.14	4.49	3.41	2.32	4.11	0.02	1.68	1.68	1.58	1.51	4.57	1.40
2	8	1	Right ↗	1.19	1.69	1.29	0.37	1.59	0.20	12.81	4.55	0.12	0.12	35.26	11.02
1	8	1	Left ↘	2.15	3.56	2.34	6.44	8.29	0.07	16.93	16.93	5.52	5.40	7.09	3.67
6	9	1	Thru ↓	2.99	4.99	3.25	9.92	11.06	0.07	6.39	6.39	6.20	5.84	12.55	3.73
6	6	1	Right ↙	2.01	3.35	2.16	2.34	4.16	0.05	4.06	4.06	1.20	1.09	8.67	2.66
4	2	1	Left ↗	0.56	3.76	0.75	1.47	2.04	0.07	7.71	7.71	1.39	1.37	11.16	3.09
4	2	1	Thru →	0.64	4.26	0.85	2.53	3.07	0.05	4.34	4.34	2.25	2.16	9.58	2.40
4	2	1	Right ↘	0.56	3.75	0.75	1.23	1.92	0.04	2.27	2.27	0.84	0.81	13.34	1.87
8	4	1	Left ↙	0.59	1.30	0.78	0.77	1.34	0.10	6.12	9.12	0.69	0.68	16.77	4.45
8	4	1	Thru ←	1.83	4.07	2.44	3.47	5.49	0.06	4.53	4.54	2.83	2.73	11.10	2.27
8	4	1	Right ↖	1.30	2.89	1.73	0.83	2.18	0.06	4.57	4.57	0.67	0.64	11.68	2.72





Additional Notes:

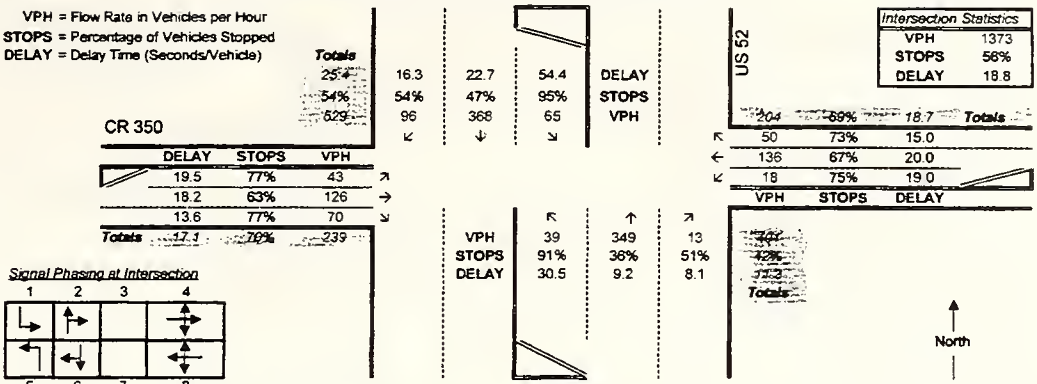
Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit

Platoon Settings - > 11 Vehicles in 10 seconds

F:\Jay\Research\Excel Files\Period3\50%\00-45-60-25-13_11-10\

P3a-50.xls School of Civil Engineering - Purdue University Printed on 7/10/98 at 9:07 AM

Figure D-6 Period 3 Configuration A-50

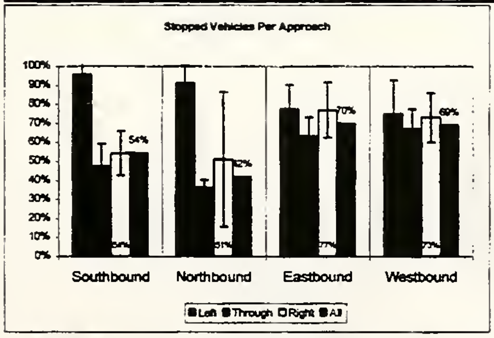


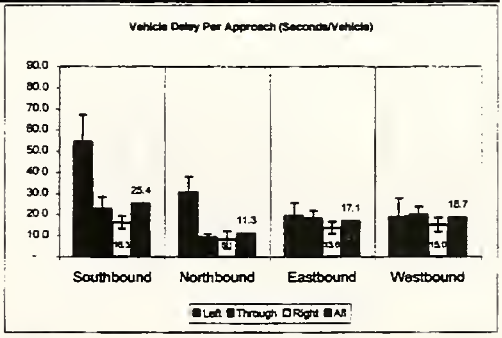
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	8.72	9.60	7.30	4.79	12.09	0.60	78.17	30.55	3.60	3.74	91.14	33.35
2	8	1	Thru ↑	61.06	57.25	66.35	13.37	79.72	0.83	54.86	8.24	7.84	7.61	36.30	45.97
2	8	1	Right ↗	2.21	3.15	2.39	0.48	2.86	0.80	51.43	8.09	0.12	0.12	51.06	44.43
1	8	1	Left ↘	9.63	16.06	10.46	14.66	25.12	0.43	93.48	54.38	10.52	10.11	95.35	23.49
6	6	1	Thru ↓	55.15	91.95	59.92	34.75	94.67	0.64	61.77	22.67	16.21	14.78	47.32	35.25
6	6	1	Right ↙	14.34	23.90	15.57	6.52	22.09	0.71	55.39	16.29	1.21	1.06	54.22	39.06
4	2	1	Left ↗	1.60	10.65	2.13	3.43	5.56	0.39	31.50	19.50	2.84	2.81	77.34	17.83
4	2	1	Thru →	4.73	31.50	6.30	9.62	15.92	0.40	30.21	18.21	7.50	7.23	63.36	18.13
4	2	1	Right ↘	2.60	17.35	3.47	3.95	7.42	0.48	25.58	13.58	2.27	2.07	78.97	21.40
8	4	1	Left ↙	1.94	4.30	2.58	1.32	3.90	0.67	54.99	16.99	0.92	0.92	75.01	30.10
8	4	1	Thru ←	15.27	33.65	20.38	11.43	31.79	0.65	55.86	19.98	7.69	7.63	67.09	29.08
8	4	1	Right ↖	5.58	12.40	7.44	3.03	10.48	0.71	50.99	14.99	1.58	1.48	73.06	31.89

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.23	3.19	2.42	1.83	3.99	0.05	7.27	7.25	1.58	1.58	9.11	2.98
2	6	1	Thru ↑	3.13	4.47	3.40	2.10	3.83	0.02	1.58	1.58	1.47	1.43	3.83	1.29
2	8	1	Right ↗	1.19	1.69	1.29	0.36	1.58	0.20	12.68	4.16	0.13	0.13	35.25	10.94
1	6	1	Left ↘	2.18	3.61	2.35	5.32	7.17	0.08	12.70	12.70	4.29	4.17	7.10	3.03
6	6	1	Thru ↓	3.25	5.42	3.54	8.63	10.29	0.08	5.66	5.65	5.27	4.86	11.95	3.24
6	θ	1	Right ↙	2.01	3.35	2.19	1.66	3.55	0.04	2.99	2.99	0.58	0.49	11.77	2.06
4	2	1	Left ↗	0.55	3.86	0.73	1.35	1.97	0.08	5.78	5.78	1.24	1.21	12.91	2.85
4	2	1	Thru →	0.82	4.15	0.83	2.45	3.07	0.05	3.64	3.64	2.17	2.09	9.87	2.27
4	2	1	Right ↘	0.57	3.77	0.75	1.31	1.86	0.06	2.89	2.89	1.01	0.95	14.44	2.57
8	4	1	Left ↙	0.59	1.30	0.78	0.75	1.31	0.10	8.89	8.89	0.67	0.57	17.64	4.38
8	4	1	Thru ←	1.78	3.95	2.37	3.08	5.15	0.04	3.82	3.83	2.51	2.42	10.37	1.99
8	4	1	Right ↖	1.35	3.00	1.80	0.71	2.28	0.05	3.33	3.32	0.55	0.53	12.84	2.06



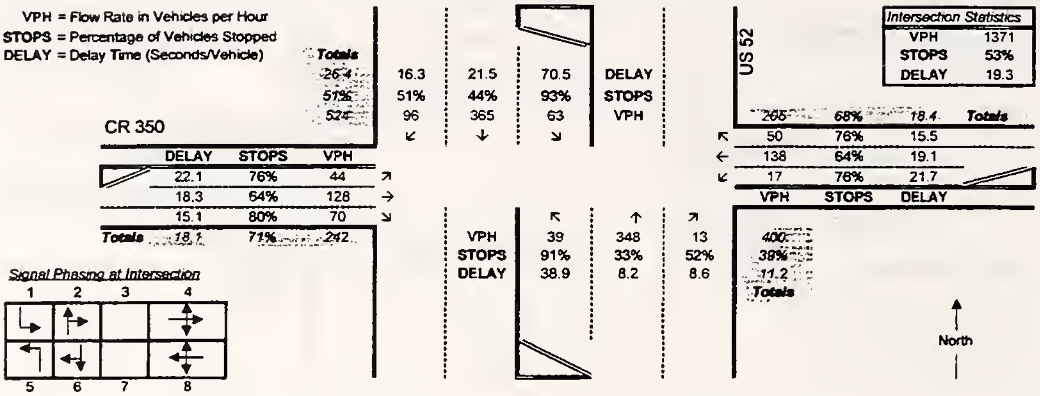


Additional Notes:

Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 20 Delay, 13 Inhibit
Platoon Settings - > 16 Vehicles in 15 seconds

F:\Jay\Research\Excel Files\Period3\50%\00-45-60-20-13_16-15\

Figure D-7 Period 3 Configuration B-50

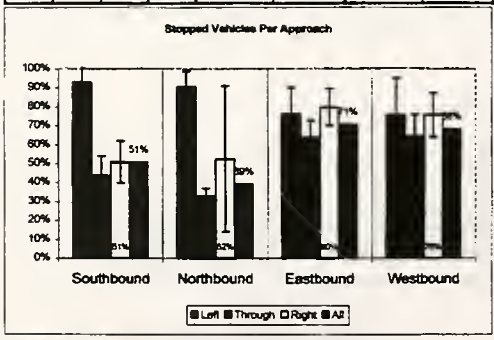


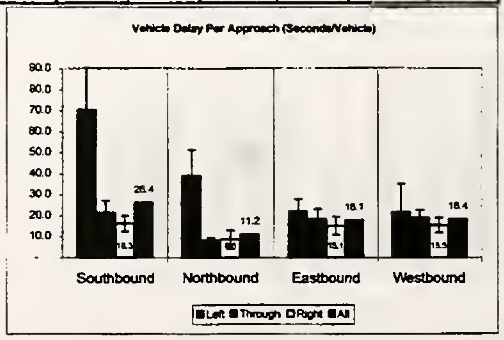
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	6.69	9.56	7.26	6.16	13.43	0.55	84.58	38.92	5.21	5.17	90.73	30.34
2	6	1	Thru ↑	60.87	86.95	66.12	11.88	78.01	0.65	53.83	8.21	6.66	6.48	32.65	46.63
2	6	1	Right ↗	2.21	3.15	2.39	0.50	2.90	0.60	51.95	6.59	0.18	0.18	52.40	44.02
1	6	1	Left ↘	9.45	15.75	10.28	18.27	28.54	0.37	108.59	70.49	14.53	14.17	92.91	20.29
6	6	1	Thru ↓	54.73	91.25	59.48	32.64	92.10	0.65	60.62	21.52	14.89	13.42	43.55	35.91
6	6	1	Right ↙	14.37	23.95	15.61	6.51	22.12	0.71	55.40	16.31	1.31	1.17	50.89	39.14
4	2	1	Left ↗	1.63	10.85	2.17	3.86	6.03	0.36	34.06	22.08	3.22	3.16	76.10	16.21
4	2	1	Thru →	4.79	31.95	6.39	9.89	16.28	0.41	30.30	18.30	7.53	7.23	63.70	18.27
4	2	1	Right ↘	2.60	17.35	3.47	4.35	7.82	0.45	27.15	15.15	2.64	2.45	79.79	20.40
8	4	1	Left ↙	1.91	4.25	2.55	1.48	4.03	0.65	57.74	21.74	1.10	1.09	75.76	29.16
8	4	1	Thru ←	15.52	34.50	20.69	11.02	31.71	0.66	55.12	19.13	7.40	7.15	64.41	29.51
8	4	1	Right ↖	5.60	12.45	7.47	3.12	10.59	0.70	51.45	15.46	1.64	1.54	75.62	31.82

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	2.23	3.19	2.43	3.02	4.96	0.07	12.34	12.32	2.82	2.79	7.92	3.92
2	6	1	Thru ↑	2.62	4.03	3.07	1.94	4.05	0.02	1.29	1.27	1.42	1.35	4.22	1.13
2	6	1	Right ↗	1.19	1.69	1.29	0.39	1.63	0.20	12.85	4.45	0.18	0.18	38.46	10.80
1	6	1	Left ↘	2.24	3.73	2.43	5.96	7.58	0.08	19.74	19.74	5.34	5.22	6.87	3.46
6	6	1	Thru ↓	3.17	5.29	3.45	8.53	9.22	0.06	5.70	5.70	5.19	4.77	10.36	3.42
6	6	1	Right ↙	2.02	3.38	2.20	1.81	3.52	0.05	3.79	3.79	0.80	0.70	11.15	2.54
4	2	1	Left ↗	0.59	3.92	0.78	1.32	2.00	0.05	5.82	5.82	1.18	1.16	13.91	2.25
4	2	1	Thru →	0.82	4.11	0.82	3.33	3.98	0.07	4.78	4.78	2.72	2.62	6.98	2.99
4	2	1	Right ↘	0.57	3.77	0.75	1.42	1.96	0.08	4.25	4.25	1.14	1.09	9.67	3.37
8	4	1	Left ↙	0.56	1.25	0.75	0.62	1.33	0.12	13.40	13.40	0.73	0.71	19.38	5.29
8	4	1	Thru ←	2.03	4.50	2.70	2.51	4.60	0.04	3.80	3.61	1.98	1.69	11.46	1.98
8	4	1	Right ↖	1.24	2.76	1.88	0.62	1.88	0.05	3.64	3.63	0.46	0.45	11.48	2.18





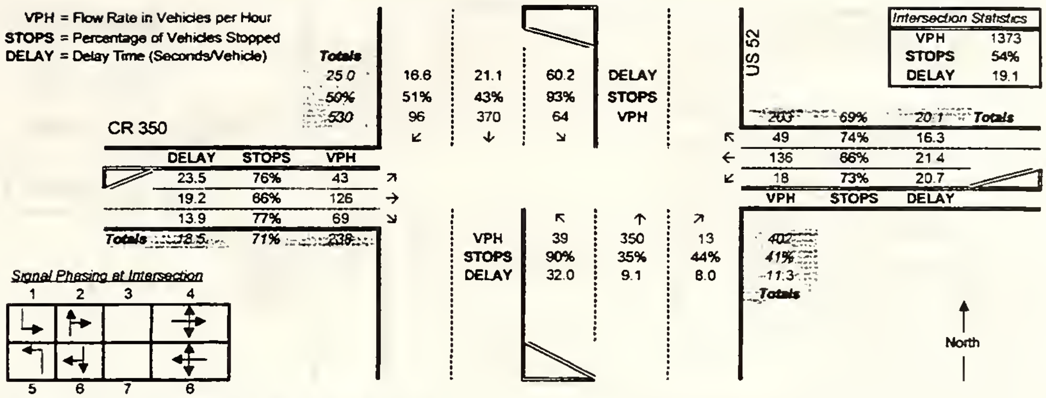
Additional Notes:

Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings - > 6 Vehicles in 10 seconds

F:\Jay\Research\Excel Files\Period3\50%\00-45-60-25-13_6-10\

P3c-50.xls School of Civil Engineering - Purdue University Printed on 7/15/98 at 11:18 AM

Figure D-8 Period 3 Configuration C-50

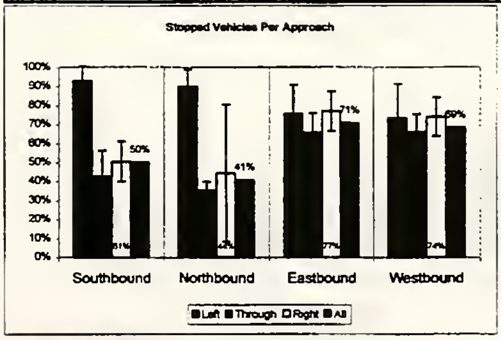


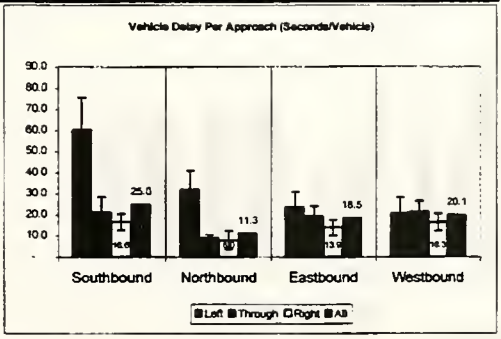
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	6.72	9.80	7.30	5.07	12.37	0.60	77.64	32.01	4.08	4.02	89.84	32.84
2	8	1	Thru ↑	61.25	87.50	66.54	13.32	79.87	0.83	54.77	9.13	7.60	7.60	35.30	46.04
2	8	1	Right ↗	2.21	3.15	2.39	0.48	2.85	0.81	51.39	8.05	0.12	0.12	44.39	44.51
1	6	1	Left ↘	9.54	15.90	10.36	15.98	28.34	0.40	99.29	60.19	12.08	11.69	82.99	22.23
8	8	1	Thru ↓	55.36	82.30	60.15	32.60	92.74	0.66	60.22	21.12	14.87	13.58	42.89	38.30
6	6	1	Right ↙	14.34	23.90	15.57	6.68	22.25	0.71	55.69	18.59	1.46	1.31	50.85	38.66
4	2	1	Left ↗	1.58	10.85	2.11	4.06	6.17	0.35	35.52	23.52	3.50	3.46	75.75	15.74
4	2	1	Thru →	4.73	31.50	6.30	10.14	18.44	0.39	31.23	19.23	7.92	7.64	65.87	17.69
4	2	1	Right ↘	2.59	17.25	3.45	4.00	7.46	0.47	25.87	13.87	2.35	2.20	77.01	21.26
8	4	1	Left ↙	1.84	4.30	2.58	1.46	4.04	0.64	56.74	20.74	1.04	1.04	73.26	29.00
8	4	1	Thru ←	15.25	33.90	20.33	12.08	32.42	0.63	57.39	21.36	8.81	8.35	65.94	28.45
6	4	1	Right ↖	5.51	12.25	7.35	3.21	10.55	0.68	52.30	18.31	1.61	1.69	74.07	31.14

