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SIMULATION OF MIDBLOCK TRAFFIC FLOW ALONG AN ARTERIAL WITH
AND WITHOUT A TWO-WAY LEFT-TURN LANE

The Ohio State University

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SIMULATION OF MIDBLOCK TRAFFIC FLOW ALONG
AN ARTERIAL WITH AND WITHOUT
A TWO-WAY LEFT-TURN LANE

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
Aly Salem Heikal, B.S., M.S.

* * * * *

The Ohio State University
1983

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Chapter I
INTRODUCTION

1.1 DIGITAL SIMULATION IN TRAFFIC ENGINEERING

Simulation implies the process of building a computerized model of a system and conducting experiments with the model for the purpose either of understanding the behavior of the system over time or of evaluating potential performance before a newly designed system is operable. The behavior of the real world system is portrayed in the model in terms of entities, their characteristics, interactions among entities, and external relationships connecting the entities with the environment. Exogeneous and endogenous variables are transformed in the system yielding cognate measures of performance. When system simulation is used to study a problem, a system methodology approach is applied. This methodology can be decomposed of four phases: formation of a computer program, validation, experimental design, and analysis of simulated data.

The recent development of computer technology has increased and accelerated the interest in the use of digital computers as a means of simulating traffic flow. Traffic simulation models have been viewed as practical and effective tools for analyzing traffic flows when one considers
factors such as traffic problem breadth and complexity, and the slow, inflexible and costly processes of field data acquisition, reduction and analysis. Models that determine the behavior of existing facilities have become of more interest to engineers because of their ability to quickly, cheaply, reliably, and conveniently depict potential problem areas in a traffic network. A representation of traffic flow on roadway such as single intersection, short sections of freeways, urban arterials, and urban networks could be incorporated in such models.

The success in traffic simulation modelling has led to a dichotomy in modelling approaches: namely microscopic and macroscopic. In microscopic modelling, traffic is portrayed by representing each vehicle using a set of variables and updating this set at fixed time intervals in a manner cognisant of the interactive effect of the surrounding vehicles, roadway geometrics and conditions, and driver behavior. In macroscopic modelling, vehicle attributes are eclipsed as vehicles are grouped into platoons and lose their individual identity. Using this approach, traffic is represented in terms of overall parameters such as average speed, traffic volume, and density. The selection between both modelling approaches involves a trade-off process. While the microscopic approach retains a high level of detail and low modelling complexity, it tends to require substantial computer resources. For an urban traffic system, a microscopic simu-
Simulation approach is recommended. The microscopic simulation model should be representative of the real world system it is modelling, i.e. the simulation model should be designed to replicate the behavior of the individual vehicles in mixed traffic streams, e.g. those that contain turning and through vehicles.

1.2 THE M ID BLO CK T URN PROBLEM

The problem of improving existing roadway networks involves two specific elements: the intersections and the streets. Intersections interrupt the traffic flow along an arterial and they control the ability of each approach to accommodate the flow of vehicles. A Progressive system that synchronizes signals along an arterial improves the quality of flow and reduces, or even eliminates, stops and delays caused by signals. However, other physical interruptions such as roadside development and its access points can have an important influence on traffic operations characteristics.

Midblock friction and its turning movements impede the smooth flow of traffic along an arterial due to the presence of left-turning vehicles. Driveway connections to arterials are actually intersections. Therefore, the efficiency and safety at these connections depend upon the traffic volumes and the access control policy. Access to driveways may include denial of all left turns (entry or exit), left-turn bays, and the two-way left-turn lane.
When turning movements are prohibited, it is important to find alternate paths to fulfill the desired movements; otherwise, longer routes and turbulent driving conditions (while searching for alternate routes) may occur. An excessive amount of travel and delay is always created by around-the-block movements.

Left-turn bays represent a compromised solution which benefits from the already existing traffic gaps without disturbing the flow of traffic. However, two problems limit the use of this type of treatment. As turning movement increases, longer bays are needed to provide enough storage. This, in turn, may block the access to other driveways and the use of these bays becomes more hazardous.

The two-way left-turn lane (TWLTL hereafter) has emerged as a successful treatment to the midblock left-turn problem. The TWLTL refers to the center lane which handles left-turn movements from both directions of an arterial. The major function of the TWLTL is to provide a deceleration and storage lane for left-turning vehicles to driveways thereby alleviating delays and stops for straight through vehicles.

A center lane is economic and advantageous for smooth traffic operations. It is economical because of low construction cost beside it does not need right-of-way acquisition. Operationally, it separates the opposing traffic flows, serves as a deceleration lane for turning vehicles, a pedestrian refuge, and an emergency functions such as detour routes.
Existing warrants for the installation of a TWLTL along an arterial were suggested by Harwood and Glennon (1). The TWLTL is warranted at average daily traffic volumes higher than 10,000 and a total left-turn movements in 1 mile of at least 20% of the through traffic volumes during peak periods. This warrant appears to be empirical without cited origin. Moreover, little research has been conducted to determine the interrelationships between the existing traffic streams. This apparent lack of information is caused by the difficulty in collecting the necessary data.

1.3 REVIEW OF STUDY TECHNIQUES
The emergence of the TWLTL as a special traffic control device to handle midblock turns has stimulated considerable amount of research efforts. Since the first installation of the TWLTL in Seattle, Washington in 1952, there have been many studies and reports about the application of the TWLTL. The literature which has been found and reviewed has generally been found to focus on results of accident studies. Few studies have investigated the operational characteristics of the TWLTL.

Four study techniques have been used to demonstrate the feasibility of providing a TWLTL facility: before-and-after accident studies, regression analysis, operational studies, and simulation studies.
1.3.1 Accident Studies

The objective of an accident investigation is to study and compare the frequency and severity of accidents occurring on arterial streets before and after the installation of the TWLTL. A typical study procedure would include comparing the number and types of accidents which occurred in some time before the TWLTL to the number and types of accidents which occurred in an equivalent period of time after the installation.

Accident studies have shown that there is a great deal of variability in reduction of accidents by introducing the TWLTL. Ray (2) reported a 13-month experience in Sacramento County, California. There was no indication about the involvement of left-turn vehicles in the before study. Sawhill and Neuzil (3) concluded that there was no indication that the number of the TWLTL accidents decreased with the use due to the short after period. However, the total number of accidents was dropped from a range of 60 to 70 to the level of 45 accidents per year in the Airport Way site. Hoffman (4) reported a reduction of 33 percent of the total accidents.

The preceding review revealed two important issues incorporated with the accident studies technique. They are:

1. There is a need for a complete accident history of the study section to provide meaningful results.

2. No quantitative accident reduction figures attributed to the installation of the TWLTL could be drawn from any of the before-and-after accident studies.
1.3.2 Regression Analysis Studies
The purpose of using multiple regression analysis is to provide insight into the characteristics of the sites and parameters used in the analysis. A standard regression analysis provides expressions for predicting the dependent variable (e.g., number of accidents caused by left-turning vehicles).

Shaw and Michael (5) used the regression analysis technique to warrant the construction of a median lane at an intersection by conducting a cost-benefit analysis using predicted delay times and accident rates. A major study was conducted by Walton et al (6) to predict accident rates at TWLTL sections and concluded that by combining midblock and intersection data improved the predictability of equations concerning accidents, accidents severity, and accidents rates.

In summary, the regression analysis has not been widely used to predict accident rates and delay times at a TWLTL section. This technique is subject to a wide variety of independent variables which makes it difficult to set a standard equation applicable to different sites.

1.3.3 Operational Studies
The purpose of this technique is to measure the effectiveness of installing TWLTLs by conducting before-and-after studies and comparing traffic flow parameters. In this re-
spect, two major studies were found: Sawhill and Neuzil (2) and Nemeth (7).

Sawhill and Neuzil (2) indicated the following observations on the driver's behavior related to TWLTs:

1. The average travel distance within TWLT for the local driver is 200-ft and the out-of-town driver is 140-ft.
2. Most drivers enter the TWLT on a reverse curve path and entry is completed within 40-50 ft.
3. Turning vehicles from generators and into the through lanes make little use of the TWLT as an acceleration lane.
4. Few drivers use the TWLT as a passing lane.
5. Many drivers begin to decelerate in the through lanes just before entering TWLT.

Before-and-after studies were conducted by Nemeth (7) at three sites in Ohio. The purpose was to investigate the effect of the TWLT on traffic flow conditions and on safety. The conclusions of the analyses were that the introduction of the TWLT resulted in significant increase in the running speed, and reduction in number of brakings and weavings. The study yielded a step-by-step decision making strategy to implement the TWLTs.

1.3.4 Simulation Studies

Two studies were conducted by McCoy et al (8,9) to study the effect of installing a TWLT along two-lane and four-lane arterials, respectively. The studies were accomplished through the construction of two macroscopic simulation
models: the first with a TWLTL, and the second without TWLTL. Both studies yielded isograms of the stops and delay reductions resulted from installing a TWLTL. Further discussion of both models are provided in Chapter II.

1.4 STUDY TECHNIQUE

Simulation allows a wide class of traffic systems to be modeled in an efficient and parsimonious manner. In this research, simulation was selected as the study technique for the following reasons:

1. A simulation model can test a range of variables under controlled conditions, thus the effect of one variable on the overall system can be determined.

2. A number of measures of performance can be selected and collected thereby providing a means of quantitative evaluation.

3. Manpower costs are negligible in computer.

1.5 RESEARCH OBJECTIVES

The purpose of this research is to develop a microscopic simulation model in order that traffic engineers may use it to predict the operational effects of the TWLTL. The model (ARTSIM hereafter) will simulate traffic operations on a two-way two-lane and a two-way four-lane arterial with and without a TWLTL. ARTSIM will simulate conditions of free-flow, car-following situations, left-turn maneuvers, and lane change. An experimental design procedure will be used to study the impact of the TWLTL on the system's measures of
performance at different levels of each variable. The implementation of the model will include the following three phases:

1. An experimental design procedure will be used to quantify the operational improvements in quality of flow due to the installation of the TWTL;

2. A small scale simulation study will be carried out to identify the effect of driveway distribution along the simulated arterial in phase (1); and

3. The Highway Capacity Manual (36) has recommended an approximate method to determine the level of service along arterials with midblock turning movements. Using conclusions from phases (1) and (2), an alternate method will be developed.

The model will generate statistics of the following measures of effectiveness: travel time, number of stops, stopped-delay time, and number of lane change maneuvers. Other secondary measures of effectiveness, such as the number of utilized maximum deceleration rates and fuel consumption rates, are provided.

1.6 OVERVIEW OF CHAPTERS II, III & IV

Chapter II begins with a brief review of some of the simulation models which have been useful in analyzing traffic systems. The intent of this Chapter is twofold: to demonstrate that studying various types of traffic systems through a generalized model is not of practical use or feasible, and to provide enough theory about advanced concepts in simulation analysis.
Chapter III presents the development of a microscopic simulation model. Using a discrete-event simulation discipline, the traffic flow along a hypothetical arterial is simulated using SIMSCRIPT II-5 language. Since SIMSCRIPT is an event-oriented language, logical relationships which cause changes of state in traffic facility are easy to represent in the model. Vehicles are described in terms of temporary entities. These entities are characterized by their attributes: speed, position, acceleration, destination, and others. Each type of entities is grouped in a set which represents a traffic lane. A car-following model, a lane change logic, and a left-turning maneuver logic are incorporated in the model to provide realistic representation of the real world traffic.

The implementation of the model under various flow rate conditions begins in Chapter IV. A fractional factorial procedure is exercised as a practical means to analyze the effect of the TWLTLs under possible variations in traffic flow characteristics. A new level of service procedure is introduced to provide a more realistic approach to find the level of service at the midblock section. In the final analysis, this procedure constitutes a general approach to traffic systems with different midblock geometrics.
Chapter II
TRAFFIC MODELS AND CONCEPTS OF SIMULATION

2.1 INTRODUCTION

The study of traffic flow using simulation has been pursued extensively by researchers in the Transportation field. Much of this interest has been generated by the difficulties inherent in developing a cost-effective control policy using manual techniques. Since many types of traffic flow problems require more than a standard simulation model, recognition of this fact is best acknowledged by classifying the simulation models by the following four areas of application: (1) Single intersection; (2) Arterial routes; (3) Area traffic control; and (4) Freeway and corridor control.

The intent of this Chapter is to demonstrate that it is difficult to set down a formal simulation model which would be applicable in analyzing most or even all transportation systems. The Chapter will, also, attempt to present some of the major aspects of digital simulation analysis.

The discussion begins in sections 2.2 and 2.3 by reviewing some simulation models which have been useful in traffic studies. It was beyond the scope of this thesis to conduct an extensive review of all simulation models developed to date. Therefore, the discussion that follows will
concentrate on single intersection and arterial route simulation models. Section 2.4 examines the process of building a simulation model. The most important phase in simulation is the production, collection, and interpretation of output data. Some of the ways in which this problem may be addressed will be reviewed in section 2.5.

2.2 SINGLE INTERSECTIONS

The model designed for an individual intersection is a basic component in the single system development for arterial routes and street network. Traffic signals allocate the right-of-way through an intersection according to demand. Considerable number of simulation models have been developed for an isolated intersection to study different operational characteristics and to assess existing or proposed intersection designs. This section provides a brief description of some simulation models and two simulation packages, and summarizes the most important functions of these models.

Kell (10, 11) developed a microscopic simulation model for an orthogonal intersection of two-way two-lane streets. The primary purpose of the model was to evaluate the effect of installing a traffic signal at the intersection on vehicular delay to warrant installing traffic signals. Total intersection delay was the final output of the simulation at different approach volumes and turning movements. The study resulted in developing a multiple regression model relating total delay to street volumes.
A microscopic simulation model was developed by Gerlough and Wagner (12) representing traffic operations at an isolated intersection. A wide range of traffic characteristics at an intersection of two four-lane streets was simulated to determine the effectiveness of various types of control policies, followed by field implementation of the most promising control type. Five control policies were subject to analyses: (1) fixed-time signal; (2) fixed-time optimized; (3) basic queue control; (4) queue-length arrival-rate control; (5) modified space-presence control. The basic queue control compared favorably with the rest of the intersection controllers. Statistical assessment of traffic operations were based on the following measures of effectiveness: delay, travel time, travel speed, queue length.

The TEXAS model: It is the first attempt to provide a microscopic traffic simulation package restricted to simulation of traffic at a single intersection. It was developed by the center for Highway Research at the University of Texas at Austin in 1971 (13). The package exists in a FORTRAN IV version and may be used on both CDC and IBM computers. Emphasis was placed on making the package user oriented and on minimizing computational requirements.

The purpose of this package is primarily to handle a single multi-lane, multi-leg, mixed traffic intersection operating under various control alternatives. These include fixed-time, actuated traffic signal, or sign-controlled
operation. The program has the capacity to simulate 5 driver classes and 15 vehicle classes; 6 approaches with 6 lanes per approach; 1000-ft lane lengths; sight restrictions; uncontrolled operation; 8-phase signal control with skip phase; 2 detector types and 5 detectors per lane; 72 signal intervals.

The program is decomposed of three processors: a geometry processor, a driver-vehicle processor, and a simulation processor. The geometry processor (GEOPRO) stores all geometric details of a simulation run, identifies points of conflict, and determines minimum available sight distance along each approach. The driver-vehicle processor (DVPRO) generates individual driver-vehicle units and describes their characteristics. The simulation processor (SIMPRO) simulates the movement of each driver-vehicle unit in response to geometry, traffic and control policies, and gathers performance statistics.

There are three types of input are required by TEXAS:

1. Input to GEOPRO: title, information about each approach, sight distance restriction, and other options.

2. Input to DVPRO: approach volume, headway distribution, mean and 85th percentile speed, and percentage of turning movements and driver and vehicle type.

3. Input to SIMPRO: output from GEOPRO and DVPRO, simulation parameters, type of intersection control, and input to different driver-based behavior routines.

Linear acceleration and deceleration models, and a noninteger generalized car-following model are used. New simulation
techniques include lane change decision, sight distance restriction checking, and intersection conflict checking are used.

There are two types of outputs available from TExAS:
1. Echo of input cards from GEOPRO, DVPRO, and SIMPRO.
2. Summary statistics include delay, total travel time, total travel distance, speed, maximum queue length, and actuated signal performance.

The SOAP model: The package was developed by the University of Florida Transportation Research Center in 1977 (14). SOAP is a macroscopic model capable of providing and evaluating a wide range of signal control plans at isolated intersections, such as fixed-time and actuated multi-phase signal. The model can analyze two to four-legged intersections with turning movements.