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	2.23	3.19	2.42	2.21	4.35	0.08	8.69	8.69	1.99	1.97	8.92	3.46
2	8	1	Thru ↑	3.17	4.52	3.44	2.27	4.59	0.02	1.49	1.48	1.58	1.50	4.46	1.23
2	8	1	Right ↗	1.19	1.69	1.29	0.37	1.58	0.20	12.78	4.56	0.12	0.12	38.18	11.08
1	8	1	Left ↘	2.15	3.58	2.34	5.21	7.02	0.06	15.39	15.39	4.52	4.40	8.53	3.28
6	6	1	Thru ↓	3.00	5.00	3.26	11.91	13.32	0.07	7.32	7.32	7.43	6.78	13.65	3.93
6	6	1	Right ↙	1.98	3.28	2.13	2.20	4.01	0.05	3.79	3.79	1.01	0.91	10.49	2.58
4	2	1	Left ↗	0.56	3.66	0.73	1.68	2.23	0.06	7.24	7.24	1.66	1.64	15.00	2.92
4	2	1	Thru →	0.68	4.42	0.88	2.90	3.52	0.06	4.60	4.60	2.44	2.34	10.06	2.73
4	2	1	Right ↘	0.58	3.75	0.75	1.57	2.14	0.05	3.61	3.61	1.29	1.23	10.37	2.83
8	4	1	Left ↙	0.59	1.30	0.78	0.72	1.34	0.06	7.71	7.71	0.68	0.66	17.89	3.57
8	4	1	Thru ←	1.85	4.34	2.60	3.39	5.17	0.06	5.16	5.17	2.81	2.73	9.50	2.56
6	4	1	Right ↖	1.30	2.90	1.74	0.63	2.10	0.05	4.11	4.12	0.52	0.49	10.06	2.31



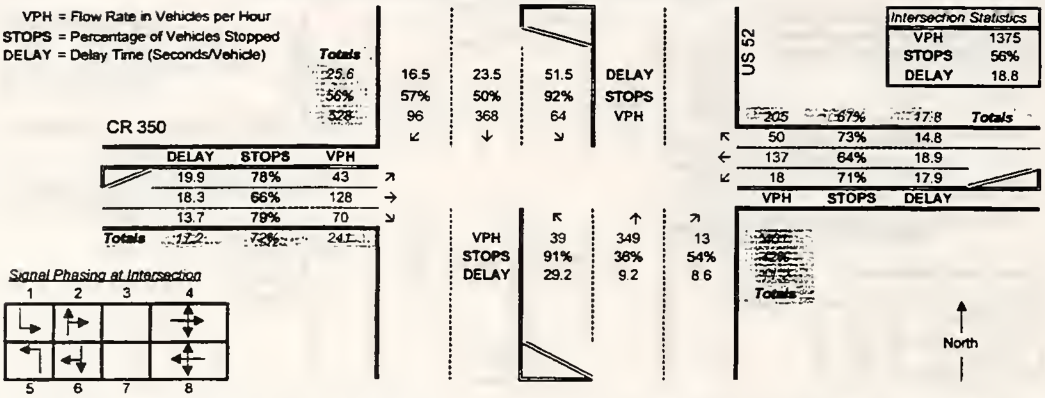


Additional Notes:

Period 3 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 30 Delay, 13 Inhibit
Platoon Settings - > 6 Vehicles in 05 seconds

F:\Jay\Research\Excel Files\Period3\50%\00-45-60-30-13_6-05\

Figure D-9 Period 3 Configuration D-50

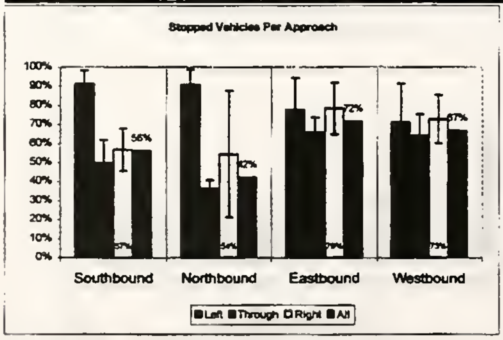


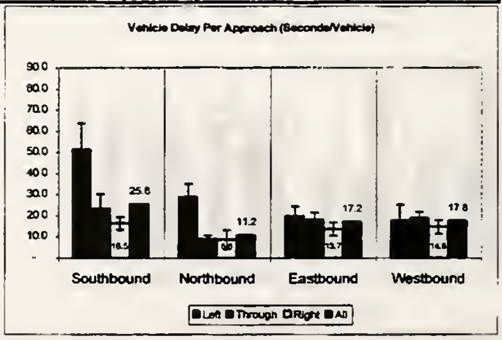
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	6.69	9.56	7.26	4.64	11.90	0.61	74.85	29.22	3.69	3.64	90.96	33.87
2	6	1	Thru ↑	61.04	67.20	66.31	13.38	79.69	0.83	54.85	9.23	7.88	7.67	36.31	45.97
2	6	1	Right ↗	2.21	3.15	2.39	0.49	2.89	0.80	51.98	8.68	0.16	0.16	54.40	43.98
1	6	1	Left ↘	9.51	15.85	10.33	13.90	24.23	0.44	90.80	51.50	9.82	9.43	91.53	24.25
6	6	1	Thru ↓	55.06	91.80	59.82	36.04	96.86	0.63	62.61	23.51	16.50	14.96	49.74	34.88
6	6	1	Right ↙	14.31	23.85	15.54	6.59	22.13	0.70	55.62	16.52	1.31	1.16	56.71	38.93
4	2	1	Left ↗	1.61	10.70	2.14	3.54	5.66	0.38	31.88	19.86	2.90	2.69	77.74	17.31
4	2	1	Thru →	4.77	31.80	6.36	9.75	16.11	0.40	30.27	18.27	7.50	7.22	65.64	16.07
4	2	1	Right ↘	2.60	17.30	3.46	3.97	7.43	0.47	25.74	13.74	2.29	2.09	78.57	21.26
8	4	1	Left ↙	1.94	4.30	2.58	1.25	3.83	0.68	53.92	17.92	0.65	0.64	71.26	30.50
8	4	1	Thru ←	15.36	34.15	20.48	10.85	31.33	0.66	54.92	16.92	7.33	7.07	64.16	29.57
8	4	1	Right ↖	5.63	12.50	7.50	3.02	10.52	0.71	50.81	14.62	1.56	1.47	72.81	31.99

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	2.23	3.19	2.43	1.86	4.13	0.05	5.88	5.88	1.59	1.57	7.96	2.61
2	6	1	Thru ↑	2.92	4.19	3.16	2.15	4.11	0.02	1.46	1.45	1.51	1.44	4.30	1.21
2	6	1	Right ↗	1.19	1.88	1.29	0.37	1.59	0.20	12.67	4.48	0.13	0.13	33.26	10.90
1	6	1	Left ↘	2.20	3.68	2.39	5.40	7.42	0.08	12.31	12.31	4.21	4.13	6.83	3.32
6	6	1	Thru ↓	3.51	5.85	3.61	10.75	12.42	0.07	6.76	6.76	5.98	5.46	12.03	3.69
6	6	1	Right ↙	1.94	3.23	2.11	1.63	3.42	0.04	2.97	2.97	0.59	0.51	11.16	2.07
4	2	1	Left ↗	0.56	3.71	0.74	1.39	2.07	0.06	4.59	4.59	1.22	1.19	16.52	2.70
4	2	1	Thru →	0.60	4.01	0.80	2.44	3.05	0.05	3.46	3.46	2.19	2.10	6.09	2.04
4	2	1	Right ↘	0.58	3.76	0.75	1.26	1.67	0.05	3.10	3.10	0.86	0.86	13.54	2.42
8	4	1	Left ↙	0.60	1.34	0.80	0.51	1.19	0.06	7.39	7.39	0.37	0.37	20.11	3.69
8	4	1	Thru ←	1.80	4.07	2.44	2.49	4.85	0.04	2.98	2.98	1.99	1.93	11.20	1.62
8	4	1	Right ↖	1.29	2.87	1.72	0.69	2.17	0.04	3.22	3.22	0.58	0.54	12.67	1.96



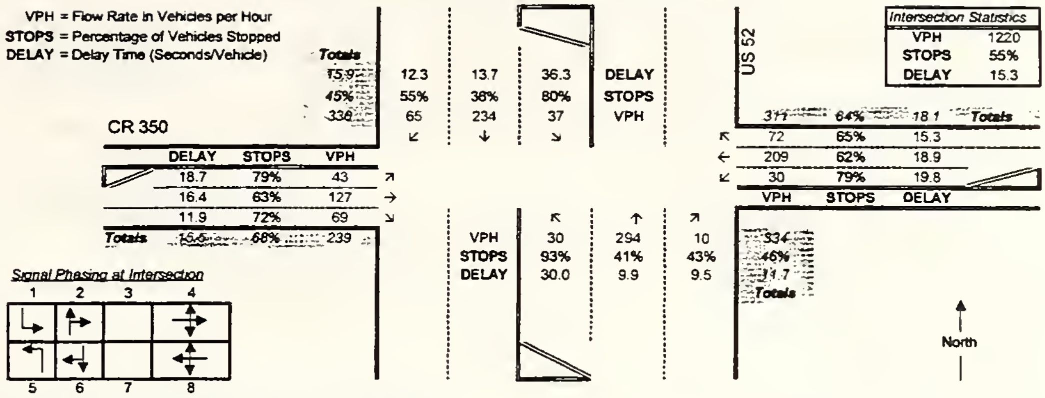


Additional Notes:

Period 3 Baseline Conditions with 50% Side Street Volume using CID Interface

F:\Jay\Research\Excel Files\Period3\50%\Existing\

Figure D-10 Period 3 Configuration E-50

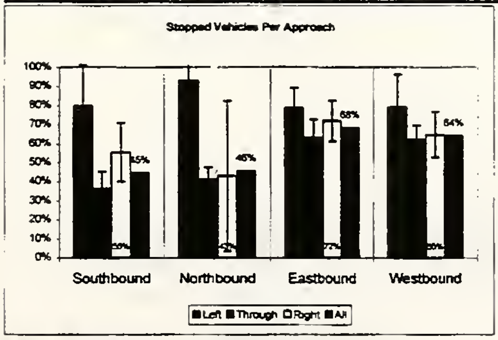


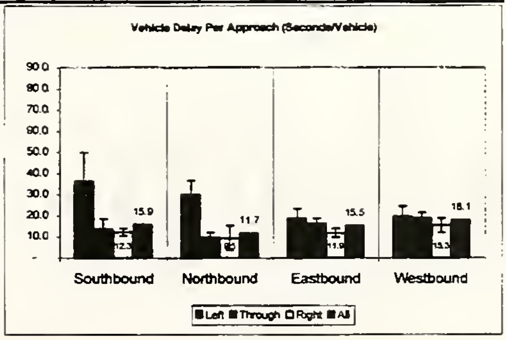
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	5.18	7.40	5.63	3.60	9.23	0.61	75.62	29.99	2.90	2.87	83.13	33.58
2	8	1	Thru ↑	51.31	73.30	55.75	12.10	67.63	0.82	55.57	8.94	7.16	7.01	41.09	45.40
2	8	1	Right ↗	1.75	2.50	1.90	0.42	2.32	0.79	52.84	8.50	0.14	0.12	42.98	43.41
1	8	1	Left ↘	5.46	9.10	6.93	5.72	11.65	0.54	75.41	38.31	4.87	4.75	79.92	29.53
6	6	1	Thru ↓	34.87	58.30	37.99	13.40	51.39	0.75	52.82	13.72	7.04	6.64	36.08	41.22
6	6	1	Right ↙	9.69	18.15	10.52	3.32	13.84	0.76	51.43	12.33	0.61	0.55	55.45	42.04
4	2	1	Left ↗	1.61	10.75	2.15	3.42	5.57	0.40	30.75	18.75	2.65	2.81	78.79	18.00
4	2	1	Thru →	4.75	31.65	6.33	8.61	14.94	0.43	28.35	16.35	6.32	6.08	63.14	19.17
4	2	1	Right ↘	2.58	17.20	3.44	3.40	6.84	0.51	23.89	11.69	1.69	1.57	71.85	22.75
8	4	1	Left ↙	3.31	7.35	4.41	2.40	6.61	0.65	55.79	19.79	1.42	1.41	79.14	29.22
8	4	1	Thru ←	23.41	52.05	31.22	16.41	47.63	0.66	54.87	18.87	9.00	8.47	61.97	29.57
8	4	1	Right ↖	6.05	17.90	10.74	4.61	15.34	0.70	51.33	15.34	1.78	1.55	64.64	31.67

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	1.65	2.64	2.01	1.23	3.12	0.05	6.68	6.67	1.03	1.03	9.63	2.79
2	8	1	Thru ↑	3.02	4.32	3.28	2.56	4.26	0.03	2.10	2.10	1.87	1.82	6.61	1.68
2	8	1	Right ↗	1.08	1.54	1.17	0.35	1.48	0.20	13.55	5.61	0.15	0.15	39.48	11.01
1	6	1	Left ↘	1.75	2.92	1.90	2.73	4.28	0.10	13.44	13.44	2.35	2.29	21.45	5.38
6	6	1	Thru ↓	2.96	4.93	3.21	5.28	7.15	0.07	4.92	4.92	3.81	3.63	9.10	3.61
6	6	1	Right ↙	1.89	3.15	2.05	0.81	2.75	0.03	1.74	1.74	0.30	0.28	15.31	1.44
4	2	1	Left ↗	0.56	3.71	0.74	1.52	2.19	0.08	4.68	4.68	1.28	1.28	10.61	2.87
4	2	1	Thru →	0.61	4.05	0.61	1.62	2.20	0.04	2.46	2.46	1.29	1.23	9.51	1.63
4	2	1	Right ↘	0.58	3.87	0.77	1.00	1.66	0.04	2.07	2.07	0.63	0.56	10.73	1.63
8	4	1	Left ↙	1.22	2.70	1.62	1.04	2.53	0.05	4.68	4.68	0.67	0.66	17.17	2.39
8	4	1	Thru ←	2.59	5.76	3.48	3.30	6.23	0.03	2.81	2.60	2.09	2.01	7.48	1.39
8	4	1	Right ↖	2.08	4.82	2.77	1.60	4.15	0.05	3.38	3.39	0.78	0.69	11.89	2.08



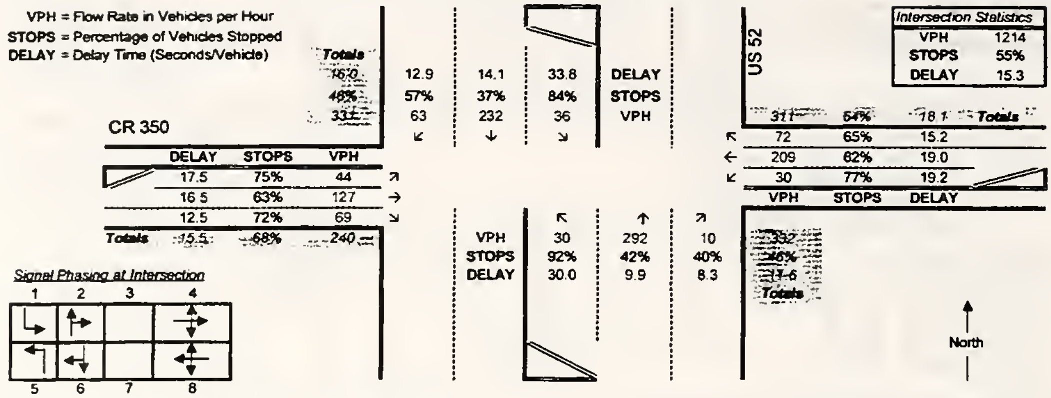


Additional Notes:

Period 4 Premption Settings -> 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings -> 11 Vehicles in 10 seconds