A trial-and-error optimization procedure is used to find the cycle length that produces the minimum delay, subject to queueing constraints. The effective green times for the critical movements are allocated according to the degree of saturation of each movement. The model utilizes Webster's method (15) in computing delay for undersaturated conditions.

Three types of input cards are required by SOAP. They are:
1. Instruction cards - include problem definition, initialization, and some user's options.
2. Parameter cards - include definition of pattern analysis, signal control plan, left-turn type, and necessary information for progression analysis; and
3. Data cards - include minimum green time, queue discharge rate, approach volumes, percentage of buses and trucks.

To design a signal, SOAP examines all possible phasing schemes and selects the one that produces minimum green time. The next step SOAP determines the timing patterns to be implemented. Analysis in SOAP is accomplished by computing the measures of performance that allow the user to quantify the effect of the designed control strategy. The evaluation step provides a comparison of several alternative schemes.

There are three types of outputs available from SOAP. They are:

1. Echo of input data and error messages when appropriate;
2. design recommendations - include phase sequences and length, cycle lengths; and
3. Measures of effectiveness - include delay, degree of saturation, maximum queue length, percentage of stops, excess fuel consumption, and left-turn conflicts.

The aforementioned simulation models have provided a great deal of theoretical background about various aspects of intersection operation and vehicular movements within the intersection. Each model has been developed for a specific purpose and, as a result, direct comparison is not valid.

More recent simulation models have been developed to study left-turn movements at an intersection. Messer and Fambro (16) developed a periodic scan simulation program to investigate the effects of signal phasing and length of
left-turn bay on capacity. Traffic operations were simulated on one intersection approach which included a protected left-turn lane and an adjacent through lane. Two signal phasings were studied: leading and lagging left-turn phase sequences. The study yielded a multiple regression model to estimate the capacity and saturation flow of a given left-turn bay.

Lee and Mulianazzi (17) considered a cost-benefit approach as an appropriate technique to warrant a left-turn lane for priority intersections. Therefore, they developed two simulation models on an uncontrolled intersection of a two-lane two-way street with the minor street controlled by a STOP sign. The first model simulated traffic operations of the intersection without a left-turn lane. The second model simulated the traffic operations of the same intersection approach when a left-turn lane of infinite length was provided for the major street. The purpose of the two models was to provide estimates of the hourly delay time savings due to inclusion of the left-turn lane, and use the left-turn lane length as an input to cost-benefit analysis. The study yielded a step-by-step procedure to decide whether left-turn lane should be provided for the uncontrolled intersection under study.
2.3 ARTERIAL STREETS

The traffic on an arterial is primarily controlled by setting the traffic signal control. Variation in signal control include: (1) signal cycle length; (2) splits; (3) offsets. Other secondary control plans such as re-routting traffic and left-turn denials may be considered.

The primary objective of coordinating traffic signals is to minimize vehicular delay by optimizing the signal coordination. A number of research efforts have been devoted to various aspects of signal coordination along an arterial in attempt to provide ideal coordination under the prevailing conditions. Little has been found to investigate traffic operations on an arterial without signal control plan. It is the objective of this section to give a brief review of some of these studies.

In general, traffic operations are simulated by a collection of intersection models linked together by street segments. These segments extend from the end of the preceding intersection to the next one. Control over the routing of vehicles is accomplished by routing vehicles attributes which specify the paths to be taken by vehicles as they cross the intersection.

Saleeb and Hartly (18) reported a simulation study limited to traffic behavior through two intersections linked by a one-way street. The intersections were controlled by coordinated fixed-time signals. The first intersection was
considered isolated and, therefore, its traffic volume input had a Poisson distribution. The second intersection was fed by the platoons leaving the first one intersection. The effects of different traffic parameters on the mean delay time and mean queue length were investigated. These parameters include offset, degree of saturation, saturation rate, and traffic volume.

A research was conducted by Wagner et al (19) to develop and test several advanced concepts for operating traffic signal systems on urban arterial streets. The TRANS model was used to evaluate 11 alternative traffic signal systems employing various control concepts. The most influential strategic control concept tested was Webster's method for optimizing signal control length and splits. Three methods to design offset plans were tested: the Yardeni time space model, the Little maximal bandwidth method, and the delay / difference-of-offset method. All three methods produced significant improvement in operational effectiveness when applied in combination with the Webster technique. However, they failed to produce significant improvements when applied independently.

The MAXBAND Model: The model has been developed for the Federal Highway Administration (FHWA) by Little and Kelson (20) in April 1980. The purpose of the model is to maximize bandwidth using a mixed-integer optimization formula. The model uses the formula developed by Little (21) with added
set of generalizations. The program is designed to handle arterials and simple three-entry networks that contain as many as 17 signals. The program is written in FORTRAN IV.

In MAXBAND, the user may supply the green splits, or as an alternative, the user can provide the traffic volume and capacity information and the program will calculate the green splits using Webster's method. In this case, the volume and capacity information are provided and classified into 4 through movements and 4 left-turn movements for each intersection.

The basic input to MAXBAND are as follows:

1. Overall problem information: title, range of cycle lengths, etc.
2. Network geometry: order of signals and the distance between them.
3. Green splits (or traffic flows and capacities)
4. Left-turn patterns: leading or lagging time.
5. Queue discharge time as a fraction of the cycle length.

The output of the program is divided into 3 parts: input cards, a data summary, and a solution report. The input section is an echo of the input cards. The data summary section contains the linear programming codes, and summary information for each intersection and link including the general input of the signal control pattern. The solution report contains the following information:

1. An indicator for whether an optimal solution has been achieved.
2. Statistics describing the linear programming elements used to solve the problem.

3. General performance statistics including cycle length and bandwidth, optimal left-turn pattern, duration and offsets of splits, and travel times and speeds on links.

The PASSER II Model: The model was developed to facilitate the design of a progression system along an arterial, and capable of dealing with multi-phase signals. PASSER II is a microscopic, deterministic optimization model developed by the Texas Transportation Institute at Texas A&M University in 1973 (22). The model is written in FORTRAN IV and can be used on IBM 360/370 facilities.

The model computes phase intervals, offsets, and movement demand/capacity ratios to evaluate the level of service at each intersection. The green times are computed by proportioning time according to the volumes plus lost times, subject to the minimum time constraints. The model developers combined the optimized unequal bandwidth mixed-linear programming model developed by Little (21) with methods for handling multi-phase signal.

The basic inputs to PASSER II include turning movements, saturation capacity, and minimum green times for each movement. For progression analysis, distance between intersections, average link speed, queue clearance intervals, and permissible phasing sequences are provided.

The standard output include an echo of the input, progression parameters (optimal cycle length, offsets, phase
sequences and splits, bandwidth in seconds), and speed in each direction as well as two measures of effectiveness: bandwidth efficiency and degree of saturation. As an option to the user, time-space diagrams can be provided.

The Nebraska Model: McCoy et al (8,9) conducted two studies at the University of Nebraska to quantify the effects of TWLTL on the efficiency of traffic flow on two-way two-lane and two-way four-lane arterials, respectively. In each study, two simulation models were developed using GPSS language to simulate traffic operations along an arterial with and without TWLTL.

The input to the two models consist of the following types of information:

1. Traffic characteristics: include traffic volume and average speed in each direction, and percentage of left-turning traffic in each driveway; and

2. Street geometry: include length of street segment, and the number and location of driveways.

In each study, the two models were validated against data collected from street segments in Lincoln, Nebraska. The models showed no significant statistical differences when comparing the simulated and observed mean delay times and number of stops at wide range of traffic characteristics and different street geometry.

The output includes the following data:

1. Number of vehicles entering and exiting the system;
2. Number of attempted left-turns;
3. Number of stops and stopped-delay; and
4. Travel time.

The studies yielded isograms of the reductions in stops and delay at three levels of driveway density: 30, 60, and 90 driveways per mile, and three traffic flow levels: low, medium and high. These isograms were used as an input to evaluate the effectiveness of a TWLTL using a cost-effectiveness procedure.

Discussion: Since the objective of this research is to quantify the operational effectiveness of a TWLTL, the following unfavorable observations are made about the Nebraska models. In the model with TWLTL:

1. A left-turn vehicle remains in the main lane until it reaches its designated entry point to the TWLTL. The entry point is always 80-ft upstream the driveway into which the vehicle enters. Sawhill and Neuzil (3) indicated in their study that a fairly symmetrical distribution was evident for local drivers with an average travel distance of about 200-ft in TWLTL.

2. Once the left-turn vehicle enters the TWLTL, it moves at a speed of 10 mph until it either exits at the driveway or stops behind vehicles already waiting to turn left. The 10 mph speed assumption was found to be unreasonable and without a profound basis. However, Sawhill and Neuzil in their study indicated that a driver may reduce his speed before entering the TWLTL (from 30 mph to 25 or 20 mph). This was due to unpleasant driving over traffic buttons.

In the model without TWLTL, if a left-turn vehicle waits more than 30 seconds searching for an acceptable gap in the opposing traffic, the attempt is aborted and the vehicle traverses the entire segment as if it were a straight-through vehicle. Waiting time more than 30 seconds caused the system to break down especially at high traffic volumes.
Therefore, reduction in stops and delay can not be regarded as accurate and reliable measures.

2.4 REQUIREMENTS FOR DIGITAL SIMULATION

Russell (24) indicated that for simulation to be useful, it should satisfy three conditions:

1. The simulation model has the ability to replicate the essence of the real world system without extraneous modelling yet inserting the important features of the system;

2. The simulation language offers the ability to reduce the programming and project time by allowing easy programming structure; and

3. The results of simulation must be displayed in a meaningful and convenient form to the user.

The development of a simulation model involves several steps:

2.4.1 Simulation Goals

Since the purpose of studying a system will determine the nature of the information that should be gathered, there is no unique model of a system. Different models of the same system may be produced by different analysts to study different aspects of the system as shown in sections 2.2 & 2.3. Thus, defining simulation goals has to be clearly specified. Definition of goals means describing relationships which need to be studied in the system and expressing the system performance by gathering information as functions of the variables of the system. In traffic,
effectiveness are considered: travel time and speed, acceleration noise, number of lane changers, average queue length, and level of service.

2.4.2 System Modelling

The task of deriving a model of a system may be divided into two subtasks: establishing model structure, and describing system dynamics. Establishing model structure determines the system layout and identifies the entities, attributes, and activities of the system. System layout may include: geometrics, traffic characteristics, driver behavior, and vehicle performance. An actual vehicle on the highway is a physical entity. Its speed, acceleration and position are unique attributes of each vehicle. Describing system dynamics includes the values of attributes and system layout, and the relationships involved in the activities in the model.

2.4.3 Simulation Languages

All formal simulation languages have unique characteristics. Some are better suited for certain classes of problems than others. The relative importance and usefulness of a simulation language to a potential user is a function of the user's interests and modelling goals. All users, however, are generally interested in the following common criteria of a language:

1. It facilitates model construction and formulation.
2. It is easy to learn and use.
3. It provides adequate debugging and error diagnostics.
4. It can be used to a wide range of problems.

A number of programming languages have been produced to simplify the task of writing discrete system simulation programs. A list of 4 languages will be found in reference (23). Each language is based upon a set of concepts used for describing the system.

The user of a program must learn the different concepts of the particular language he is using and be able to describe the system in terms of these concepts. Given such a description, the simulation programming system is able to establish a data structure that forms the system image. Routines are supplied to represent the activities in the system, such as scanning events, updating the clock, gathering statistics and maintaining events in time and priorities.

In general, most simulation languages view the world in terms of entities with attributes and activities. It was beyond the scope of this section to discuss all the simulation languages that are available. Instead, the discussion will be limited to two languages: GPSS and SIMSCRIPT II-5. The reason for choosing these two languages is that GPSS is among the most widely used languages in traffic simulation models, and SIMSCRIPT is the language negotiated to implement in this dissertation.
2.4.3.1 GPSS (General Purpose Systems Simulation)

GPSS is a simulation language originally developed by G. Gordon for the IBM Corporation in the early 60s and has been evolved through several versions to the latest version in 1975.

**General Description:** The system to be simulated in GPSS is described as a block diagram in which the blocks represent the activities, and lines joining these blocks indicate the sequence in which the activities can be executed. Where there is a choice of activities, more than one line leaves a block and the condition of choice is stated at the block.

**Scanning Times:** Clock time is represented by an integer number, with the interval of real time corresponding to a unit of time chosen by the user. The scanning time may be a fixed time or a random variable, and it can be made to depend upon conditions that exist in the system.

**Events:** The program maintains records of when each event in the system is due to move. It proceeds by completing all movements that are scheduled for execution at a particular instant of time that can be performed. Where there is more than one event due to move, the program processes events according to a priority discipline system. When all events at an instant of time are executed, the program advances the clock to the time of the next most imminent event and report the process of executing events.
2.4.3.2 SIMSCRIPT II-5

The SIMSCRIPT simulation language was developed by H. M. Markowitz in the early 1960s, and has evolved through several versions to the latest and most powerful version SIMSCRIPT II-5 (24). SIMSCRIPT is a complete programming language. It requires a special compiler and is available on certain computer systems: CDC/6000-7000, IBM S/360-370, UNIVAC/1100, and VAX.

General Description: In describing the system, SIMSCRIPT uses the entities and attributes concept. For reasons of programming efficiency, it distinguishes between temporary and permanent entities. The former type represent the entities that are short lived in the system; they are created and destroyed during the execution of the program. The latter type represent the entities that remain during the run. The user can define sets linking group of temporary entities having a common property. Sets facilitate entering and removing entities from the system.

Activities are considered extending over time with their beginning and ending marked as events occurring instantaneously. Each type of event is described by an event routine.

The Timing Routine: The event notices are filed in chronological order. Whenever an event relinquishes control, the program automatically returns to a section of the program
that selects the next event notice. The clock is updated to the time of that event and control is passed to the event routine associated with the event notice. If there should be no event notices, the program assumes the simulation is complete and relinquishes control to the MAIN routine.

2.4.4 Validation

The user expects the results of the simulation to approximate the performance of the system being studied if the actual system could be observed. Therefore, the question of validity is an important one. The simplest and most direct means of validation is to obtain measurements from an actual, operating highway facility, model the facility using the simulation model, and to compare the output with that collected from the field. Tests of statistical significance are usually used to compare the two sets of measurements at a certain level of acceptance. Elements of validation may include the following:

1. Headway distributions;
2. Running speed, including mean, variance;
3. Lane Change frequency; or
4. Queue clearance interval.
2.5 ADVANCED CONCEPTS IN SIMULATION ANALYSIS

The actual construction, debugging, and production of a workable simulation model is only a starting point for more comprehensive simulation analysis. Several advanced areas of digital simulation analysis are as follows: Design of computer simulation experiments, Variance reduction techniques, Statistical analysis of simulation output, and Optimization of simulation parameters.

2.5.1 Design of Simulation Experiments

Once a simulation model has been constructed and meaningful system statistics are being generated, the user may be interested in learning more about the behavior of the system being studied. In particular, it might be desirable to quantify the effects of deliberately changing relevant parameters over a given set of system's measures of performance. Therefore, experimental designs are used to analyze, quantify, and predict the effects of the various parameters involved.

The primary purpose of experimental designs is to determine which variables are most important, how these variables influence the response of the simulation model. Experimental design procedures can be distinguished in the following manner:

Screening of the important factors: This process is suited for investigating many factors by selecting fewer number of combinations using the following designs:
1. $2^{k-p}$ designs: All k factors are at 2 levels and only a fraction (k-p fraction) is examined.

2. Random design: The combinations of factor levels are randomly selected from among all possible combinations.

3. Supersaturated design: The combinations are selected so that the cognate measures of performance are as good as possible.

4. Group-screening design: All k factors are combined in g groups then these groups are examined using 2 design or supersaturated design.

Further investigation of the important factors: After the selection of the important factors based on one of the above screening designs, two designs are used to keep the number of combinations small:

1. $2^{k-p}$ design: Same as discussed in the screening process.

2. Response surface design: These designs combine the $2^{k-p}$ design with additional combinations so that a response (i.e. a regression model) may be developed as a function of the independent variables.

The reader is referred to (25) for further discussion of these designs.

2.5.2 Variance Reduction Techniques (VRT)

Simulation experiments are designed in order to gain meaningful information about certain aspects of the system under study. For example, in simulating an isolated intersection one might be interested in the expected waiting time or the queue length which develops during the red time interval. Now, since simulation is a random process, the output
printed at the end of a simulation run would of a random variable. Therefore, simulation output always contains statistical fluctuation. A variance reduction technique is one which reduces the inherent random deviation in the statistical output. Or more precisely, a VRT reduces the variance of the system variants by replacing the original sampling procedure by a new procedure that yields the same expected value but with a smaller variance. Shannon (26) and Kleijnen (25) reviewed the basic techniques developed in variance reduction methods. They include:

**Common Random Numbers:** This technique is applicable when the problem is to compare two alternatives where we are interested in the relative difference between the two systems rather than the absolute value of either one. The variance of the difference between the estimated response of system 1, \( \bar{X} \), and the estimated response of system 2, \( \bar{Y} \), is given by:

\[
\text{Var}(\bar{X} - \bar{Y}) = \text{Var}(\bar{X}) + \text{Var}(\bar{Y}) - 2\, \text{Cov}(\bar{X}, \bar{Y})
\]

Hence, this variance is decreased if the covariance term is positive. This can be accomplished by the control of the random numbers during the two runs.

**Antithetic Variables:** This technique tries to create a negative correlation between two observations, one is generated using the random number \( r \) and the other observation is generated from the "antithetic" partner \((1-r)\). This negative correlation between the two observations is desirable
to decrease the variance of the estimated mean. The mean response of a system from the two runs is estimated by:

$$\bar{X} = \frac{1}{2} (X_1 + X_2)$$

Where $X_1$, $X_2$ are the responses of run 1 and run 2, respectively. The variance of the estimate $\bar{X}$ is given by:

$$\text{Var} (\bar{X}) = \frac{1}{4} (\text{Var}(X_1) + \text{Var}(X_2) + 2 \text{Cov}(X_1, X_2))$$

Hence, the variance of $\bar{X}$ decreases if $X_1$ and $X_2$ are negatively correlated.

**Importance Sampling:** The basic idea is to disturb the original sampling process using another one. This distortion is corrected by weighting factors to account for using a different process, so that the average of the corrected observations is still unbiased estimator of the mean of the original process. The difficulty in using this technique is in choosing the appropriate distorted distribution.

**Stratified Sampling:** The distribution function to be sampled is broken up into several classes according to an extra variable called the stratification variable, each class is sampled separately, and the results are combined into a single estimate. The size of each class can be determined by dividing the total simulation interval into a number of equally sized classes, or to choose classes such that the variance is the same for each class. If a class is known by great variability, a large number of samples would be required to improve the precision of the estimate. The
unbiased estimate of the population mean, \( \overline{X}_{ST} \), is defined as:

\[
\overline{X}_{ST} = \sum_{k=1}^{K} p_k \overline{X}_k
\]

where \( p_k \) is the probability that an observation belongs to the \( k \)th class, and

\( \overline{X}_k \) is estimated mean of the \( k \)th class.

The variance of the stratified estimator is given by:

\[
\text{Var} (\overline{X}_{ST}) = \sum_{k=1}^{K} p_k \left( \frac{\sigma_k^2}{n_k} \right)
\]

where \( \sigma_k^2 \) is variance within a stratum

\( n_k \) is number of observations in a class.

To determine the confidence interval for the population mean:

\[
\overline{X}_{ST} + t_{\alpha} S(\overline{X}_{ST})
\]

where \( t_{\alpha} \) may be determined from the table for Student's t-statistic.

2.5.3 **Statistical Analysis of Simulation Output**

The values of most, or even all, system variables will fluctuate as the simulation proceeds, so that no one measurement can represent the value of a variable. Because of the experimental nature of simulation, it seems natural to apply statistical methods to simulation results. The purpose here is to review the methods being used in analyzing simulation results. A more comprehensive discussion of the statistical aspects can be found in Ref.(25).
Simulation Run Statistics: In a simulation run, the simplest approach to estimate the mean of a variable is by accumulating n successive values and dividing by n. It should be noted that some variables such as waiting time in a queue depend on the waiting times of its predecessors. These variables are said to be autocorrelated.

Another problem that might be faced is nonstationary distributions. When a simulation run is started, the system is idle and service time is minimum. So, a sample that includes early arrivals will be biased. The bias diminishes as the length of the simulation run is extended, and the sample size increases.

Replication of Runs: One way to obtain independent results is to repeat the simulation. Repeating the experiment with different random numbers gives a set of independent determinations $X_i$ (i = 1, ..., n) of the sample mean. The overall average, $\overline{X}$, of the averages is estimated as

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

The Student's t-statistic can be used to construct a confidence interval as follows:

$$\overline{X} \pm t_{\alpha} \frac{S_X}{\sqrt{n}}$$

Where $S_X$ is the standard deviation calculated from the $X_i$.

Elimination of Initial Bias: Two approaches can be taken to remove the bias: the system can be started in a more representative state than the empty state, or the first part
of the simulation run can be removed. The later approach is the more common one. The run is started from an idle state. After a certain period of time, all accumulated statistics are cleared out, retaining the values of the attributes associated with the entities remaining in the system at the end of that time. The initial interval is determined by a trial-and-error procedure.

**Continued Run:** Three approaches can be employed to analyze a prolonged run: independent subruns, estimation of serial correlation, and independent blocks. In the independent subruns, the long continued run is divided into n subruns after discarding the transient observations of the run. To minimize the correlation among subruns, a subrun should be long enough so that the correlations can be neglected for practical purposes. The alternate approach is to estimate the correlation among the individual observations in the whole run. Hence variance serial correlation coefficients are utilized to estimate the variance of the run. In the third approach, a block is formed when the system returns to its empty state, including the transient state. So the block size depends on the return to the empty state.

**Batch Means:** The batch means procedure establishes confidence intervals for simulation results without relying upon replications. The procedure utilizes a single long
run, preferably with the initial bias removed, divided into a number of segments to separate the observations into batches of equal size. The sample means are treated as independently, identically distributed variables. The batch means procedure has the advantage of repetition. However, it is necessary to assume that the individual batch means are independent. This assumption can be justified if the batch length is sufficiently long. The effect of autocorrelation between two successive batches diminishes as the separation between the data increases, and it can be ignored if the interval size is long enough. The reported experiments using the batch means procedure have shown superiority over the replication method.

2.5.4 Optimization of Simulation Parameters

Although simulation is primarily a tool for system analysis, it may be employed in systems optimization. Optimization of simulation experiments can be achieved through an interface with a linear and non-linear programming technique.

2.6 SUMMARY AND DISCUSSION

Progress in traffic flow simulation has been in the direction of including more driver characteristics and environmental factors in the model and utilizing stochastic rather than deterministic models. Most available traffic flow
models, as discussed in this Chapter, have been limited to general rather than specific problems. Unfortunately, there is a wide variety of geometrics and traffic flow conditions that can not certainly be encompassed in one general model.

The review of the available models revealed that the only efforts directed towards studying the effect of the TWLTLs have lacked the following:

1. The models are macroscopic type, that is, the inter-vehicle relationships and driver behavior and response under variety of traffic volumes have not been addressed.

2. The assumptions made regarding the left-turning vehicle behavior prior to and during occupying the TWLTL do not match those obtained from the field, which may limit the reliability of the results.

3. There is no enough measures of performance to quantify the effect of the TWLTL. Measures of potential conflicts and stopped-delay times as well as savings in fuel consumption need to be collected. Effect of the TWLTL on the outside lanes and on left-turning vehicles have been ignored.

4. The problem of capacity and level of service have not been investigated.

5. There is a need for a more comprehensive controlled experimentation to guide future research toward the more critical problems.

The following Chapter presents two steps in attacking these problems, the first involving development of a microscopic simulation model with and without the TWLTL, and the second involving application of the model by means of experimental design procedure to assess the parameters effects on the overall system.
Chapter III
DEVELOPMENT OF THE ARTSIM MODEL

3.1 GENERAL

A simulation model has been developed to investigate various aspects of the TWLTL operation and vehicular movement along an arterial. The ARTSIM model considers a two-way arterial section with two lanes in each direction without any traffic signals. The model utilizes the information obtained from the literature. The effects of installing a TWLTL are expressed in terms of the delay to straight-through vehicles.

3.2 MODEL FORMULATION

This section describes formulation and testing of the simulation model. The following assumptions regarding vehicular flow are embedded in each model:

1. Traffic consists of passenger cars of similar dimensions and operating characteristics.

2. Lane changing is permitted from the inside and outside lanes except into the TWLTL where only left-turning vehicles move from the inside lanes to the TWLTL.

3. All vehicles enter the system with an actual speed depending upon car-following behavior.
3.2.1 Road and Vehicle Representation

A sketch of the simulated arterial is shown in Figure (3.1). To avoid a breakdown in the system due to queue buildup, the approach lengths should be long enough to accommodate the buildup of traffic behind a turning vehicle in the case without TWLT. Some short trial runs disclosed that as traffic volumes approached capacity (as will be seen in section 4.2), the storage capacity of the inside lanes was exceeded and resulted in some abnormal model behavior. Therefore, additional revisions were made by dividing the approach length into two separate segments: the first is 250-ft and is chosen based on the field observation that a left-turn vehicle starts entering the TWLT at an average distance of 250 ft upstream of its intended driveway (3), and the second is user specified and depends on the traffic flow (a range of 150-300 ft is recommended based on the results from some short trials). The simulated arterial is assumed to be straight and level, and far from traffic signals.

Vehicles travelling North are generated at section 1-1, while those travelling South are generated at section 4-4. Vehicles are assumed to be traversing along the center line of the lane. As a vehicle is processed in the system, its position is increased and its speed is updated.

Straight-through northbound vehicles exit at section 4-4, while left-turners from lane 3 exit at the left-hand
Figure 3.1- Geometry of simulated arterial with TWLTL
side driveways. Southbound vehicles exit at section 1-1, while turning vehicles exit at the right-hand side driveways. Sections 2-2 and 3-3 represent the end of the approach lengths and the point at which some turning vehicles from lane 3 and lane 2 respectively, start entering the TWLTL to exit at the first driveway.

For easy identification of the vehicle being processed, its name is a composite of the lane number and direction of travel, e.g. NB3 type is a northbound vehicle travelling on lane 3.

Two types of movements are experienced in the inside lane. First, a vehicle traverses the entire arterial segment and exits at the end of the segment. Second, a vehicle traverses a portion of the segment and exits at either side by turning left. No right turns are permitted in the model.

3.2.2 Vehicle Arrival Generation

Vehicles are generated randomly at the entry points of each direction on a per-lane basis using a shifted negative-exponential distribution. This distribution is shown in Figure (3.2) and has the form:

\[ P( h \geq t ) = \exp \left( -\frac{(t-T)}{(\bar{h}-T)} \right) \]

Where \( p(h \geq t) \) = probability that a headway is greater than or equal to \( t \)

\( \bar{h} \) = minimum intervehicular headway (see Figure 3.2), and

\( \bar{h} \) = average headway (seconds/veh)
Figure 3.2- Plot of shifted negative-exponential distribution
Dawson and Chimini indicated in their study (27) that the average minimum headway between free flowing vehicles was held constant at a value of 0.75 seconds at all flow rates from 150 to 1050 vph.

The inverse transformation method was used to generate random headways from the aforementioned distribution. In doing so, the cumulative distribution function $F(t)$ is first obtained as:

$$F(t) = 1 - \exp\left(-\frac{(t-T)}{(\sigma-T)}\right)$$

By generating a random number $r$, and setting $F(t)=r$, headway $h$ can be determined from the following expression:

$$h = T - (\sigma-T)\ln(1-r)$$

As each vehicle is generated, its flow characteristics are determined randomly; impending turning movement type, target speed, and lane change probability. All left turners are assumed to be travelling in the inside lane since generation time based on the assumption that every driver would select a lane consistent with his intended turning movement. Therefore, a left turner shall travel in the inside lane and will not change it until entering the TWLTL. The turning movement is randomly determined from the input left turn probability, together with its destination by randomly choosing one of the driveways. The target speed is also determined randomly from a truncated normal distribution. The lane arrival time is set to the current simulation time, and the lane change probability is randomly determined for each
lane from the input lane change probability. Refer to Figure (3.3) for a complete list of attributes of the NB3 vehicle unit. Similar attributes are defined for the SB2 type. The NB4 and SB1 types will carry same attributes without those concerning the left turning maneuver.

Some attributes are determined once a vehicle is generated, such as lane arrival time, others are determined every scanning time, such as speed, acceleration and position. Initially, the vehicle is given a position zero (at the entry point). Its actual speed is determined depending on the position and speed of the lead vehicle. If it does not have a leader or its target speed is less than the actual speed of the leader, the vehicle is given its target speed. Otherwise, the car-following rule is checked. If the rule is satisfied, the vehicle is given its target speed, otherwise it is given the actual speed of its leader. Thus, the speed and position of the new vehicles are determined.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link arrival time</td>
<td>AR3.TIME</td>
</tr>
<tr>
<td>Current speed (ft/sec)</td>
<td>V3</td>
</tr>
<tr>
<td>Target speed (ft/sec)</td>
<td>TGTV3</td>
</tr>
<tr>
<td>Current position (ft)</td>
<td>X3</td>
</tr>
<tr>
<td>Acceptable gap size</td>
<td>GAP3</td>
</tr>
<tr>
<td>Acceptable lag size</td>
<td>LAG3</td>
</tr>
<tr>
<td>Probability of turning left</td>
<td>PRLT3</td>
</tr>
<tr>
<td>Position where entering TWLTL</td>
<td>PSLTM</td>
</tr>
<tr>
<td>Time when entering TWLTL</td>
<td>TSLTM</td>
</tr>
<tr>
<td>Maximum allowable turning speed</td>
<td>VMAXT</td>
</tr>
<tr>
<td>Turning radius</td>
<td>R3</td>
</tr>
<tr>
<td>Flag to mark if vehicle has found a suitable gap</td>
<td>FLG</td>
</tr>
<tr>
<td>Location of intended driveway</td>
<td>EXIT</td>
</tr>
<tr>
<td>Arterial segment where a turning vehicle searches for a suitable gap</td>
<td>GS3</td>
</tr>
<tr>
<td>Probability of lane changing</td>
<td>PRLC3</td>
</tr>
<tr>
<td>Time a lane-change maneuver started</td>
<td>TLC3</td>
</tr>
<tr>
<td>Acceptable lag size for a lane-change maneuver</td>
<td>LCLAG3</td>
</tr>
<tr>
<td>Flag to mark if vehicle has switched its lane</td>
<td>B3</td>
</tr>
</tbody>
</table>

Figure 3.3 List of attributes of the NB3 vehicle type
3.2.3 Car-following Algorithm

The dynamics of a single-lane traffic stream can be replicated in a simulation model through the implementation of a car-following algorithm. The basic equation of this algorithm has the form:

\[ \text{Response } (t+T) = \text{Sensitivity } \times \text{Stimulus } (t) \]

Where response \((t+T)\) is the reaction of a driver to the motion \((\text{stimulus}(t))\) of the vehicle immediately preceding him. The driver's reaction is limited to the change of speed in proportion to the magnitude of the stimulus.

Two different routines are used to handle vehicle behavior. First, free behavior routine which is applied only to those vehicle whose motion is not influenced by a lead vehicle that is in motion. This routine applies when the vehicle is the leader of a platoon, or when its lead vehicle is at least 200-ft away from it. When any of the previous conditions do not apply, a car-following routine is invoked.

In the car-following routine, a vehicle responds to a lead vehicle according to a stimulus-response equation. The car-following algorithm used in this research closely follows the INTRAS model developed by Bullen and Athol (28) with minor modifications. In this algorithm, the response of the subject vehicle depends on the separation between the vehicle and its leader and their respective speeds at the
time when the subject vehicle is processed. The safe space headway is assumed to be:

\[ 10 + L + kv + bk(u-v) \]

where \( L \) = car length in feet; 
\( v \) = speed of the subject vehicle at time \( t \); 
\( u \) = speed of the lead vehicle at time \( t \); 
\( k \) = driver sensitivity, and 
\( b = \begin{cases} .10 & \text{if } u-v \leq 10 \\ 0 & \text{otherwise} \end{cases} \)

The car-following model is concluded from the previous equation and has the form:

\[ a = \frac{2(x-y-L-10-v(k+T)-bk(u-v))}{(T+2kT)} \]

where \( a \) = acceleration of the subject vehicle 
\( T \) = scanning interval 
\( x \) = position of the leader at time \( (t+T) \) 
\( y \) = position of the subject vehicle at time \( t \) 
\( u \) = speed of the leader at time \( (t+T) \)

In a scanning interval, the position and speed of the leader are first determined at time \( t+T \); the acceleration of the subject vehicle at time \( t \) is then determined using the car-following model. The position and speed of a vehicle is always updated using the following equations:

\[ y(t+T) = y(t) + u(t)T + 0.5a(t+T)T \]
\[ u(t+T) = u(t) + a(t+T)T \]
The calculated acceleration value is modified if it violates the constraints of the speed profile provided by the Transportation and Traffic Engineering Handbook (29) and shown in Table (3.1).