F:\Jay\Research\Excel Files\Period4\100%\00-45-60-25-13_11-10\

Figure D-11 Period 4 Configuration A-100

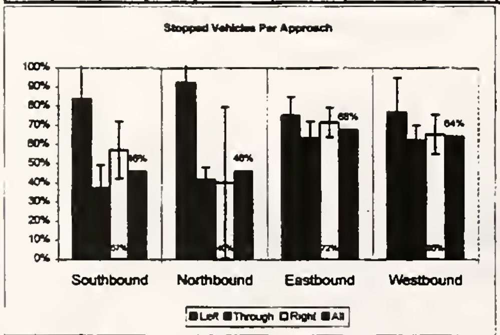


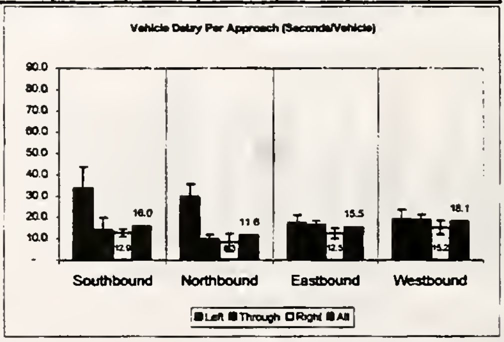
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	5.22	7.45	5.66	3.63	9.30	0.61	75.57	29.95	2.90	2.87	92.25	33.54
2	6	1	Thru ↑	51.03	72.90	55.44	11.95	67.39	0.62	55.48	9.85	7.04	6.92	41.88	45.47
2	6	1	Right ↗	1.75	2.50	1.90	0.40	2.30	0.60	51.61	8.26	0.14	0.12	40.08	44.27
1	6	1	Left ↘	5.40	9.00	5.87	5.30	11.17	0.55	72.95	33.85	4.33	4.20	83.85	30.16
6	6	1	Thru ↓	34.76	57.95	37.76	13.66	51.42	0.74	53.20	14.10	7.09	6.66	37.16	41.00
6	6	1	Right ↙	9.45	15.75	10.26	3.35	13.62	0.75	51.95	12.86	0.69	0.62	57.15	41.61
4	2	1	Left ↗	1.63	10.85	2.17	3.19	5.38	0.41	29.53	17.53	2.58	2.53	75.34	18.52
4	2	1	Thru →	4.75	31.65	6.33	8.72	15.05	0.42	28.51	18.51	6.43	6.19	63.27	19.04
4	2	1	Right ↘	2.57	17.15	3.43	3.55	6.98	0.49	24.50	12.50	1.67	1.74	71.53	22.23
8	4	1	Left ↙	3.31	7.35	4.41	2.33	6.74	0.66	55.16	19.16	1.36	1.33	76.75	29.56
8	4	1	Thru ←	23.41	52.05	31.22	16.56	47.77	0.66	55.02	19.03	9.15	6.64	62.27	29.49
8	4	1	Right ↖	6.01	17.80	10.68	4.54	15.21	0.70	51.16	15.19	1.77	1.57	65.25	31.75

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	1.64	2.63	2.00	1.24	3.12	0.05	5.78	5.79	1.04	1.03	10.63	2.57
2	8	1	Thru ↑	2.86	4.09	3.11	2.30	4.31	0.02	1.76	1.76	1.60	1.55	6.27	1.42
2	8	1	Right ↗	1.06	1.54	1.17	0.38	1.61	0.20	12.69	4.12	0.16	0.15	39.43	10.90
1	6	1	Left ↘	1.63	3.04	1.96	2.38	4.16	0.06	9.94	9.94	1.74	1.67	21.34	4.31
6	6	1	Thru ↓	3.13	5.22	3.40	5.74	7.39	0.08	5.68	5.66	4.27	4.05	11.96	4.14
6	6	1	Right ↙	1.74	2.90	1.69	0.71	2.45	0.03	1.83	1.64	0.33	0.29	14.87	1.49
4	2	1	Left ↗	0.56	3.73	0.75	1.21	1.89	0.05	3.42	3.42	0.90	0.92	9.48	2.15
4	2	1	Thru →	0.62	4.13	0.63	1.64	2.33	0.03	2.01	2.01	1.22	1.18	8.89	1.38
4	2	1	Right ↘	0.58	3.87	0.77	0.66	1.64	0.05	2.38	2.38	0.69	0.83	7.74	2.01
8	4	1	Left ↙	1.22	2.70	1.62	1.03	2.52	0.05	4.58	4.58	0.70	0.70	17.84	2.39
6	4	1	Thru ←	2.40	5.33	3.19	3.02	5.78	0.03	2.36	2.39	2.19	2.12	7.64	1.30
6	4	1	Right ↖	2.09	4.64	2.76	1.57	4.16	0.04	3.21	3.22	0.79	0.75	10.28	2.00



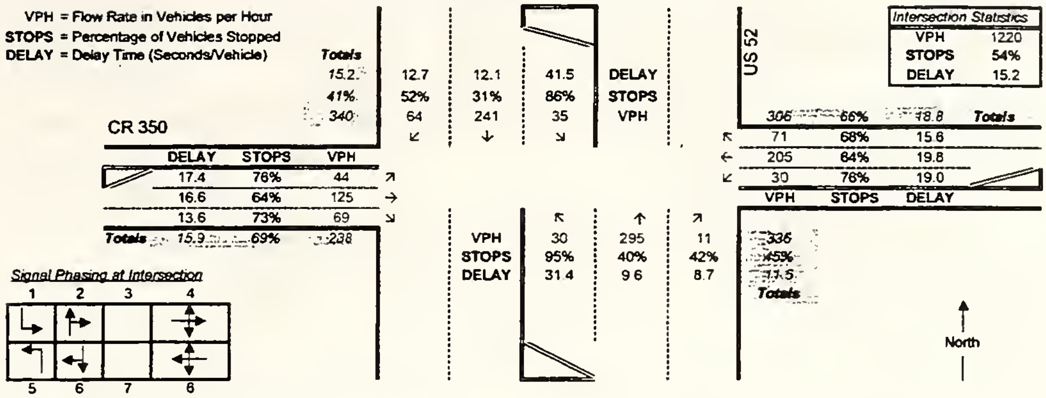


Additional Notes:

Period 4 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 20 Delay, 13 Inhibit
Platoon Settings - > 16 Vehicles in 15 seconds

F:\Jay\Research\Excell Files\Period4\100%\00-45-60-20-13_16-15\

Figure D-12 Period 4 Configuration B-100

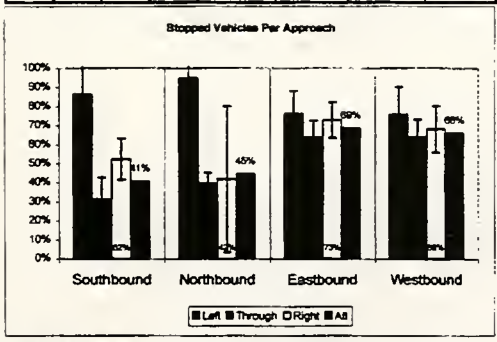


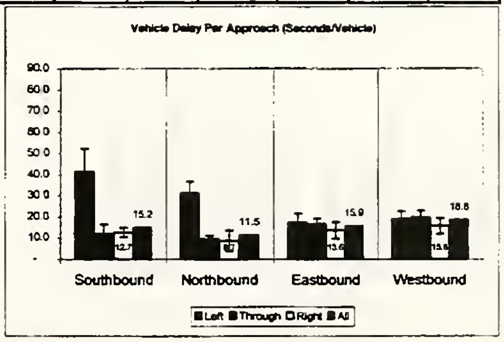
Summary of Meeasures of Effectivaness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	5.15	7.35	5.59	3.76	9.35	0.60	77.01	31.39	3.11	3.08	94.54	32.88
2	8	1	Thru ↑	51.58	73.65	56.01	11.74	67.78	0.83	55.21	9.58	6.94	6.60	39.68	45.67
2	8	1	Right ↗	1.79	2.55	1.94	0.40	2.34	0.80	52.09	8.74	0.12	0.10	41.85	43.95
1	6	1	Left ↘	5.13	8.55	5.57	6.04	11.61	0.49	60.61	41.51	5.42	5.30	86.50	27.21
6	6	1	Thru ↓	38.05	60.10	39.16	12.10	51.27	0.77	51.21	12.11	5.55	5.20	31.41	42.45
6	6	1	Right ↙	9.54	15.90	10.36	3.38	13.74	0.75	51.83	12.73	0.60	0.54	52.48	41.74
4	2	1	Left ↗	1.62	10.80	2.16	3.24	5.40	0.42	29.36	17.36	2.83	2.59	76.10	18.79
4	2	1	Thru →	4.69	31.25	6.25	6.59	14.84	0.42	28.58	16.58	8.50	8.22	63.92	19.06
4	2	1	Right ↘	2.58	17.05	3.41	3.88	7.29	0.48	25.61	13.61	2.20	2.05	72.98	21.54
8	4	1	Left ↙	3.31	7.35	4.41	2.37	6.77	0.66	54.95	18.95	1.38	1.38	75.82	29.60
8	4	1	Thru ←	22.98	51.05	30.62	16.61	47.40	0.66	55.62	19.64	9.90	9.35	64.03	29.10
8	4	1	Right ↖	7.90	17.55	10.53	4.68	15.21	0.70	51.81	15.82	2.11	1.87	68.07	31.42

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	1.78	2.54	1.93	1.24	3.02	0.04	5.37	5.38	1.08	1.07	8.21	2.38
2	8	1	Thru ↑	2.92	4.17	3.17	1.82	3.98	0.02	1.45	1.45	1.38	1.33	5.39	1.21
2	8	1	Right ↗	1.05	1.50	1.14	0.31	1.41	0.20	13.02	4.64	0.13	0.13	38.45	10.99
1	6	1	Left ↘	1.65	2.74	1.79	2.75	4.34	0.06	10.63	10.63	2.37	2.30	22.13	3.50
8	6	1	Thru ↓	2.36	3.83	2.58	4.45	5.33	0.06	4.47	4.47	2.98	2.74	11.44	3.46
8	6	1	Right ↙	1.77	2.95	1.92	0.67	2.65	0.00	2.14	2.14	0.30	0.29	10.76	1.73
4	2	1	Left ↗	0.59	3.83	0.79	1.64	2.38	0.06	4.31	4.31	1.34	1.32	12.10	2.83
4	2	1	Thru →	0.62	4.14	0.83	1.64	2.19	0.04	2.77	2.77	1.60	1.58	6.78	1.68
4	2	1	Right ↘	0.59	3.95	0.79	1.58	2.18	0.07	3.88	3.88	1.20	1.13	9.45	3.09
8	4	1	Left ↙	1.22	2.70	1.62	1.14	2.67	0.04	3.78	3.79	0.80	0.79	14.44	1.97
8	4	1	Thru ←	2.65	5.88	3.50	2.91	5.53	0.04	2.99	3.00	2.37	2.30	9.25	1.59
8	4	1	Right ↖	1.94	4.32	2.59	1.67	4.06	0.05	3.74	3.75	1.07	1.02	12.17	2.29