Two initial operational tests were carried out to test the stability of the algorithm. A platoon of five vehicles was run down in a single lane in a steady state at initial speeds of 52 ft/sec and spacings of 75-ft with driver's reaction time of 0.75 seconds. In the first test, an acceleration of -8.0 ft/sec/sec was applied to the lead vehicle until its speed was decreased to 24 ft/sec; deceleration rate was applied for 3.5 seconds. Then, a zero acceleration for 3 seconds and an acceleration of 4.85 ft/sec/sec was applied until the first vehicle reached its initial speed of 52 ft/sec. The response of the following vehicles was determined using the car-following model. The test terminated when all vehicles reached their initial speed of 52 ft/sec.

In the second test, an acceleration of -8.0 ft/sec/sec was applied to the lead car until its speed reached 24 ft/sec. Then a zero acceleration was applied until the end of the test.

Figures (3.4) through (3.7) show the response of the individual cars using speed vs time and space headway vs time. The results show that the algorithm's behavior exhibits stabilities to different driving behaviors since damped spacing oscillation is achieved in both cases.
Table 3.1

Normal Acceleration and Deceleration Rates for Passenger Cars

<table>
<thead>
<tr>
<th>Speed Change (ft/sec)</th>
<th>Acceleration (ft/sec/sec)</th>
<th>Deceleration (ft/sec/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 45</td>
<td>4.85</td>
<td>7.8</td>
</tr>
<tr>
<td>45 - 60</td>
<td>4.85</td>
<td>6.6</td>
</tr>
<tr>
<td>60 - 75</td>
<td>3.00</td>
<td>4.85</td>
</tr>
</tbody>
</table>
3.2.4 Gap Acceptance Behavior

The algorithm processes the subject vehicle which is attempting to execute an unprotected left-turning maneuver to its intended driveway. Turning vehicles accept gaps in the oncoming traffic streams based on a gap acceptance distribution.

Each left turner, upon generation, is assigned a gap and lag acceptance value from a gap and lag distribution table. Gerlough and Wagner (12) made use of a specific left-turn gap acceptance distribution and a lag acceptance distribution which are used in this research. These distributions are shown in Table (3.2).

A left turner enters the TWTL on a reverse curve path 250-ft prior to exiting. While entering it traverses a distance of 40-50 ft after initiating its lane change maneuver. It then travels another 150 ft until it reaches the start free-left-turn position. If the left turner is first in the TWTL, a decision is made to accept or reject a time lag (i.e. time required for the first through vehicle in the oncoming traffic to cross the center line of the driveway). If the lag is accepted, the vehicle continues through the turn and exit the system. Turns are assumed to follow a 90-degree circular arc. If the lag is rejected, the vehicle initiates deceleration at a constant rate required to ensure a smooth stop at the proper position for exiting the TWTL. There-
Figure 3.4 - Platoon behavior in test No. 1: speed vs time
Figure 3.5-Platoon behavior in test No.1: space headway vs time
Figure 3.6-Platoon behavior in test No.2: speed vs time
Figure 3.7 - Platoon behavior in test No.2: space headway vs time
### Table 3.2

**Gap and Lag Acceptance Distributions**

by Left Turning Vehicles

<table>
<thead>
<tr>
<th>Gap or Lag Size (Sec)</th>
<th>Probability of Accepting Lag</th>
<th>Probability of Accepting Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 - 3.5</td>
<td>0.03</td>
<td>0.15</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>0.124</td>
<td>0.32</td>
</tr>
<tr>
<td>4.0 - 4.5</td>
<td>0.300</td>
<td>0.52</td>
</tr>
<tr>
<td>4.5 - 5.0</td>
<td>0.530</td>
<td>0.69</td>
</tr>
<tr>
<td>5.0 - 5.5</td>
<td>0.730</td>
<td>0.82</td>
</tr>
<tr>
<td>5.5 - 6.0</td>
<td>0.860</td>
<td>0.90</td>
</tr>
<tr>
<td>6.0 - 6.5</td>
<td>0.940</td>
<td>0.95</td>
</tr>
<tr>
<td>6.5 - 7.0</td>
<td>0.970</td>
<td>0.97</td>
</tr>
<tr>
<td>7.0 - 7.5</td>
<td>0.990</td>
<td>0.986</td>
</tr>
<tr>
<td>7.5 - 8.0</td>
<td>0.996</td>
<td>0.993</td>
</tr>
<tr>
<td>8.0 - 8.5</td>
<td>0.999</td>
<td>0.997</td>
</tr>
<tr>
<td>8.5 - 9.0</td>
<td>1.00</td>
<td>0.998</td>
</tr>
<tr>
<td>9.0 - 9.5</td>
<td>1.00</td>
<td>0.999</td>
</tr>
<tr>
<td>9.5 - 10</td>
<td>1.00</td>
<td>1.000</td>
</tr>
</tbody>
</table>
after, the driver considers each gap appearing in the oncoming traffic and determines its acceptability. If the gap is acceptable, the vehicle starts a left turn maneuver and exits the system.

If, on arriving at the start-free-left-turn point, the vehicle has a leader, it then initiates a stop at a determined position behind its leader and a queue discharge logic is invoked.

In the case without TWLTL, a left turner keeps on travelling in the inside lane until he crosses the start-free left-turn point and negotiates a left turn maneuver as described above.

Other behavior conditions (such as stopping in queue) that may precede the foregoing standard left-turn maneuver have been included.

The decision to determine gap acceptance is accomplished in the following manner: A random number (between 0 and 1) is generated. This number is the probability of accepting a gap of size x which is obtained from an auxiliary gap acceptance table. This gap is kept constant until the vehicle exits the system. This gap is compared with the available gap. If the driver's gap is larger, the available gap is rejected. Otherwise, it is accepted and the driver starts exiting the system. With this procedure, there is no possibility that a vehicle will accept a gap smaller than one that was rejected before. Dart (30) found that 10% of
left turners accepted gaps 1-sec smaller than the largest gap rejected.

3.2.5 Lane Change Rules
Lane change is permitted under limited conditions. The likelihood of doing so is generated randomly at the time of generation. The only vehicles that can be potential lane changers are through vehicles. A vehicle may change its lane only to increase its actual speed. Two types of lane change are dealt with; changing while moving and changing from a stopped position. Three conditions have to be satisfied before a moving vehicle initiates its lane change maneuver (see Figure (3.8)):

1. Vehicle 3 travelling at a speed lower than its target speed checks the speed of the potential new leader in the receiving lane (vehicle 1) so as to pass a slower leader (vehicle 2). The purpose of this step is to prevent oscillatory lane changing. If the actual speed of this potential new leader is lower than that of the current leader, vehicle 3 will not change its lane.

2. The changing vehicle must satisfy the car-following rule in order to occupy a safe position at the end of the lane change. In this class of lane change, a changing vehicle will have a zero acceleration, i.e. it can change lanes without changing its current speed.

3. A similar check must be carried out with the potential new follower in the receiving lane. The car-following rule is checked so that the changing vehicle can safely pull over ahead without forcing the new follower to lower its speed.

In the case of a lane changing vehicle from a stopped position, it checks to see if a vehicle in the adjacent
Figure 3.8 The lane changing vehicles
receiving lane is located in the zone it must move. Then, it determines the expected travel time to the conflict zone of the next vehicle in the receiving lane. The decision to accept or reject this lane change lag is made probabilistically by reference to a lag acceptance distribution. This distribution, used in this research, is shown in Table (3.3). Gerlough and Wagner (12) made use of an identical probability distribution in an analogous situation.

Potential lane changers are selected using the following procedure: A random number (between 0 and 1) is generated. This number is the probability of lane change. If this number is greater than the input lane change probability, the vehicle is not a potential lane changer. Otherwise, the vehicle will be assigned a lag acceptance probability using the same procedure utilized for left turners.
Table 3.3

Lane Change Decision Distribution
From a Stopped Position

<table>
<thead>
<tr>
<th>Lane Change Lag (Sec)</th>
<th>Probability of Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 - 2.5</td>
<td>0.09</td>
</tr>
<tr>
<td>2.5 - 3.0</td>
<td>0.18</td>
</tr>
<tr>
<td>3.0 - 3.5</td>
<td>0.31</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>0.49</td>
</tr>
<tr>
<td>4.0 - 4.5</td>
<td>0.66</td>
</tr>
<tr>
<td>4.5 - 5.0</td>
<td>0.81</td>
</tr>
<tr>
<td>5.0 - 5.5</td>
<td>0.90</td>
</tr>
<tr>
<td>5.5 - 6.0</td>
<td>0.96</td>
</tr>
<tr>
<td>6.0 - 6.5</td>
<td>0.985</td>
</tr>
<tr>
<td>6.5 - 7.0</td>
<td>0.995</td>
</tr>
<tr>
<td>7.0 - 7.5</td>
<td>0.999</td>
</tr>
<tr>
<td>7.5 - 8.5</td>
<td>1.000</td>
</tr>
</tbody>
</table>
3.2.6 Turning Performance

A turning vehicle ceases operating under the car-following conditions when it is the first vehicle in TWLTL or when there is no leading vehicle in the segment between its position and its intended destination in the case without TWLTL. When this occurs, a turning vehicle undertakes an independent fixed turning schedule.

When a vehicle moves in a circular path, it is forced outward by a centrifugal force. At grade intersections, side friction between the tires and the pavement surface is the only component that resists the centrifugal force. Therefore, the principal requirement is that a turning vehicle must not exceed a certain maximum speed during the turn. In order to comply with this requirement, a turning vehicle decelerates (accelerates) to reach its maximum turning speed exactly at the start-free left-turn position. Maximum turning speed is related to turning radius "R" and coefficient of side friction "f" by the equation:

\[ v = fgR \]

where \( v \) = maximum turning speed; and
\( g \) = acceleration of gravity.

The AASHTO Policy on Geometric Design (31) recommends a side friction factor \( f = 0.30 \) for medium speeds. Therefore,

\( v = 9.66R \)
where \( v \) is the maximum speed in ft/sec and \( R \) is in ft. Maximum turning speed will be maintained throughout the turn until it exits the system at the driveway. This does not imply that all turning vehicles will make their turns at maximum speed. Some vehicles will be affected by other conditions such as standing in a queue. Those vehicles will make turn at lower speeds.

3.2.7 Stopping Performance

Two types of stops occur: (1) stopping as the first car in the queue, and (2) stopping behind another stopped vehicle. In the first type, the vehicle is a left-turner and it decelerates at a constant rate required to bring the vehicle to a complete stop at a precisely defined position, usually at the proper position for exiting in either case. A similar model is employed for the second type, i.e. stopping behind another stopped vehicle. The principal difference is that vehicles stop at a position behind the previously stopped vehicle, with 3-5 ft clearance. This model is only employed when the leading vehicle is completely stopped. The vehicle can be a left turner or a straight vehicle.

The required stopping rate for either type is computed using the equation:

\[
\text{Deceleration} = - \frac{\text{(velocity)}}{2(P.\text{stop-position})}
\]

where velocity = actual speed of the vehicle;

\( P.\text{stop} \) = position where the vehicle has to stop; and

\( \text{position} \) = current position of the vehicle.
At no time should the stopping rate exceed the pre-defined maximum deceleration rate.

3.2.8 Queue Discharge
Traffic flow is interrupted due to the presence of a left turner waiting for a suitable gap. In the case without TWLTL, a queue buildup may occur in the inside lanes and may contain a combination of left turners and through traffic.

Starting delay is defined as the time required for the first vehicle in a queue to enter the intersection after the display of the green signal. It is the elapsed time between the beginning of the green phase and passage of a screen line. Starting delay at signalized intersections have been studied by many researchers including Gerlough (12), Berry and Gandhi (32), Capelle and Pinnell (34), King and Wilkinson (34), and Carstens (35).

Berry (32) reviewed four screen line configurations, which are shown in figure (3.9). He recommended type IV for queue discharge measurements at the entry to the intersection. In this dissertation, the screen line is defined as the center line of a driveway. The starting delay would include the reaction time of a driver and the time to accelerate to the center line of the driveway. This distance is dependent on the position of the vehicle in the queue.

The acceleration of a vehicle is computed utilizing the car-following model. Therefore, the free behavior routine is
When a car starts

When rear wheels cross screen line

Screen Line I: At stopped front wheels of first vehicle

Screen Line II: At stop line

Screen Line III: At crosswalk line

Screen Line IV: At entry to intersection

Figure 3.9. Alternative screen lines for measuring queue discharge (from (32))
applied to queue leaders and the car-following routine is applied to queue members.

In case of having a left turner among the queue members, the same starting delay logic applies provided that a left turner would stop at the proper position to negotiate a left-turn maneuver.

A test run was made to illustrate the discharge of an 8-vehicle queue. The input data for this run were: reaction time= 0.75 seconds, target speed for all vehicles = 45 ft/sec, max acceleration= 4.85 ft/sec/sec, distance between front bumpers= 22 ft (car length and clearance). Results from a test run are shown in Table (3.4) with results from related literature. The results clearly indicate that the queue-discharge algorithm employed closely replicates the field and simulation studies of the literature.
Table 4.4
Input Volume per Lane

<table>
<thead>
<tr>
<th>Average Daily Traffic</th>
<th>Flow in the Heavy Direction (veh/hr)</th>
<th>Flow in the Light Direction (veh/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Lane 3</td>
</tr>
<tr>
<td>12,000</td>
<td>690</td>
<td>363</td>
</tr>
<tr>
<td>16,000</td>
<td>920</td>
<td>483</td>
</tr>
<tr>
<td>20,000</td>
<td>1150</td>
<td>604</td>
</tr>
<tr>
<td>25,000</td>
<td>1440</td>
<td>756</td>
</tr>
<tr>
<td>33,000</td>
<td>1905</td>
<td>1000</td>
</tr>
</tbody>
</table>

<sup>a</sup> \( \frac{390}{2} \times 1.05 = 205 \text{ veh/hr} \)
3.3 LIMITATIONS OF THE MODEL

As with any simulation or analytical model, the ARTSIM model has its limitation. Accidents and its related congestion are not permitted as each generated vehicle is given an actual speed in proportion to the space headway between the subject vehicle and its leader. Besides, a driver may utilize the maximum allowable deceleration rate to maintain a safe space headway.

The impact of truck traffic on arterials in terms of sight obstruction, vehicle characteristics, and volume has not been considered in the model. However, the user may use the truck factors mentioned in the HCM to substitute for the truck volume.

3.4 INPUT REQUIREMENTS

The ARTSIM model operates on the AMDAHL 470/V8 equipment with real-time/computer-time ratios of approximately 65:1 depending on the traffic volume and simulation time.

There are two types of data input: exogenous inputs and embedded inputs. Exogenous inputs include all data which must be specified by the user. Embedded inputs are all values incorporated directly in the simulation routines; they are summarized below. The description of all exogenous inputs are provided below. It should be noted here that free format type is used where parameters are separated by at least one blank space.
<table>
<thead>
<tr>
<th>Card Type</th>
<th>Input Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>ST.TYP</strong>e street type (enter two if two-lane or four if four-lane arterial).</td>
</tr>
<tr>
<td></td>
<td><strong>CASE</strong> 1 if case with TWLTL</td>
</tr>
<tr>
<td></td>
<td>2 if case without TWLTL</td>
</tr>
<tr>
<td>2</td>
<td><strong>SEGMENT</strong> length of simulated arterial in ft.</td>
</tr>
<tr>
<td></td>
<td><strong>NLDWY</strong> number of driveways on the left-side</td>
</tr>
<tr>
<td></td>
<td><strong>NRDWH</strong> number of driveways on the right-side</td>
</tr>
<tr>
<td></td>
<td><strong>S12</strong> approach length of NB in ft.</td>
</tr>
<tr>
<td></td>
<td><strong>S34</strong> approach length of SB in ft.</td>
</tr>
<tr>
<td>3</td>
<td><strong>N.OUT</strong> number of requested subruns</td>
</tr>
<tr>
<td></td>
<td><strong>T.STOP</strong> simulation time/subrun in sec.</td>
</tr>
<tr>
<td></td>
<td><strong>C</strong> scanning time in seconds</td>
</tr>
<tr>
<td></td>
<td><strong>WARM.UP</strong> start-up time in seconds</td>
</tr>
<tr>
<td>4</td>
<td><strong>VMU1</strong> mean speed in SB in ft/sec</td>
</tr>
<tr>
<td></td>
<td><strong>VSIG1</strong> standard deviation</td>
</tr>
<tr>
<td></td>
<td><strong>VOL1</strong> volume in lane 1 (vph). Enter zero when simulating a two-lane arterial</td>
</tr>
<tr>
<td></td>
<td><strong>VOL2</strong> volume in lane 2 (vph)</td>
</tr>
<tr>
<td></td>
<td><strong>VOL3</strong> volume in lane 3 (vph)</td>
</tr>
<tr>
<td></td>
<td><strong>VOL4</strong> volume in lane 4 (vph). Enter zero when simulating a two-lane arterial</td>
</tr>
<tr>
<td></td>
<td><strong>VMU3</strong> mean speed in NB in ft/sec</td>
</tr>
<tr>
<td></td>
<td><strong>VSIG3</strong> standard deviation</td>
</tr>
<tr>
<td>5</td>
<td><strong>LCP</strong> Lane change probability. Enter any negative number when simulating a two-lane arterial.</td>
</tr>
</tbody>
</table>
NLTP  Left-turn percentage in Northbound
SLTP  Left-turn percentage in Southbound
MDEC  Maximum deceleration rate (ft/sec/sec)

6  SEED.V(1)  Seed number for vehicular interarrival
SEED.V(2)  Seed number for target speeds
SEED.V(3)  Seed number for left-turn probability
SEED.V(4)  Seed number for lane-change probability
            (must enter regardless of type of street)
SEED.V(5)  Seed number for intended driveway

7  SL  Left-hand side driveway distances array
       (the first one must be at least 250')
       enter all distances on one card.
SR  Right-hand side driveway distance array.
       use same procedure in SL.

9  LAG  Cumulative probability distribution of
       lag acceptance by a left-turner. Enter
       pairs of data, the first is a probability
       the second is lag value. The last prob.
       must be 1.0, followed by a space then a
       star. The user may use more than 1 card.

10  GAP  Cumulative probability distribution of

11  LANE.CHANGE  Cumulative probability distribution
       of lag acceptance when changing lanes.
       Use procedure outlined in 9 only when
       simulating a four-lane arterial.

12  OPTION1  1  if a Batch Means report is requested
            0  otherwise
Chapter IV
IMPLEMENTATION OF THE MODEL

4.1 INTRODUCTION

The development of the ARTSIM simulation model has provided a convenient tool to study the effectiveness of installing a TWLTL along an arterial. A study was initiated to quantify the impact of the TWLTL along a four-lane two-way arterial under various traffic characteristics. The results presented in this Chapter are not intended to encompass all of the possible combinations of driveway density and traffic characteristics, but merely to display enough examples to introduce the simulation model and its applicability.

4.2 SIMULATED ARTERIAL SEGMENT

Figure (4.1) shows a hypothetical arterial segment used throughout the course of this research. The segment consists of a two-way four-lane arterial of 1660 ft length and nine driveways unevenly spaced on both sides, five driveways on the right side and four on the left side. The driveway density is considered as 45 driveways/mile.

The approach length is divided into two parts: the distances S12 in the northbound and S34 in the southbound, and a minimum of a 250 ft segment prior to the first driveway in
Figure 4.1- Geometry of simulated arterial with TWLTL
each direction (see Figure (4.1)). The purpose of having two parts is to keep a fixed segment length upstream the first driveway of 250 ft, and to change the total approach length according to the traffic volume. A distance of 150-300 ft is recommended for S12 and S34 for low and high traffic flow, respectively. The total approach length would be S12+250 for the northbound, and S34+250 for the southbound.

4.3 SIMULATION STUDY DESIGN

In order to evaluate the installation of the TWLTL, a simulation study based upon experimental design considerations was initiated. A fractional factorial design technique was used. This technique allows the investigator to obtain enough information to fulfill the original objectives using only a fraction of all possible combinations.

The first phase of the simulation study was to identify the factors to be used throughout the study. Therefore, six pilot runs were conducted before implementing the experiment. The purpose was to test whether the model was responsive to the change in the percentage of potential lane change drivers. The results of these pilot runs are shown in Tables (4.1) and (4.2). The results show that the ARTSIM model provides flexibility to the user regarding the type of the simulated driver. However, it was decided that 50% of the driver population would be potential lane changers. This assumption is considered reasonable since no data from the field were available.
In order to consider a wide range of operating characteristics, and to keep the size of the simulation study within available resources, two independent variables were chosen to represent various conditions along an arterial with and without TWLTL. The variables were:

1. Average Daily Traffic; and
2. Percentage of left-turns from both directions of travel.

The average daily traffic was broken down to heavy and light traffic volumes using Table (4.3) to represent traffic flow during the peak hour in a Central City. The northbound approach carried the heavy traffic flow, and the southbound approach carried the light traffic. The peak hour was chosen as the 4-5 pm hour, and a directional distribution factor of 36-64% was used. A lane utilization factor of 1.05 was used to estimate the critical volume in the inside lanes (from reference (39)). This was considered a satisfactory assumption since the left-turn vehicles are generated in the inside lanes.

Five levels of average daily traffic were used as shown in Table (4.4). Some short trial runs indicated that the effect of the TWLTL was insignificant below 12,000 veh/day. Other runs disclosed that jammed flow conditions occurred at traffic volumes higher than 33,000 veh/day.

In order to find jammed flow conditions for a particular case, the user is referred to Figure (4.2) obtained from Reference (39) or to the set of curves provided in the
### Table 4.1

**Number of Lane-Change Maneuvers in the Heavy Direction**

<table>
<thead>
<tr>
<th>Lane Change %</th>
<th>In the Case With TWLTL</th>
<th>In the Case Without TWLTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADT=30,000</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>LT=20%</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>51</td>
</tr>
</tbody>
</table>

### Table 4.2

**Number of Lane-Change Maneuvers in the Light Direction**

<table>
<thead>
<tr>
<th>Lane Change %</th>
<th>In the Case With TWLTL</th>
<th>In the Case Without TWLTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADT=30,000</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>LT=20%</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>26</td>
</tr>
</tbody>
</table>
Table 4.3 - Hourly Distribution of Total Travel
(source (37))

<table>
<thead>
<tr>
<th>H</th>
<th>CBD</th>
<th>Central City</th>
<th>Suburb</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBD</td>
<td>All Orientations</td>
<td>Radial</td>
<td>X-Town</td>
</tr>
<tr>
<td>R</td>
<td>% ADT</td>
<td>DIR</td>
<td>SPLIT</td>
</tr>
<tr>
<td>24-1</td>
<td>1.5</td>
<td>46</td>
<td>1.5</td>
</tr>
<tr>
<td>1-2</td>
<td>1.0</td>
<td>46</td>
<td>1.0</td>
</tr>
<tr>
<td>2-3</td>
<td>0.5</td>
<td>44</td>
<td>0.5</td>
</tr>
<tr>
<td>3-4</td>
<td>0.5</td>
<td>42</td>
<td>0.5</td>
</tr>
<tr>
<td>4-5</td>
<td>1.0</td>
<td>54</td>
<td>0.5</td>
</tr>
<tr>
<td>5-6</td>
<td>2.0</td>
<td>50</td>
<td>1.5</td>
</tr>
<tr>
<td>6-7</td>
<td>4.0</td>
<td>60</td>
<td>5.0</td>
</tr>
<tr>
<td>7-8</td>
<td>9.0</td>
<td>64</td>
<td>8.5</td>
</tr>
<tr>
<td>8-9</td>
<td>7.0</td>
<td>66</td>
<td>6.5</td>
</tr>
<tr>
<td>9-10</td>
<td>5.0</td>
<td>60</td>
<td>4.5</td>
</tr>
<tr>
<td>10-11</td>
<td>5.5</td>
<td>54</td>
<td>5.0</td>
</tr>
<tr>
<td>11-12</td>
<td>6.0</td>
<td>54</td>
<td>5.0</td>
</tr>
<tr>
<td>12-13</td>
<td>5.5</td>
<td>50</td>
<td>5.0</td>
</tr>
<tr>
<td>13-14</td>
<td>5.0</td>
<td>50</td>
<td>5.0</td>
</tr>
<tr>
<td>14-15</td>
<td>6.0</td>
<td>48</td>
<td>5.5</td>
</tr>
<tr>
<td>15-16</td>
<td>6.5</td>
<td>46</td>
<td>6.5</td>
</tr>
<tr>
<td>16-17</td>
<td>9.5</td>
<td>42</td>
<td>9.0</td>
</tr>
<tr>
<td>17-18</td>
<td>7.0</td>
<td>33</td>
<td>8.0</td>
</tr>
<tr>
<td>18-19</td>
<td>4.5</td>
<td>44</td>
<td>5.0</td>
</tr>
<tr>
<td>19-20</td>
<td>3.5</td>
<td>46</td>
<td>4.0</td>
</tr>
<tr>
<td>20-21</td>
<td>2.5</td>
<td>46</td>
<td>3.5</td>
</tr>
<tr>
<td>21-22</td>
<td>2.5</td>
<td>46</td>
<td>3.0</td>
</tr>
<tr>
<td>22-23</td>
<td>2.0</td>
<td>44</td>
<td>3.0</td>
</tr>
<tr>
<td>23-24</td>
<td>1.0</td>
<td>46</td>
<td>2.5</td>
</tr>
<tr>
<td>Average Daily Traffic</td>
<td>Flow in the Heavy Direction (veh/hr)</td>
<td>Flow in the Light Direction (veh/hr)</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------------------------------</td>
<td>-------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Lane 3</td>
<td>Lane 4</td>
</tr>
<tr>
<td>12,000</td>
<td>690</td>
<td>363</td>
<td>327</td>
</tr>
<tr>
<td>16,000</td>
<td>920</td>
<td>483</td>
<td>437</td>
</tr>
<tr>
<td>20,000</td>
<td>1150</td>
<td>604</td>
<td>546</td>
</tr>
<tr>
<td>25,000</td>
<td>1440</td>
<td>756</td>
<td>684</td>
</tr>
<tr>
<td>33,000</td>
<td>1905</td>
<td>1000</td>
<td>905</td>
</tr>
</tbody>
</table>

\(^a\) \(\frac{390}{2} \times 1.05 = 205\) veh/hr
following sections. It is believed that either one should give good starting values without wasting significant computer time.

Three levels of percentage of left-turns were used: 10, 20, and 30%. In any simulation run, the left-turn percentage was kept the same for both heavy and light directions of traffic flow.

During the experiment, a number of factors were kept constant. These included the following:

1. Percentage of potential lane-change drivers of 50%.
2. Driver's reaction time of 0.75 seconds.
3. Maximum attainable deceleration rate of 14 ft/sec/sec.
4. A left-turn vehicle would always try to occupy the TWTLT 200 ft prior to its intended driveway.
5. All traffic flows were during the evening peak-hour.
6. Vehicle interarrival headways followed the shifted negative-exponential distribution. The amount of shift is 0.75 seconds.
7. The desired speeds were determined according to a normal distribution, with a mean of 35 mph and the standard deviation was assumed to be 10% of the mean.
8. The left-turn gap acceptance distribution values specified in section 2.3 were utilized during the simulation study.
9. Lane change lag acceptance distribution specified in section 2.3 were also used for the simulation study.

It was necessary to assume some period of simulation time during which the system would reach a steady-state operation. It was decided that a 100-second period would be used as a start-up period to load the system prior to
Figure 4.2 Maximum capacity based on conflicting volume and critical gap (Source (39))
collecting the system's measures of effectiveness. This is because at the end of the 100-second period, 17 vehicles will have exited the system (assuming a travel time of 30 seconds and a 4-second headway). Therefore, a steady-state operation is assumed to have been attained.

After discarding the transient-state observations, the prolonged run approach was used to obtain the steady-state observations. Each continued run consisted of ten subruns, each was 15-minute of simulation time. All results counters were reset to zero after the start-up period and each subrun, the random number generator was left untouched.

4.4 RANDOM NUMBER CONTROL

Since the objective of this study was to compare two systems, the first with a TWLTL and the second without TWLTL, it was intuitively reasonable to compare the two systems under the same environment. This could be accomplished by providing the same starting conditions. Therefore, for each pair of runs, two parameters were kept the same; all input variables and the same random numbers. When simulating the two systems input values are generated using the same initial values for the random number generators. Five random number streams were used and distributed as follows:

1. Interarrival headway distribution (SEED.V(1)).
2. Truncated normal distribution of desired speeds (SEED.V(2)).
3. Probability of turning left (SEED.V(3)).
4. Probability of lane change (SEED.V(4)).
5. Destination of left-turn vehicles (SEED.V(5)).

The user is referred to Fishman (23) for initial Pseudo random numbers for SIMSCRIPT.

4.5 MEASURES OF EFFECTIVENESS

Four measures of effectiveness (MOEs) were identified to assess the impact of installing a TWLTL along a two-way four-lane arterial. The four MOEs are: number of stops to through traffic in the inside lanes, number of lane-change maneuvers, travel time of through vehicles, and travel time of left-turning vehicles (i.e. time to complete a left-turn including the waiting time for a suitable gap). A typical output is provided in Appendix (C).

4.6 ANALYSIS OF THE RESULTS

The results presented in this section are the averages of the above-defined MOEs collected from extended simulation runs; each was divided into 10 subruns each of 15-minute simulation time. The batch means procedure (23) was used to establish 95% confidence intervals for the means of the above-defined measures of effectiveness. The batch means procedure has the advantage over independent replications of only requiring computer time for one start-up period. The procedure utilizes a single run divided into a number of segments to separate the observations into batches of equal
sizes. The sample means are assumed to be independently, identically distributed variables. The procedure tests for independence among batches by computing Von-Newman's statistic. If the test fails, it doubles the batch sizes until the hypothesis of independence is accepted or the number of batches fall below eight.

4.6.1 Reductions in Number of Stops

Stops to through traffic in the inside lanes occur due to the presence of left-turning vehicles waiting for an acceptable gap. Figures (4.3) and (4.4) summarize the reductions in number of stops for both heavy and light directions, respectively. The installation of the TWLLT eliminated stops in the inside lanes in both directions, as would be expected. The results for the case with TWLLT showed that no stops occurred at any combination of traffic flow and left-turning volume level. The discussion of the results for the heavy and light directions of traffic flow, in that order, are made as follows:

Heavy Direction:

Figure (4.3) shows that the number of stops to through traffic in the inside lane in the case without TWLLT increases as traffic flow increases. The effect of left-turning volume on the number of stops is insignificant at traffic flow level of 1150 veh/hr or less. Analyses of the differences in number of stops at traffic flow levels of
Figure 4.3 Number of stops to through traffic in the heavy direction (without TWLTL)
Figure 4.4 Number of stops to through traffic in the light direction (without TWLTL)
1440 and 1905 veh/hr were conducted to determine the effect of left-turning volume levels.

At the 1440 veh/hr level, analyses of the number of stops at 10% and 20% left-turning volume levels indicated that there was a significant difference. The average of the difference was 8 stops/15 min. with a 95% confidence interval of 1 and 15 stops/15 min. Analysis of the difference in number of stops at 20% and 30% left-turning volume levels indicated that the difference was statistically insignificant because the results at the 30% left-turning volume level were well within the confidence interval of the results for the 20% left-turning volume level. Similar results were obtained at traffic flow level of 1905 veh/hr.

Light Direction:

Figure (4.4) shows that the number of stops to through traffic in the inside lane increases as traffic flow increases. The effect of left-turning volume levels on the number of stops is insignificant at traffic flow level of 650 veh/hr or less. At traffic flow levels of 810 and 1070 veh/hr, analyses of the differences in number of stops were conducted to determine the effect of left-turning volumes.

At the 810 veh/hr level, the difference in the number of stops at the 20% and 30% left-turning volume levels was statistically insignificant because the number of stops at the 20% left turns were within the confidence interval of the results for the 30% left turns. The number of stops at
the 10% left-turning volume level were outside the confidence intervals of the results for the 20% and 30% left-turning volume levels indicating a significant effect. Similar conclusions were obtained at traffic flow level of 1070 veh/hr.