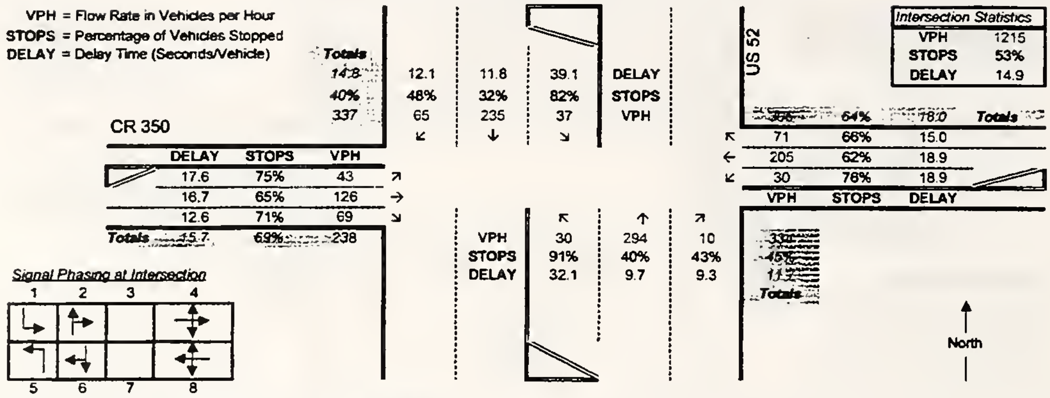
Additional Notes:

Period 4 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings - > 6 Vehicles in 10 seconds

F:\Jay\Research\Excel Files\Period4\100%\00-45-60-25-13_6-10\

P4c-100.xls School of Civil Engineering - Purdue University Printed on 7/15/98 at 11:18 AM

Figure D-13 Period 4 Configuration C-100

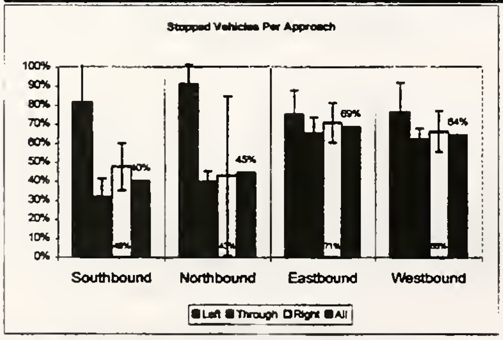


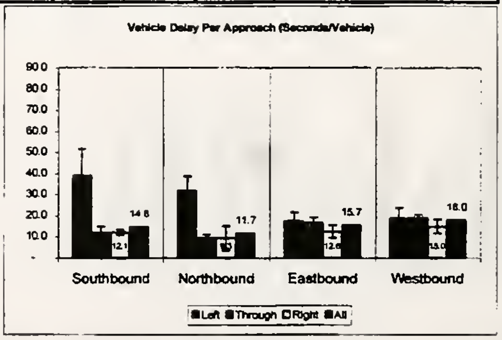
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	5.16	7.40	5.63	3.83	9.46	0.59	77.67	32.05	3.12	3.09	91.18	32.67
2	8	1	Thru ↑	51.42	73.45	55.86	11.88	67.74	0.82	55.38	9.74	7.05	6.91	39.86	45.58
2	8	1	Right ↗	1.75	2.50	1.90	0.40	2.30	0.79	52.68	9.34	0.14	0.12	42.98	43.54
1	6	1	Left ↘	5.52	9.20	6.00	6.30	12.29	0.51	78.17	39.07	5.32	5.18	81.82	28.38
6	6	1	Thru ↓	35.24	58.73	38.29	11.50	49.79	0.77	50.68	11.78	5.61	5.44	31.91	42.61
6	6	1	Right ↙	9.66	16.10	10.49	3.22	13.71	0.77	51.16	12.06	0.47	0.45	47.58	42.25
4	2	1	Left ↗	1.61	10.75	2.15	3.21	5.36	0.41	29.64	17.64	2.67	2.62	75.20	18.58
4	2	1	Thru →	4.73	31.50	6.30	6.78	15.06	0.42	28.73	18.73	6.53	6.29	65.26	18.82
4	2	1	Right ↘	2.57	17.15	3.43	3.60	7.03	0.49	24.62	12.62	1.88	1.73	70.92	22.23
8	4	1	Left ↙	3.29	7.30	4.38	2.34	6.72	0.66	64.68	18.88	1.41	1.39	78.19	29.74
8	4	1	Thru ←	23.05	51.25	30.74	16.14	46.87	0.66	54.92	16.90	9.30	8.61	62.00	29.51
8	4	1	Right ↖	7.98	17.70	10.62	4.47	15.09	0.71	50.97	14.98	1.83	1.63	68.12	31.90

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	1.65	2.64	2.01	1.33	3.21	0.05	6.64	6.64	1.11	1.11	10.20	2.78
2	6	1	Thru ↑	3.47	4.96	3.77	1.63	4.43	0.02	1.32	1.31	1.13	1.12	5.50	1.09
2	6	1	Right ↗	1.06	1.54	1.17	0.32	1.44	0.20	13.49	5.76	0.15	0.15	41.91	11.02
1	6	1	Left ↘	1.85	3.09	2.01	3.14	4.80	0.09	12.73	12.73	2.44	2.37	20.92	4.88
6	6	1	Thru ↓	2.98	4.94	3.22	3.16	4.90	0.05	3.20	3.20	2.49	2.36	9.46	2.66
6	6	1	Right ↙	1.64	2.73	1.78	0.61	2.30	0.02	1.34	1.34	0.22	0.21	12.33	1.11
4	2	1	Left ↗	0.55	3.68	0.74	1.45	2.13	0.06	3.93	3.93	1.21	1.19	12.48	2.68
4	2	1	Thru →	0.64	4.30	0.86	1.74	2.38	0.04	2.54	2.54	1.20	1.15	6.22	1.56
4	2	1	Right ↘	0.58	3.67	0.77	1.16	1.81	0.06	2.94	2.94	0.64	0.78	10.42	2.50
8	4	1	Left ↙	1.18	2.62	1.57	1.15	2.62	0.06	4.97	4.97	0.88	0.87	15.83	2.58
8	4	1	Thru ←	2.72	6.03	3.62	2.28	5.56	0.02	1.64	1.64	1.45	1.40	5.68	0.87
8	4	1	Right ↖	1.98	4.37	2.62	1.61	4.06	0.05	3.24	3.25	1.07	1.01	10.77	2.05





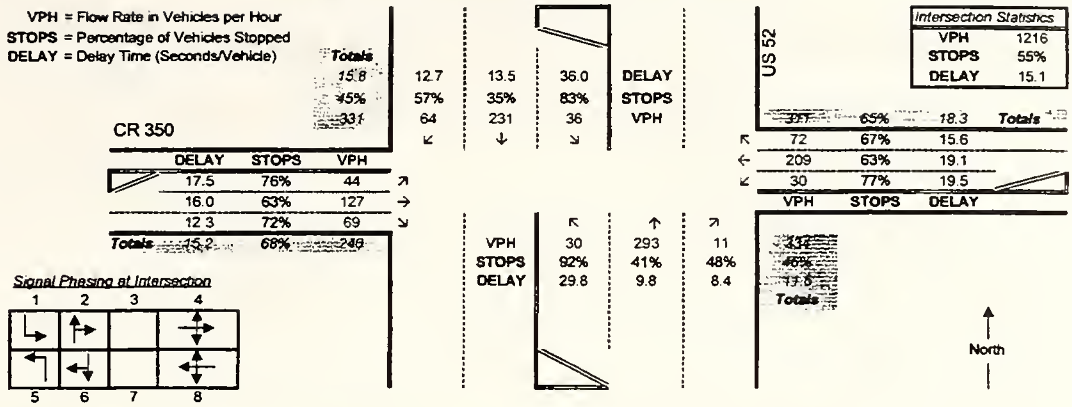
Additional Notes:

Period 4 Premption Settings - > 00 Min, 45 Max, 60 Reservce, 30 Delay, 13 Inhibit
Platoon Settings - > 6 Vehicles in 05 seconds

F:\Jay\Research\Excell Files\Period4\100%\00-45-60-30-13_6-05\

P4-100.xls School of Civil Engineering - Purdue University Printed on 7/10/98 at 9:08 AM