The conclusion drawn is that the TWLTL would bring about significant reductions in number of stops to through traffic at traffic flow level higher than 650 veh/hr in the light direction and 1150 veh/hr in the heavy direction. Analyses of the differences in the number of stops indicated that these differences are statistically insignificant at left-turning volume levels higher than 10%.
4.6.2 Reduction in Travel Time

Travel time has been recognized as a measure of quality of flow in urban arterials. An added element is included which allows the MOE to be more clearly understood: a specific distance unit. The simplest form is average travel time per distance per vehicle. This MOE is used in displaying all results.

Figures (4.5) and (4.6) show the impact of installing a TWLTL on the average travel time per through vehicle in the heavy and light directions of traffic flow, respectively. The direct result of eliminating stops in the inside lanes by installing a TWLTL (as discussed above in section 4.6.1) is decreases in travel time values. The figures show that reductions in travel time values are insignificant up to traffic flow of 1150 veh/hr in the heavy direction and 650 veh/hr in the light direction. Over and above this threshold, sharp reductions in travel time values could be attained by installing a TWLTL.

Figure (4.5) shows that travel time values in the heavy direction increase as the left-turning volume level increases. Analyses of the differences in travel time values at the 1440 veh/hr level indicated that these differences were statistically insignificant at the 10% and 20% left-turning volume levels. The differences in travel time values at 20% and 30% left-turning volume levels were significant.
Figure 4.5 - Effect of percent left turns on travel time of straight vehicles in the heavy direction.
Figure 4.6 - Effect of percent left turns on travel time of straight vehicles in the light direction
Analyses of the difference in travel time values at the 1905 veh/hr flow level showed no significant difference at the 20% and 30% left-turning volume levels.

Figure (4.6) shows that travel time values, in the light direction, increase as the left-turning volume increases. Analyses of the difference in travel time values at 20% and 30% left-turning volume levels indicated that this difference is statistically insignificant at traffic flow level of 810 veh/hr.

To provide basis for further investigation, Figures (4.7) through (4.9) were constructed. In the case without TWLTL, the results indicated that the longer a turn vehicle stayed in the inside lane, through traffic experienced more delay as indicated by higher travel times. This correlation became more important at high traffic flow. In the case with TWLTL, however, no correlation was noticed since all turn vehicles cleared the inside lane and no delay was imposed on through traffic.

The conclusion drawn is that savings in travel time values due to installation of a TWLTL is significant at traffic flow levels higher than 1150 veh/hr in the heavy direction and 650 veh/hr in the light direction. Over and above this threshold, the effect of left-turning volume levels on travel time values varies with no particular pattern.
Figure 4.7-Travel time for straight and left-turn vehicles in the heavy direction at 10% left turn:

- **ST**: straight-through veh.
- **LT**: left-turn veh.

Travel time of left-turners (sec./veh/290'):

<table>
<thead>
<tr>
<th>Flow (vph)</th>
<th>Travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>690</td>
<td>6</td>
</tr>
<tr>
<td>920</td>
<td>7</td>
</tr>
<tr>
<td>1150</td>
<td>8</td>
</tr>
<tr>
<td>1440</td>
<td>9.5</td>
</tr>
<tr>
<td>1905</td>
<td>11</td>
</tr>
</tbody>
</table>

Flow (vph) vs. Travel time of straight vehicles (sec./veh/1650')

- **ST**: straight-through veh.
- **LT**: left-turn veh.

Legend:
- **Dotted line**: without TWLTL
- **Solid line**: with TWLTL
Figure 4.8 - Travel time for straight and left-turn vehicles in the heavy direction at 20% left turn

ST: straight-through veh.
LT: left-turn veh.

Flow (vph) vs. Travel time of left-turners (sec./veh/290')

Flow (vph) vs. Travel time of straight vehicles (sec./veh/1660')

- without TWLTL
- with TWLTL
Travel time of left-turners (sec./veh/290')

ST : straight-through veh.
LT : left-turn veh.

Figure 4.9 - Travel time for straight and left-turn vehicles in the heavy direction at 30% left turn
4.6.3 Frequency of Lane-change Maneuvers

Figures (4.10) through (4.15) show the number of successful lane change attempts in a 15-minute simulation time. Each figure shows that the average number of lane change maneuvers decreased, at all combinations of traffic volumes and left-turn percentage, due to installation of the TWLTL. By reducing the number of lane change maneuvers, smooth traffic flow can be reached as the internal friction between weaving vehicles and other surrounding vehicles is reduced.

Analyses of the differences in number of lane-change maneuvers for the two cases, with and without TWLTL, indicated that there was insignificant differences only at traffic flow of 690 veh/hr in the heavy direction, and traffic flow of 390 veh/hr in the light direction.

The manner in which these lane changes occurred appeared to be random. Vehicles tagged with lane change probability of 50% or higher would pull out and change lanes whether it was stopped behind a turn vehicle (regardless of its position in the queue) or travelling at a speed lower than its target speed. Since in the case with TWLTL turn vehicles clear the inside lanes, less friction between the straight vehicles existed and there was less need for lane change. In the case without TWLTL, more friction existed in the inside lanes as turn vehicles slowed down or stopped until finding an acceptable gap.
Figure 4.10 Number of lane changes in the heavy direction at 10% left turns
Figure 4.11 Number of lane changes in the heavy direction at 20% left turns
Figure 4.12 Number of lane changes in the heavy direction at 30% left turns
Figure 4.13 Number of lane changes in the light direction at 10% left turns
Figure 4.14 Number of lane changes in the light direction at 20% left turns
Figure 4.15 Number of lane changes in the light direction at 30% left turns
ARTSIM does not take into account drivers who are familiar with the left-turn problem. They would tend to use the outside lane prior to reaching the driveways to minimize their delay. Although utilization of the outside lanes appeared to be higher in the case without TWLTL, this had no effect on the travel time of through traffic in the outside lanes.

4.6.4 Effect on Left-Turn Vehicles

Travel time statistics for left-turn vehicles were collected for the 290 ft zone prior to exiting the system. This travel time was computed from the time a turn vehicle decided to enter the TWLTL until it exited the system, including waiting for a suitable gap.

As can be seen from Figures (4.16) through (4.19), travel time increased as traffic volume increased. In general, the left-turn percentage had little effect on travel time because of the following:

1. A turn vehicle decreased its speed to the maximum allowable turning speed as it enters the 290 ft zone.

2. Neither the TWLTL nor the stops in the inside lanes greatly altered the gap sizes so that turn vehicles would wait less time until finding an acceptable gap.
Figure 4.16 Travel time of left-turners from the heavy direction (with TWLTL)

Figure 4.17 Travel time of left-turners from the heavy direction (without TWLTL)
Figure 4.18 Travel time of left-turners from the light direction

Figure 4.19 Travel time of left-turners from the light direction (without TWLTL)
The impact of the TWLTL on left-turn vehicles can be seen from Figures (4.20) through (4.25). The TWLTL did not generally reduce the travel time for turn vehicles from the heavy direction. This is attributed to the gap sizes in the light direction which were generally accepted or found faster in either model as indicated from the travel time values. Turning from the light direction had benefited from the TWLTL especially when the jammed flow conditions at 33,000 veh/day were reached.

The conclusion here is that left-turn percentage has little effect on travel time. The TWLTL provides wider gaps for the left-turn vehicles as turning vehicles from the opposing direction clear the inside lane by occupying the TWLTL. The opposite is not valid for turn vehicles from the heavy direction. Access to abutting land use activities was not generally improved by installing the TWLTL.
Figure 4.20 Travel time of left-turners from the heavy direction at 10% left turns.

Figure 4.21 Travel time of left-turners from the light direction at 10% left turns.
Figure 4.22 Travel time of left-turners from the heavy direction at 20% left turns.

Figure 4.23 Travel time of left-turners from the light direction at 20% left turns.
Figure 4.24 Travel time of left-turners from the heavy direction at 30% left turns.

Figure 4.25 Travel time of left-turners from the light direction at 30% left turns.
4.7 **DRIVEWAY DISTRIBUTION**

The previous results were limited to a hypothetical arterial segment with 9 randomly spaced driveways with an average density of 45 driveways/mile. It was felt that a study of the driveway distribution was necessary to sort out the impact of the TWLTL on different driveway distributions with identical average driveway density of 45 driveways/mile. Therefore, another hypothetical arterial of the same length and number of driveways was considered as shown in Figure (4.26). Driveways were uniformly distributed with a spacing of 140 ft between every two driveways on each side of the arterial. The same number of driveways on each side was used as in the first arterial. In this limited phase of study, one level of traffic volume was used: 1440 veh/hr in the heavy direction and 810 veh/hr in the light direction, to represent traffic flow conditions during the peak hour. Three left-turning volume levels were used: 10%, 20%, and 30% of the total traffic volume in each direction of travel.
Figure 4.26 - Arterial segment with uniformly distributed driveways.
In this simulation study, statistics of four measures of effectiveness (MOEs) were collected from the ARTSIM model. The four MOEs were: number of stops to through traffic in the inside lanes, travel times of through traffic, number of lane-change maneuvers, and travel times of left-turning vehicles (i.e. time to complete a left turn including waiting for an acceptable gap).

A total of six extended simulation runs were conducted; each was divided into 10 subruns each of 15-minute simulation time. A start-up period of 100-second was used in each extended run to load the system prior to collecting the observations from the simulation run.

Figures (4.27) through (4.34) show the results obtained for both random and uniform driveway distribution cases at the three left-turning volume levels. At each left-turning volume level in both cases, the mean of each MOE and its 95% confidence interval are displayed except for the travel times of left-turning vehicles shown in Figures (4.33) and (4.34) because the confidence intervals were very small. The discussion of the results for the heavy and light directions of traffic flow, in that order, are made separately as follows:

Heavy Direction:

1. The travel time of left-turning vehicles remained practically the same at the three left-turning volume levels. Figure (4.33) shows that the travel times in
Figure 4.27 Comparison of the number of stops in the heavy direction

Figure 4.28 Comparison of the number of stops in the light direction
Figure 4.29 Comparison of number of lane changes in the heavy direction

Figure 4.30 Comparison of number of lane changes in the light direction
Figure 4.31 Comparison of travel time of straight-through vehicles in the heavy direction

Figure 4.32 Comparison of travel time of straight-through vehicles in the light direction
Figure 4.33 Comparison of travel time of left turners from heavy direction

Figure 4.34 Comparison of travel time of left turners from light direction
the uniform and random cases have the same average values.

2. The number of stops in the random case increased as the left-turning percentage increased (see Figure (4.27)). The number of stops in the uniform case increased as the left-turning percentage increased from 10% to 20%. As the left-turning percentage increased to 30%, the number of stops in the uniform case showed no change. No conclusions, however, could be drawn due to the wide confidence intervals at the 30% left-turn volume level, e.g. the number of stops could be as high as 38 stops/15 min. or as low as 21 stops/15 min. A plausible explanation of this wide interval is the variation in traffic flow conditions from a 15-minute subrun to another subrun. Analyses of the difference in number of stops for the random and uniform cases indicated that there was a significant difference only at the 30% left-turning volume level. The average of the difference in number of stops was 9 stops/15 min. with a 95% confidence interval of 5 and 13 stops/15 min.

3. The travel time of through traffic in the random and uniform cases increased as the left-turning percentage increased (see Figure (4.29)). The average increase in the two cases amounted to about 10% of the average travel time, and was considered insignifi-
cant. The differences in travel times for the random and uniform cases were statistically insignificant at the 95% confidence level because the results from the uniform case were well within the confidence intervals of the results obtained from the uniform case.

4. The number of lane-change maneuvers in the two cases increased as the left-turning percentage increased from 10% to 20% (see Figure (4.29)). As the left-turning percentage increased to 30%, a decrease in the number of lane changes occurred due to the presence of fewer potential lane changers in the through traffic. That is, as left-turning percentage increased from 20% to 30% at the fixed traffic volume of 1440 veh/hr, the number of through vehicles dropped from 1152 veh/hr to 1008 veh/hr, and there was a decrease in the number of potential lane changers. Analyses of the differences in number of lane-change maneuvers for the two cases indicated that these differences were statistically insignificant at the 95% confidence interval.

Light Direction:

1. The travel times of left-turning vehicles (i.e. time to complete the turn including the waiting time for a suitable gap) increased in the two cases as the left-turning percentage increased from 10% to 20%. As the left-turning percentage increased to 30%, the
travel time values decreased due to the presence of wide gaps in the opposing traffic (see Figure (4.34)). That is, as left-turning percentage increased from 20% to 30% at the fixed opposing traffic volume of 1440 veh/hr, the number of through vehicles in the opposing direction dropped from 1152 veh/hr to 1008 veh/hr, which resulted in the presence of wider gaps.

2. The number of stops in the two cases increased as the left-turning percentage increased from 10% to 20%. This was due to the increase in travel times of left-turning vehicles (i.e. time to complete a turn) as explained above. As the left-turning percentage increased to 30%, the number of stops decreased in response to the decrease in travel time of left-turning vehicles. However, no conclusions could be drawn regarding this decrease in number of stops due to having a wide confidence interval, e.g. in the uniform case, the number of stops ranges from 5 to 39 stops/15 min. A rational explanation for this wide range is the variation in traffic flow conditions from a 15-minute subrun to another subrun. Analyses of the differences in number of stops for the uniform and random cases indicated that these differences were statistically insignificant except at the 10% left-turning percentage. The average of the differ-
ence in number of stops was 6 stops/15 min. with 95% confidence interval of 4 and 8 stops/15 min.

3. The average travel times of through traffic in the random and uniform cases increased as the left-turning percentage increased from 10% to 20%. This was due to the increase in travel times of left-turning vehicles (i.e. time to complete a turn) as explained in point 1 in this section (see Figure (4.32)). As the left-turning percentage increased to 30%, the average travel times of through traffic in the two cases decreased in response to the decrease in travel times of left-turning vehicles. Analyses of the differences in travel times for the two cases were statistically insignificant at the 95% confidence interval.

4. The number of lane-change maneuvers in the two cases increased as the left-turning percentage increased from 10% to 20% (see Figure (4.30)). As the left-turning percentage increased to 30%, a decrease in the number of lane changes occurred due to the presence of fewer potential lane changers in the through traffic. That is, as left-turning percentage increased from 20% to 30% at the fixed traffic volume of 810 veh/hr, the number of through vehicles dropped from 648 veh/hr to 567 veh/hr, and there was a decrease in the number of potential lane changers.
Analyses of the differences in number of lane-change maneuvers for the two cases indicated that these differences were statistically insignificant at the 95% confidence interval.

The conclusion drawn is that for the particular driveway density tested (i.e. 45 driveways/mile), the driveway distribution does not have a significant effect on traffic MOEs except for the number of stops in the inside lanes. The results from this simulation study indicated that the difference in number of stops from the random and uniform cases are significant at the 10% and 30% left-turning volume levels. Also, at the 30% left-turning volume level, variation in traffic flow conditions from one 15-minute subrun to another could result in a wide confidence interval for the number of stops.

4.8 SUGGESTED PROCEDURE TO ESTABLISH LEVEL OF SERVICE

The problem associated with the determination of the level of service of arterials with midblock turning movements has long been of interest to those persons who must make decisions relative to the proper installation of the TWLTL. The Highway Capacity Manual (36) has acknowledged this problem. It states:

Analyze each significant midblock restriction as a special case. No specific procedures can be described for these analyses; procedures already covered in this manual must be adapted to each particular case.
The Manual suggests that midblock driveways might be best analyzed as signalized intersections with assumed cycle time. A green to cycle time ratio of 0.70 was used in one of the examples in the Manual.

While the level of service of an at-grade intersection is dependent on the geometrics of the actual intersection area, the level of service of an arterial involves a long street section. Traffic operations along an arterial section should be investigated over an appreciable length to relate the level of service to delays and resulting speeds. The speed measure used in arterial analysis is the average overall travel speed.

The average overall speeds resulting from the case without TWLTL during the peak hour were computed using the total travel times of through traffic. Figure (4.35) shows the average overall speeds of the light direction during the peak hour, and Figure (4.36) shows the average overall speeds of the heavy traffic during the same time. While through traffic in the heavy direction maintained high speeds because turning vehicles cleared the inside lane due to the presence of wide gaps in the oncoming light traffic, through traffic in the light direction experienced more delays as turning vehicles waited longer times for suitable gaps in the oncoming heavy traffic. Because the travel times of through traffic in both directions were collected over a relatively long arterial segment, the travel times
and resulting average overall speeds were insensitive to the relatively short delays encountered in the midblock area, except at volumes higher than 1440 veh/hr in the heavy direction and the corresponding 760 veh/hr in the light direction. Therefore, the speed measure is not a sensitive indicator of the level of service in the midblock area. There is a need to study the points of traffic interruptions and their effect on traffic operations along the entire street segment.

Midblock driveways and related turning movements affect considerably the quality of flow as shown in previous sections. The effect is primarily displayed in terms of two measures: stops and delays. The Highway Capacity Manual (36) has selected six levels of service categories, designated A through F, that encompass a working range of conditions - from a condition of free flow to a condition of jammed flow - to interpret the quality of flow on freeways, arterials, and intersections. This study introduces levels of service criteria along the same rules with one exception: capacity. Capacity, which is identified with level of service E, would not be very meaningful when studying arterials with midblock turning movements because of the numerous combinations of driveway densities, turning volumes, and through traffic. Instead, this study suggests a simplified method recognizing the effect of left turn vehicles on through traffic that results in stops in the inside lane.
Figure 4.35 - Relationship between flow and average overall speed in the light direction.

Figure 4.36 - Relationship between flow and average overall speed in the heavy direction.
The number of stops is chosen as a measure to determine the level of service. During the course of this study, an arterial is considered as operating at level of service E if the average number of stops per vehicle in the inside lane is one or more.

Having introduced a new definition of level of service E, the next step is to establish level of service categories, A through E, that cover the entire range of traffic operations. To avoid being totally arbitrary, it was necessary to look for a parallel approach. The Highway Capacity Manual (36) has employed the load factor to define the level of service of a signalized intersection. The load factor is defined as the ratio of the total number of green intervals that are fully utilized during the peak hour to the total number of green intervals during the same period. The Manual has used the load factor concept as a measure that interprets the degree of congestion at a signalized intersection. This study suggests level of service categories somewhat along the lines prescribed by the load factor concept recommended by the Manual. The suggested level of service stratifications for arterials with midblock turning movements were constructed by assigning level of service 'A' to traffic conditions involving a vehicular stoppage of not over 0.1 and level of service 'E' to conditions involving average vehicular stoppages greater than or equal to one. Intermediate level of service stratifications (i.e. B, C, and D)
were constructed using the load factor concept stratification with cut off points of 0.3, 0.7, and 1.0 as shown in Table (4.5). Again, these level of service stratifications were somewhat arbitrarily selected using those prescribed by the load factor concept. Since no literature was found that examines the level of service determination along arterials with midblock turning movements, there was a need to adapt the already existing load factor concept.

Based on the above-defined level of service stratifications, the following simulation study was designed to generate a nomograph to be used by traffic engineers as a guideline for level of service determination. Basic design variables included traffic volume, turning volume, and driveway density. Driveways were uniformly distributed at each driveway density.

**Study Procedure:** In this section specific steps are presented in order to establish actual level of service ranges of an arterial with midblock turning movements for a wide range of traffic volumes and driveway densities. First, it was necessary to select a reasonable length of block to be simulated. Based on typical urban arterial demands, an ITE report (42) has recommended an arterial spacing of 0.25-0.5 miles be used in designing an urban arterial street system in an urban area. Based on this, a segment of a two-way four-lane arterial 0.4 miles long (2100 ft) bounded by two traffic signal controlled intersections was selected.
Table 4.5

Levels of Service for Arterials
with Midblock Turning Movements

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Average Number of Stops per Vehicle in the Inside Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>C</td>
<td>&lt; 0.7</td>
</tr>
<tr>
<td>D</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>E</td>
<td>≥ 1.0</td>
</tr>
</tbody>
</table>
However, to stay away from the influence of the traffic signals on the traffic flow, vehicles were generated 200-ft downstream of one intersection and removed from the system 200-ft upstream of the other intersection. Therefore, the length of the simulated arterial was fixed at 1700 ft (0.322 miles).

The next step was to identify the working range of service volume values. An upper limit on the capacity of the simulated arterial is defined by the capacity of the intersections. Using the procedures outlined in the Highway Capacity Manual, this value was computed as 1500 veh/hr per direction assuming a green split of 0.5. The service volume at level of service 'C' was computed as 1255 veh/hr. Based on these results, three levels of traffic volumes were defined: 1100, 1300, and 1500 veh/hr per direction. At each level, a lane utilization factor of 0.5 was used for both directions of travel.

The next step was to select a working range of driveway densities. A small scale survey of distances between driveways and lengths of city blocks was conducted along a section of North High street in Columbus, Ohio, which currently incorporates a TWLTL. The average distances between driveways were found to be 130 ft. The average length of a city block was found to be 490 ft. Based on these averages, three levels of driveway spacings were used: 100, 250, and 450 ft. These levels were selected to simulate low, medium,
and high levels of driveway densities. The 100-ft spacing represents the minimum driveway spacing (limited by minimum size of traffic generators), and the 450-ft spacing represents the length of a city block. The 250-ft represents a typical driveway spacing. At each level, the distances between driveways were kept the same. The geometrics of the three arterial cases are shown in Figure (4.37).

The turning volumes are the number of left turns per hour made into each driveway. In this study, all driveways had the same left turn volume. At each traffic volume, level of service ranges from C to E were determined by increasing the turning volume for each driveway density. Since the Highway Capacity Manual has selected the level of service C for urban design practice, it is suggested in this study that levels of service better than C would not call for a TWLTL installation and level of service worse than E would call for remedial traffic engineering improvements. Therefore, the level of service range from level C (corresponding to one stop per each third vehicle) to level E (corresponding to one stop or more per vehicle) was used to define the effective range of TWLTL applicability.

Findings: The typical driveway density has been chosen as that corresponding to the medium driveway density (i.e. 250 ft spacing). Figure (4.38) shows the level of service ranges for the medium driveway density at different combinations of traffic volumes and turning volumes. On curve M1
Figure 4.37 Geometry of the three simulated arterials
the level of operation is C which represents approximately one stop per each third vehicle in the inside lane. On curve M2 the level of operation is E which represents one stop per vehicle in the inside lane. Therefore, curves M1 and M2 define the recommended effective range of TWLTL applicability.

Figure (4.38) shows that turning volume decreases as through volume increases to maintain the same level of operation. On curve M1 turning volume per driveway ranges between 22 veh/hr (1 turn every 2.7 minutes) and 43 veh/hr (1 turn every 1.4 minutes). On curve M2 turning volume ranges between 58 veh/hr (approximately 1 turn every minute) and 112 veh/hr (1 turn every 0.54 minutes). These results were compared with trip generation data compiled from a previously published research investigation (43). The trip generation data were expressed in average daily trips, and were converted in this study to hourly volumes using Table (4.1). The average trip end rates for a drive-in-restaurant along a two-way four-lane arterial were found to range from 52 veh/hr (1 turn every 1.15 minutes) to 147 veh/hr (1 turn every 0.408 minutes). These trip end rates clearly indicate that the area between curves M1 and M2 covers a volume range comparable to a typical land use development along an arterial.

Figure (4.38) can be decomposed into two zones: zone 1 below curve M1, and zone 2 above curve M1. Zone 1 represents smooth to stable traffic operations where turning
Figure 4.38 Relationships of levels of service C and E to traffic flow and turning volume at medium driveway density.
movements are easily made and average vehicular stoppages are less than 0.3 (i.e. less than one stop per each third vehicle in the inside lane). In zone 1, a TWLTL installation would not bring about potential savings in stops in the inside lane. It, however, can provide a storage lane for turning vehicles and can be used for emergency functions (e.g. detour route).

Zone 2 can be further divided into two sub-zones: zone 2a between curves M1 and M2, and zone 2b above curve M2. Zone 2a represents a zone of increasing restriction to drivers and back-ups which may develop behind turning vehicles. In zone 2a, a TWLTL installation would bring about potential savings in stops ranging from one stop per each third vehicle to one stop per vehicle in the inside lane. Zone 2b represents a zone where a TWLTL installation would bring about strong potential savings in stops: more than one stop per vehicle in the inside lane. In this study, the area between curves M1 and M2 define the recommended effective range of TWLTL applicability.

Having identified the effective range of TWLTL installation at a typical driveway density (the 250-ft spacing), the next step is to study the effect of higher and lower driveway densities on this effective range. First, the high driveway density has been chosen as that corresponding to 100 ft spacing. In Figure (4.39) the level of operation on curve H1 is C, and on curve H2 is E. Therefore, curves H1
Figure 4.39 Relationships of levels of service C and E to traffic flow and turning volume at medium and high driveway densities.
and H2 define the thresholds for TWLTL applicability for high driveway density. With reference to the TWLTL effective range between M1 and M2, the effect of a higher density (or lower spacing than the average spacing of 250 ft) is the lowering of curve M1 to a position between M1 and H1 (say M1'). However, the difference between lines M1 and M1' is not very high (a difference of 1 turn per driveway every 6 minutes).

The next step is to study the effect of a lower driveway density, i.e., driveway spacing higher than the average spacing of 250 ft. In Figure (4.40) the level of operation on curve L1 is C, and on curve L2 is E. With reference to the TWLTL effective range between M1 and M2, the effect of lower density is the movement of curve M2 upwards to M2' between M2 and L2. The difference in the effective range as defined by M2 and M2' is not very high (a difference of 1 turn per driveway every 4 minutes) except at traffic volumes lower than 1300 veh/hr per direction (a difference of up to 1 turn per driveway every 1.5 minutes).

The conclusion of these comparisons is that the range between curves M1 and M2 is representative of the effective range of TWLTL applicability along an arterial with a typical driveway density (the 250-ft spacing). The results of higher or lower driveway densities on the effective range is not very high except at low driveway density (the 450-ft spacing) at traffic volumes lower than 1300 veh/hr per direction.
Figure 4.40 Relationships of levels of service C and E to traffic flow and turning volume at low and medium driveway densities
The level of service ranges at all combinations of traffic volumes, turning volumes, and driveway densities are shown in Figure (4.41). It is interesting to point out that level of service E at the high driveway density (100 ft spacing) almost overlaps the level of service C of the low driveway density (the 450 ft spacing). This overlap indicates that both driveway spacings have covered the entire range of possible driveway spacings from a minimum of 100-ft to the length of a city block of 450-ft.

The provisions of the developed nomographs contained in Figures (4.38) through (4.41) have been obtained using the ARTSIM model. To test the validity of the model, several tests were conducted as discussed in Chapter III (see sections 3.2.3 and 3.2.8). The results of the tests were completely satisfactory. To ensure the applicability of the ARTSIM model and the practicality of the nomographs, further validation tests are recommended to adapt the model to the local traffic conditions.
Figure 4.41 Relationships of levels of service C and E to traffic flow and turning volume at low, medium, and high driveway densities.
4.9 EFFICIENCY OF THE MODEL

Computer running time is affected by the duration of the simulation run, traffic flow, and geometrics of the simulated street. In this research, the computer running times consumed by ARTSIM depend strongly on traffic flow rather than the percent left turns. Based on results from implementing the model on the AMDAHL 470/V8 facility, the average real-time/running-time ratio is approximately 65/1. Based on this ratio, it is necessary to examine the operating efficiency of ARTSIM against other well documented microscopic models: such as NETSIM (40) and FREECON (41). At comparable traffic volumes, ARTSIM is approximately 2.7 times faster than NETSIM, and 5.9 times faster than FREECON. These ratios clearly indicate that the model developed in this dissertation is far more economical than some of the existing simulation models. Therefore, traffic engineers would be able to fully test and gather information needed regarding the TWLTL within reasonable computer costs.

4.10 SUMMARY

The simulation model representing the operation of traffic on a four-lane two-way arterial with and without a TWLTL was successfully formulated and programmed for operation on the AMDAHL 470/V8 digital computer facility. The model performed satisfactorily in every respect within the limits described in the Chapter.
Through an experimental design procedure, it was possible to assess the impact of the TWLTL on four measures of effectiveness. The simulation results demonstrated the benefit gained by through traffic when a TWLTL was provided. Delay in terms of travel time, number of stops, and stopped-delay time was used, and a set of curves were developed. The principal factors determining the level of delay were found to be the traffic volumes on both directions, the percentage of left-turning vehicles, and driveway distribution.

A level of service procedure was suggested using the average number of stops per vehicle in the inside lane as a measure of the level of service. By selecting the desired level of service, or average number of stops per vehicle, traffic engineers can utilize ARTSIM, or the nomograph presented in this Chapter to determine if a TWLTL is applicable.
Chapter V
SUMMARY AND CONCLUSIONS

5.1 OVERVIEW OF RESULTS AND POTENTIAL APPLICATIONS

The use of simulation in studying the dynamic behavior of traffic systems allows, through the construction of microscopic models, a flexible and informative procedure for studying the driver-vehicle response to complex geometrics and control policies. Prediction of traffic performance is particularly important before implementing new control strategies for alleviating congestion on existing highway networks. Simulation models also find possible applications in the study of automated transportation systems such as the personal rapid transit (PRT) systems. Here, operational and design considerations such as operating procedures for demand responsive stations, empty vehicle shuttling, and capacity during peak hours would all benefit from implementation of a simulation model.

Development of representative and rigorous mathematical models of traffic systems is often complicated by such factors as stochastically varying traffic volumes, the complexity of traffic flow conditions, and type of control. In this research, simulation has been used as a convenient, economical and a powerful tool to analyze the effect of installing
a TWLTL on a two-way four-lane arterial. The ARTSIM model can predict the impact of TWLTLs on the quality of flow along arterials, and the effect of newly constructed drive-ways abutting roadside developments on traffic flow of arterials with and without TWLTLs.

The general approach presented was first to isolate traffic flow characteristics associated with TWLTLs, and then to build a microscopic simulation model to determine changes in traffic systems due to the installation of a TWLTL. The ARTSIM model is programmed using SIMSCRIPT II-5 language. This language has proven its flexibility and capability to greatly simplify the building of simulation models for traffic operations. The model is readable, manageable, and adaptable to different computer systems.

The ARTSIM model includes driver-vehicle routines that generate individual driver-vehicle units and describe their characteristics. To provide an organized structure and descriptive clarity of the system being simulated, the driver-vehicle units are represented in the model in terms of four classes of temporary entities that are grouped into their respective sets. Such a grouping provides a descriptive power of defining the interrelationships between each class of entities. The system activities are executed in the model by employing the concept of events. This concept allows reproducing the behavior of the system when changes, due to interaction between system entities, occur. Events occur in-
stanteneously and are executed in zero simulated time. The Timing Routine in SIMSCRIPT keeps track of the simulated time and organizes the scheduling of the event routines.

As each driver-vehicle unit is generated, it is assigned stochastically a set of attributes (performance characteristics), such as desired speed, acceptable gap size, destination, etc. (refer to Chapter III for a complete list). Each unit's movements along the arterial is controlled by microscopic car-following, queue-discharge, lane-change algorithms, and by the turning movements. The model has provided a means of generating realistic traffic conditions that showed satisfactory behavior at different driving conditions when validated against published literature (see sections 3.2.3, 3.2.8). Such a model is potentially useful for providing the traffic engineer with forecasts of the expected traffic behavior and it could alert him to the likelihood of saturated conditions before they occur.

The implementation phase of the ARTSIM model has been conducted on the AMDAHL 470/V8 facility. In general, the computer running time of a simulation model is affected by the duration of the simulation, the traffic volumes, and the geometrics of the simulated arterial. The average real-time/running-time ratio has been approximately 65/1 for ARTSIM. The left-turning percentage has a minimal effect, and so does the driveway distribution. The operating efficiency has been compared to other well documented simulation models
with comparable traffic volumes, as shown in Chapter IV. The ARTSIM model is approximately 2.7 times faster than NETSIM, and 5.9 times faster than FREECON. In effective models such as the one developed in this research, there is added confidence in conducting extensive simulation study within the limited computer resources.

The ARTSIM model is used to conduct a before-and-after simulation study on a two-way four-lane arterial section, with and without a TWLTL. The output of the simulation study include average reductions in number of stops, delay, and number of lane change maneuvers. Based on results from the simulation study, the following conclusions can be made:

1. The principal factors which determine the level of delay on arterials without TWLTLs are the traffic volumes, the left-turn percentage, and the driveway distribution. Stops and delay increase, as would be expected, as the traffic volume and left-turn percentage increase. The comparison between two driveway distributions has highlighted the effect of location of access points along an arterial. Figures (4.29) through (4.36) show insignificant differences in the measures of effectiveness for both driveway distributions. These differences were computed at traffic volume of 25,000 veh/day and at left-turn percentages of 10%, 20%, and 30%.
2. The improvement in quality of flow to through traffic due to the installation of the TWLTL becomes more significant at traffic volumes higher than 20,000 veh/day. Although in a previous work Harwood and Glennon (1) warrant the TWLTL at traffic volumes higher than 10,000 veh/day and a total of at least 20% left turns along a 1-mile arterial section, the effect of TWLTL has, in this study, been found to be insignificant below 12,000 veh/day for the simulated arterial.