Figure D-14 Period 4 Configuration D-100

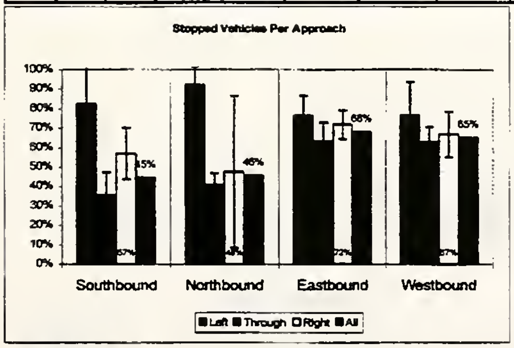


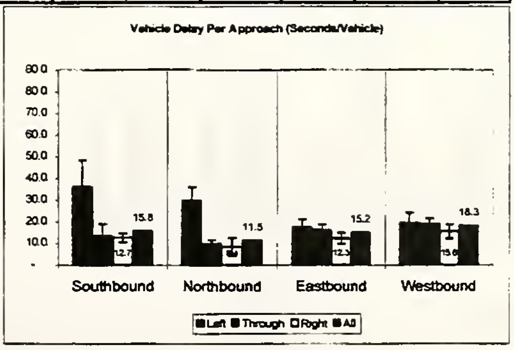
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	5.22	7.45	5.66	3.68	9.35	0.61	75.40	29.78	2.97	2.95	92.35	33.66
2	6	1	Thru ↑	51.17	73.10	55.59	11.85	67.44	0.83	55.38	9.75	6.99	6.85	40.62	45.55
2	6	1	Right ↗	1.79	2.55	1.94	0.40	2.34	0.80	51.74	6.39	0.13	0.11	47.56	44.15
1	6	1	Left ↘	5.37	6.95	5.83	5.61	11.45	0.53	75.12	36.02	4.72	4.80	82.52	29.50
6	6	1	Thru ↓	34.58	57.65	37.57	13.03	50.60	0.75	52.64	13.54	6.96	6.56	35.49	41.42
6	6	1	Right ↙	9.80	16.09	10.43	3.37	13.80	0.76	51.78	12.68	0.66	0.62	57.07	41.78
4	2	1	Left ↗	1.62	10.80	2.16	3.22	5.38	0.42	29.45	17.45	2.64	2.59	78.34	18.63
4	2	1	Thru →	4.78	31.70	6.34	8.48	14.82	0.43	28.02	16.02	6.17	5.93	63.19	19.43
4	2	1	Right ↘	2.58	17.20	3.44	3.50	6.84	0.50	24.32	12.32	1.77	1.65	71.81	22.42
8	4	1	Left ↙	3.31	7.35	4.41	2.40	6.81	0.66	55.55	18.55	1.42	1.41	78.62	29.38
8	4	1	Thru ←	23.46	62.15	31.28	16.64	47.92	0.66	55.08	19.08	9.18	6.66	62.80	29.47
8	4	1	Right ↖	8.03	17.85	10.71	4.66	15.38	0.70	51.55	15.55	1.84	1.60	66.62	31.54

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	1.84	2.63	2.00	1.41	3.25	0.05	6.43	6.44	1.20	1.20	9.16	2.82
2	6	1	Thru ↑	2.99	4.28	3.28	2.13	4.20	0.02	1.68	1.69	1.47	1.43	5.85	1.37
2	6	1	Right ↗	1.05	1.50	1.14	0.35	1.48	0.20	12.68	4.03	0.14	0.13	39.00	10.85
1	6	1	Left ↘	1.82	3.03	1.86	2.66	4.36	0.09	12.46	12.46	2.21	2.13	20.84	4.85
6	6	1	Thru ↓	3.52	5.87	3.82	5.87	7.72	0.07	5.45	5.45	4.06	3.88	11.84	4.03
6	6	1	Right ↙	1.92	3.20	2.06	0.83	2.78	0.03	1.97	1.97	0.35	0.31	13.23	1.62
4	2	1	Left ↗	0.57	3.78	0.76	1.45	2.16	0.05	3.69	3.69	1.17	1.15	10.31	2.34
4	2	1	Thru →	0.61	4.07	0.61	1.87	2.48	0.04	2.67	2.67	1.52	1.45	9.44	1.80
4	2	1	Right ↘	0.58	3.87	0.77	0.87	1.62	0.06	2.48	2.48	0.69	0.84	7.44	2.12
8	4	1	Left ↙	1.22	2.70	1.62	1.14	2.84	0.05	4.72	4.72	0.77	0.77	17.12	2.44
8	4	1	Thru ←	2.53	5.63	3.38	3.40	6.32	0.03	2.56	2.56	2.32	2.25	7.53	1.37
8	4	1	Right ↖	2.06	4.63	2.77	1.62	4.23	0.05	3.34	3.34	0.74	0.68	11.61	2.04





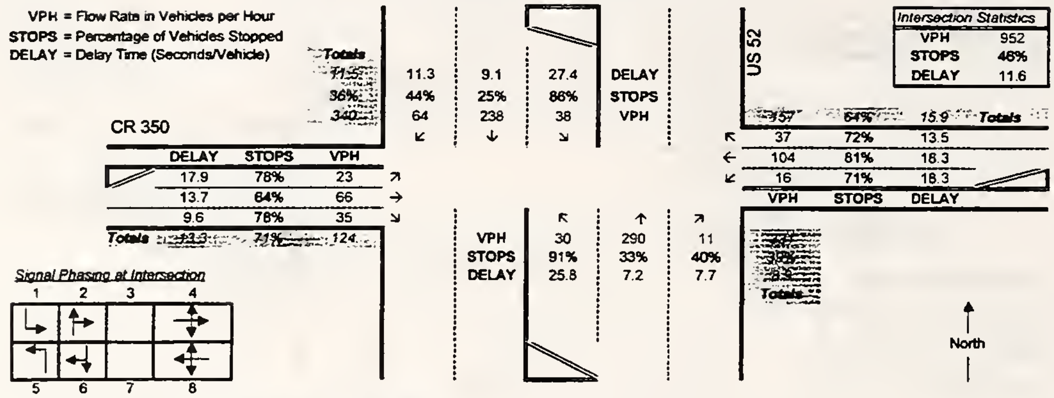
Additional Notes:

Period 4 Existing Conditions with 100% Side Street Volume using CID interface control

F:\Jay\Research\Excel Files\Period4\100%\Existing\

E4-100.xls School of Civil Engineering - Purdue University Printed on 7/10/98 at 9:07 AM

Figure D-15 Period 4 Configuration E-100

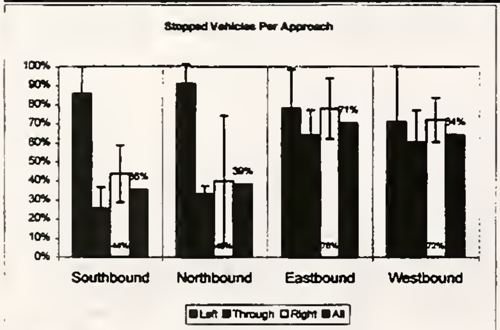


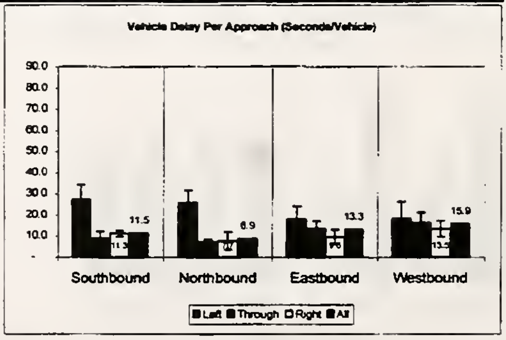
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	5.22	7.45	5.66	3.08	8.74	0.64	71.44	25.81	2.35	2.33	91.28	35.49
2	6	1	Thru ↑	50.86	72.35	55.02	8.72	63.74	0.86	52.87	7.25	4.46	4.39	33.05	47.69
2	6	1	Right ↗	1.79	2.55	1.94	0.35	2.29	0.61	51.07	7.74	0.07	0.06	40.16	44.75
1	6	1	Left ↘	5.64	9.40	8.13	4.26	10.39	0.59	66.45	27.36	3.29	3.18	65.93	32.85
6	6	1	Thru ↓	35.69	59.50	38.77	8.98	47.76	0.81	48.19	9.09	3.18	2.83	25.46	44.98
6	8	1	Right ↙	8.60	16.00	10.43	3.01	13.44	0.78	50.42	11.32	0.37	0.33	43.73	42.86
4	2	1	Left ↗	0.84	5.60	1.12	1.67	2.79	0.42	29.94	17.94	1.40	1.38	78.06	18.67
4	2	1	Thru →	2.48	16.50	3.30	3.82	7.12	0.47	25.72	13.72	2.99	2.94	64.14	21.35
4	2	1	Right ↘	1.30	6.65	1.73	1.38	3.11	0.57	21.62	9.62	0.67	0.64	78.10	25.46
8	4	1	Left ↙	1.76	3.90	2.34	1.15	3.49	0.68	54.28	18.28	0.81	0.81	71.09	30.44
8	4	1	Thru ←	11.67	25.96	15.56	7.17	22.73	0.69	52.30	16.30	4.72	4.57	60.53	31.22
8	4	1	Right ↖	4.16	9.25	5.55	2.02	7.56	0.73	49.54	13.54	0.83	0.87	72.13	32.88

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	8	1	Left ↖	1.87	2.67	2.00	1.08	3.00	0.05	5.86	5.88	0.88	0.83	9.99	2.78
2	8	1	Thru ↑	2.70	3.88	2.93	1.46	3.49	0.02	1.21	1.20	0.86	0.83	4.44	1.09
2	6	1	Right ↗	1.05	1.50	1.14	0.30	1.40	0.20	12.60	4.19	0.06	0.06	34.19	11.02
1	6	1	Left ↘	1.78	2.96	1.93	1.51	3.20	0.05	7.02	7.02	1.19	1.16	14.16	3.49
8	6	1	Thru ↓	2.39	3.98	2.59	3.01	4.05	0.05	3.24	3.24	1.57	1.37	11.38	2.74
8	6	1	Right ↙	1.73	2.88	1.88	0.62	2.40	0.02	1.39	1.39	0.11	0.11	14.97	1.20
4	2	1	Left ↗	0.32	2.16	0.43	0.67	1.21	0.09	6.44	6.44	0.78	0.77	20.54	4.11
4	2	1	Thru →	0.42	2.80	0.56	1.28	1.73	0.08	3.42	3.42	1.01	0.99	13.07	2.62
4	2	1	Right ↘	0.35	2.32	0.46	0.68	0.92	0.07	3.29	3.29	0.50	0.47	15.82	3.34
8	4	1	Left ↙	0.65	1.45	0.87	0.56	1.28	0.10	7.88	7.88	0.50	0.50	29.12	4.48
8	4	1	Thru ←	1.51	3.36	2.02	2.53	4.19	0.07	4.92	4.92	1.88	1.80	16.57	2.94
8	4	1	Right ↖	1.01	2.24	1.35	0.49	1.60	0.06	3.63	3.82	0.35	0.32	11.56	2.52

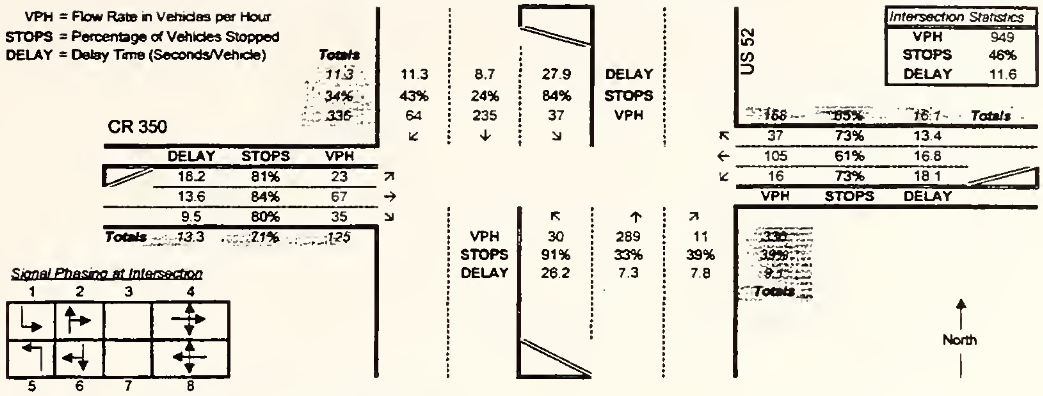




Additional Notes:

Period 4 Premption Settings - > 00 Min, 45 Max, 60 Reservice, 25 Delay, 13 Inhibit
Platoon Settings - > 11 Vehicles in 10 seconds
F:\Jay\Research\Excell Files\Period4\50%\00-45-60-25-13_11-10\

Figure D-16 Period 4 Configuration A-50

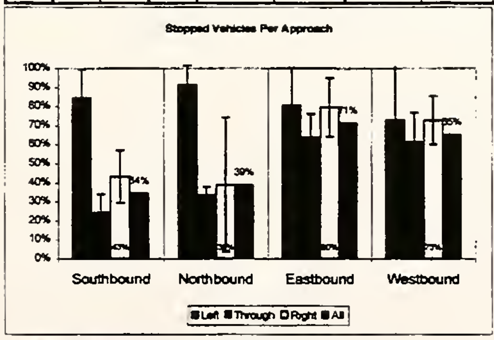


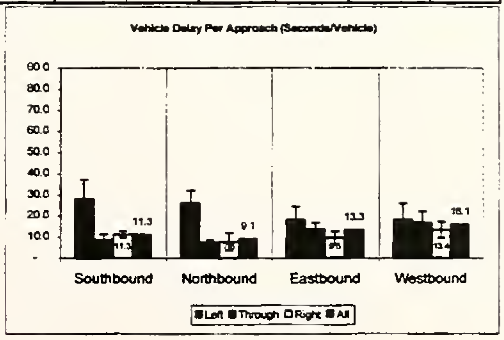
Summary of Meeasures of Effectiveness Average Values:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	5.22	7.45	5.66	3.13	8.79	0.64	71.83	26.20	2.41	2.39	91.28	35.31
2	6	1	Thru ↑	50.54	72.20	54.91	8.79	63.70	0.86	52.93	7.32	4.54	4.45	33.44	47.63
2	6	1	Right ↗	1.79	2.55	1.94	0.35	2.29	0.61	51.10	7.78	0.07	0.07	38.93	44.73
1	6	1	Left ↘	5.55	9.25	6.03	4.30	10.33	0.59	67.02	27.92	3.42	3.34	84.35	32.74
6	6	1	Thru ↓	35.21	58.70	38.25	8.48	46.73	0.82	47.75	8.85	2.98	2.77	24.00	45.35
6	6	1	Right ↙	9.60	16.00	10.43	3.00	13.43	0.78	50.40	11.30	0.36	0.32	42.98	42.89
4	2	1	Left ↗	0.65	5.65	1.13	1.70	2.83	0.41	30.21	18.21	1.43	1.40	60.58	16.59
4	2	1	Thru →	2.49	16.80	3.32	3.82	7.14	0.47	25.62	13.82	2.95	2.89	63.60	21.39
4	2	1	Right ↘	1.30	8.65	1.73	1.37	3.10	0.57	21.52	9.52	0.65	0.63	79.54	25.59
8	4	1	Left ↙	1.76	3.90	2.34	1.13	3.47	0.68	54.08	18.08	0.80	0.80	72.92	30.54
8	4	1	Thru ←	11.74	26.10	15.65	7.42	23.08	0.69	52.76	16.76	4.82	4.83	61.28	31.00
8	4	1	Right ↖	4.14	9.20	5.52	1.98	7.50	0.73	49.38	13.39	0.93	0.87	72.69	32.99

Summary of Measure of Effectiveness Standard Deviations:

	Link		Lane	Vehicle		Vehicle Minutes			Ratio	Sec/Veh		Veh-Min		Average	
Phase	Start	End	Group	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Speed MPH
5	6	1	Left ↖	1.87	2.67	2.03	1.07	3.00	0.05	5.67	5.88	0.85	0.84	9.99	2.79
2	6	1	Thru ↑	2.88	3.61	2.90	1.61	3.69	0.02	1.30	1.29	0.98	0.94	4.46	1.15
2	6	1	Right ↗	1.05	1.50	1.14	0.30	1.40	0.20	12.80	4.16	0.07	0.07	35.22	11.01
1	6	1	Left ↘	1.78	2.94	1.91	1.60	3.35	0.07	9.23	9.23	1.40	1.38	14.82	3.99
6	6	1	Thru ↓	2.63	4.38	2.85	2.57	4.39	0.04	2.63	2.63	1.43	1.29	9.87	2.37
6	6	1	Right ↙	1.84	3.08	1.99	0.65	2.55	0.02	1.47	1.47	0.10	0.09	13.82	1.25
4	2	1	Left ↗	0.33	2.21	0.44	0.87	1.23	0.08	6.17	6.17	0.79	0.77	19.58	3.67
4	2	1	Thru →	0.42	2.82	0.56	1.28	1.75	0.08	3.15	3.15	1.08	1.05	12.24	2.85
4	2	1	Right ↘	0.35	2.32	0.46	0.56	0.92	0.07	3.29	3.29	0.49	0.46	15.49	3.33
8	4	1	Left ↙	0.65	1.45	0.87	0.51	1.24	0.10	7.79	7.79	0.43	0.42	28.85	4.40
8	4	1	Thru ←	1.56	3.48	2.09	2.70	4.42	0.07	5.24	5.25	1.92	1.84	15.23	3.13
8	4	1	Right ↖	1.02	2.26	1.36	0.51	1.62	0.08	3.92	3.91	0.35	0.32	12.63	2.57





Additional Notes:

Period 4 Premption Settings - > 00 Min, 45 Max, 60Reservice, 20 Delay, 13 Inhibit
Platoon Settings - > 16 Vehicles in 15 seconds

F:\Jay\Research\Excel Files\Period4\50%\00-45-60-20-13_16-15\

Figure D-17 Period 4 Configuration B-50