3. The average number of stops per vehicle in the inside lane is employed as a measure of the degree of congestion along an arterial with midblock turning movements. Table (4.6) summarizes the level of service stratifications. Based on these stratifications, a nomograph has been generated using ARTSIM. This nomograph can be used traffic engineers as a guideline to determine if a TWLTL is applicable. The nomograph should be viewed as an alternate to the existing approximation procedure recommended by the Highway Capacity Manual which assumes the presence of traffic signals at the driveways. The nomograph provides a level of service ranges from level C to level E for three driveway densities: low, medium, and high. The medium density level represents the average density found along a section of the North High street in Co-
lumbus, Ohio, which currently incorporates a TWLTL. The low and high density levels represent the boundaries of driveway densities.

5.2 PROSPECTS FOR FUTURE RESEARCH

The development of guidelines for installing the TWLTL is by no means complete. This may well be the area in which the developed simulation model can have the biggest impact by providing a data base for an optimization model, since it avoids the problems associated with the TWLTL study techniques mentioned in Chapter I. Further work in this area would be useful and is highly recommended. In doing so, the following elements are of considerable interest:

1. For the type of left-turning movements made from TWLTLs to abutting driveway entrances studied in this research, field studies are required to study gap acceptance characteristics of left-turning vehicles at or near such driveways, and other characteristics affecting the left-turn maneuver.

2. A number of field studies should be conducted to further verify the validity of the simulation model. A time-lapse camera or aerial photogrammetry technique is recommended for detailed data collection.

3. There is a need to provide an evaluation of the manner in which lane changes are made along the arterial. Furthermore, a study of lane change lag accep-
tance distribution is required for this type of arterials.

4. The effect of using traffic control devices (e.g., traffic signs, pavement markings) in guiding turning traffic into the TWLTL should be tested. The impact of the currently adopted Manual on Uniform Traffic Control Devices (MUTCD) standards could be manipulated in a simulation model to explore their functions in providing informational needs to drivers.

In conclusion, speculation about the future of simulation in analyzing transportation systems is proper and desirable in view of the potential of this traffic analysis tool. The field of transportation, as it exists today and is likely to exist for many years to come, deals with systems which are largely governed by human factors. It seems extremely unlikely that theoretical models would be of satisfactory use. As the importance of including dynamic considerations in the analysis of transportation systems has been recognized, the use of simulation for studying existing system may well turn out to be the most informative and reliable technique. Given the problems which exist today in transportation field and the likelihood of severe constraints on resources in the future, simulation would be a powerful tool for understanding the forces that shape and form our current transportation problems. It would also be instrumented in finding constructive solutions to the problems of tomorrow.


Appendix A
DESCRIPTION OF THE MODEL'S ROUTINES

The following is a brief description of all routines in ARTSIM, and a complete listing of the program is provided in Appendix (B). The routines employed in the case with TWLTL are first described.

1-PREAMBLE: The first section in any SIMSCRIPT program is the PREAMBLE. All modelling elements must be declared in the PREAMBLE without any executable statements. Four elements are defined in ARTSIM and are given below:

a-Temporary Entities: A driver-vehicle unit is generated in the model as a temporary entity. A Temporary Entity is used to model a short lived object in the system; it is a passive structure that can be manipulated explicitly by the programmer. Temporary entities may have attributes and either belong or own sets. SB1, SB2, NB3, and NB4 are four temporary entities representing driver-vehicle units; one entity type per lane.

b-Sets: A set is a collection of entities placed according to a specified discipline. When the set discipline is omitted, entities are filed on a first-in-first-out basis. A temporary entity is filed in its designated set when
generated, and removed from it once its function has expired. LANE1, LANE2, LANE3, and LANE4 are system-owned sets: they are named after the lane number. Turning vehicles are filed when appropriate in the NTWLT and STWLT sets. LANE2, LANE3, NTWLT, and STWLT are organized according to the position of each driver-vehicle unit to assure proper ranking after a lane change maneuver.

c- Routines: Routines are defined with specified input and output arguments. The following is definition and function of the routines used in ARTSIM:

1. TNSD: A target speed is selected at random from a truncated normal distribution with a mean VMU and a standard deviation VSIG.

2. SSDC: The safe space headway is computed given the speeds of the lead vehicle and the follower.

3. TEXP: The driver-vehicle units are generated from a shifted negative-exponential distribution. The shift is amounted to 0.75 seconds. The input argument is the hourly volume, and the output argument is headway in seconds.

4. CRFEQ: The acceleration of the subject vehicle is the output argument given the speeds and positions of the lead vehicle and the subject vehicle, utilizing the car-following model.

5. ACCELERATION: The acceleration computed at any step in the model is always checked against a speed profile.

6. DECELERATION: A similar routine is provided to check any computed deceleration.

7. STATUS: It is a debugging routine to allow the programmer to trace selected variables. It is called at a specified simulation time. This routine is omitted from the final model since its function has expired.
**d- Events:** In SIMSCRIPT, an event routine is the program which describes the logic of an event at an instant in simulated time. In ARTSIM, events are scheduled every time step to update the attributes of driver-vehicle units or whenever appropriate.

There are other declarations that can be made in the PREAMBLE section such as background conditions, global variables, and performance statistics.

**2- MAIN:** For a SIMSCRIPT program, execution begins with the first statement in MAIN. It serves the following functions:

1. Reads all the user input data.
2. Prints the input echo data.
3. Schedules the beginning of the vehicle generating event for each lane (GEN1, GEN2, GEN3, GEN4).

The following parameters are generally read as the user input:

**Arterial parameters** Four variables are to be input: the number of lanes in both directions (ST.TYPE: two or four), length of simulated arterial (SEGMENT) in ft, approach length (S12, S34) in both directions, and the driveway locations on each side (SL, SR).

**Traffic parameters** Such as the hourly volume on each lane (VOL1, VOL2, VOL3, VOL4), mean speed and standard deviation
in each direction (VMU1, VSIG1, VMU3, VSIG3), proportion of
left turners (LTP), percentage of potential lane changers
(LCP) and maximum allowable deceleration rate (MDEC).

**Fuel Consumption parameters** such as the vehicle rolling
resistance parameter (K1.FUEL) and the idle fuel flow rate
parameter (K2.FUEL). These are embedded variables.

**Driver related parameters**. Three probability distributions
are inserted in the simulation program in a tabular form
where a table-look-up procedure is used. They are: gap and
lag acceptance probability for left turners (GAP, LAG) and
lag acceptance probability of a lane changer (LANE.CHANGE).
These distributions are inserted in the model as system attributes declared in the PREAMBLE. It should be noted that
the driver's reaction time is kept constant at 0.75 second
for all drivers.

**Simulation related parameters**. Included are the random
number seeds (SEED1, SEED2, SEED3, SEED4, SEED5), the scan­
ning period (C), the number of requested subruns (N.OUT),
the simulation time per subrun (T.STOP), and the start-up
period (WARM.UP).

3- **Generation Process**:  
Four routines are associated with the generation pro­
cess: GEN1, GEN2, GEN3, and GEN4. These events are identi­
cal in function and each is associated with a single lane;
e.g. GEN1 is reserved for activities in lane 1. The basic purposes of these routines are as follows:

1. Create a temporary entity that represents a vehicle and file it in a set.
2. Generate vehicle and driver attributes.
3. Schedules the next generating event depending on the interarrival headway in the lane.

Each routine assumes that each vehicle has just arrived at the system entry point on one of the lanes. When this occurs, a new time headway is randomly generated using the TEXP routine, and a new arrival time is determined. Each generated vehicle is then processed in the system by scheduling the cognate update routine.

4- Event INITIALIZ

The purpose of this event is to reset all the variates counters to zero after a start-up period, to eliminate the observations collected during the transient state. The random numbers and the entities in the system are kept untouched.

5- Vehicle Update routines

The purpose of these routines is to process all vehicles on all lanes. The following table shows the routines utilized by vehicles in the four approaches.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Vehicle</th>
<th>Free-flow routine</th>
<th>Forced-flow routine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>SB1</td>
<td>ADJS3</td>
<td>ADJS4</td>
</tr>
</tbody>
</table>
This table shows that two routines compute the position, speed and acceleration of a vehicle according to the flow condition. As a free-flow routine is first scheduled, it identifies the vehicle leading the vehicle being processed. If the processed vehicle is the first in the set or it is 200-ft away from its lead vehicle, an acceleration is computed assuming that a vehicle will always try to travel at its target speed. Otherwise, control is transferred to the forced-flow routine. When the forced-flow routine is scheduled, the lead vehicle is updated during this time-step while the subject vehicle is yet to be updated. The CRSEQ routine is called to compute the acceleration using the car-following model. The acceleration is internally checked against the speed profile using the ACCELERATION and DECELERATION routines.

Each routine determines if a turning vehicle in the inside lane has reached the 250-ft zone upstream its intended exit. If it has, control is transferred to the TWLT routine to determine if it is possible to enter the median lane. Otherwise, the free-flow routine is called after a time-step unit.
Statistics for straight vehicles are collected at a distance of 200-ft from the system boundary (rather than at the boundary) before they exit the system. This design alleviates any bias due to the absence of a lead vehicle. When straight vehicles reach the end of the simulated segment, they are removed from their sets and consequently from the system.

Control is transferred from the update routines to the stopping routines before updating the vehicle's attributes when the lead vehicle is in a stopped position or to avoid an accident by applying the maximum deceleration rate.

6- Events WAIT4(NB3), WAIT5(SB2):

The two events are designed to compute the deceleration rate necessary for a vehicle to stop behind a stopped vehicle in the inside lanes. The vehicle may be a straight or a turning vehicle. Each event always checks if it is still necessary for the vehicle to stop, that is if the lead vehicle is still stopped. As a vehicle comes to a complete stop, control is transferred to waiting events described below.

This type of event is not needed for vehicles in the outside lanes as stopping is not likely to occur.

7- Events WAIT2(NB3), WAIT3(SB2):

These events are scheduled when a vehicle comes to a complete stop. A vehicle stays in the queue until one of
the following occurs either the leader is in motion and the car-following model can be applied, or the vehicle has become the first in the queue and can be processed, or an lane change maneuver has been successful.

8- The TWLTL entry routines:

Several steps are to be checked before a turning vehicle starts entering the TWLTL from either direction of travel. Event SLTM1(NB3) (or TRVL1(SB2)) first determines whether the TWLTL or the segment between the intended driveway and the current position of the vehicle, is clear of vehicles from the opposing direction. In either case, control is transferred to event SLTM4(NB3) (or TRVL4(SB2)) to carry out the same check for vehicles in the same direction. If the roadway segment is occupied then a turning vehicle will decelerate in the inside lane using the event SLTM3(NB3) (or TRVL3(SB2)) until the vehicle can enter the TWLTL on a reverse-curve path, and the vehicle is removed from the inside lane to the TWLTL in the event SLTM2(NB3) (or TRVL2(SB2)).

9- Left-turn Update routines:

Two routines (FLTM1(NB3), FLTM(NB3)) similar to the vehicle update routines are reserved for left turners only. FLTM1(NB3) is scheduled for the first vehicle in the NTWLT set. Its acceleration is computed so as to reach a maximum turning speed at the start-free-left-turn point. FLTM(NB3)
is scheduled for the remaining left turn vehicles in the NTWLT set. Two accelerations are computed in this routine: one from the car-following routine, and one similar to that acceleration computed in the FLTM1 routine. The left turn vehicle will utilize the acceleration that results in more restrictive behavior.

The position and the speed of the left turn vehicle is updated using the computed acceleration. The routine checks if the vehicle has just arrived at the start-free-left-turn point. If it has, control is transferred to gap search routines. If it has not arrived, the routine is scheduled after a time-step unit.

Similar routines are utilized by turning vehicles from the southbound. They are: FLTM3(SB2) and FLTM2(SB2).

10- Gap Search routines:
Two routines (RMVL(NB3), UPDT1(NB3)) computes the available gap in the opposing southbound traffic. RMVL(NB3) routine is first scheduled when a left turner is in the TWLTL and in a position to negotiate a left turn maneuver. The routine searches for vehicles in the outside lane (lane 1) in the segment upstream the intended driveway. If none is found, control is transferred to UPDT1(NB3). Otherwise, the time required for the first vehicle in lane 1 to reach the center line of the driveway is computed. This time is compared to a driver's gap and a decision is made whether to accept or reject the available gap. If the gap is accepted,
control is transferred to UPDT1(NB3). Otherwise the maneuver is aborted and control is transferred to a routine depending upon the actual speed of the vehicle.

Similar strategy is utilized in the UPDT1(NB3) routine to search for gaps in lane 2. If a driver decide to accept a gap, control is transferred to MANVR(NB3) or REM1(NB3) routines to handle vehicle exiting the system. The same strategy is employed for turning maneuvers from the south-bound traffic; they are UPDT2(SB2) and UPDT3(SB2).

11- Stopping routines:

The DECLT(NB3) and SLOW(SB2) routines are scheduled when a turning vehicle in the TWLTL rejects the available gap and prepares to stop at the proper position. During stopping, it always checks the available gaps in the opposing traffic by scheduling the gap search routines, until the vehicle either stops or a suitable gap is found.

The WAIT(NB3) and WAIT1(SB2) routines are scheduled when a turning vehicle in the TWLTL has to stop behind another turning vehicle. The deceleration rate is computed such that the turning vehicle would stop 3-5 ft behind the lead vehicle, and control is transferred to the events REM4(NB3) and REM6(SB2).

12- Events REM4(NB3) and REM6(SB2):

These routines are scheduled for turn vehicles stopped in the TWLTL behind a lead vehicle negotiating a left turn
maneuver. Each routine determines if the current vehicle may move to a new position. All vehicles scheduled in this routine have a speed of zero. When the lead vehicle finds an acceptable gap, it is flagged by so and the second vehicle in the queue would start creeping to occupy the position of its flagged leader. Other vehicles in the queue follow the car-following model to occupy a new position in the TWLT.

13- Events MANVR(NB3), REM1(NB3), TRVL4(SB2), REM5(SB2):
The MANVR(NB3) and TRVL4(SB2) events are scheduled when a turning vehicle finds a suitable gap and starts exiting the system. Moving vehicles are handled in either event by maintaining the maximum turning speed. Stopped vehicles are processed by the REM1(NB3) or REM5(SB2) event routine. Vehicles are removed from the system as soon as they enter the driveway, and statistics are collected.

14- Events REM3(NB3), REM2(SB2):
These routines are scheduled immediately before a left turner is removed from the system. The average time spent in the system and fuel consumption are attributes computed for each left turner from the point they start entering the TWLT.

15- Lane Change process:
The lane-change process is handled by two routines. The first routine checks the space headway between the po-
potential lane changer and potential new follower in the receiving lane. If it is safe, the second routine is scheduled to check the space headway between the potential new lead vehicle and the lane changer. If it is safe, the vehicle is moved from the origin lane to the adjacent lane carrying its attributes.

These routines are always scheduled when a potential lane changers travels at a speed lower than its target speed. Lane change is permitted after a vehicle has travelled 100-ft in the system to establish stability. Since left-turners are generated in the inside lanes, they are not potential lane changers. Cross reference table is provided below for routines used with each vehicle type.

<table>
<thead>
<tr>
<th>Potential lane changer</th>
<th>check follower routine</th>
<th>check leader routine</th>
<th>stopped position</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB1</td>
<td>LNCH1</td>
<td>LNCH2</td>
<td></td>
</tr>
<tr>
<td>SB2</td>
<td>LNCH7</td>
<td>LNCH8</td>
<td>LNCH</td>
</tr>
<tr>
<td>NB3</td>
<td>LNCH5</td>
<td>LNCH6</td>
<td>LNCH9</td>
</tr>
<tr>
<td>NB4</td>
<td>LNCH3</td>
<td>LNCH4</td>
<td></td>
</tr>
</tbody>
</table>

The purpose of LNCH9(NB3) and LNCH(SB2) is to search for an acceptable lag in the outside lanes for straight vehicles stopped in lane 2 or lane 3. These routines examine traffic in the outside lanes to determine whether an on-com-
ing vehicle is so close as to preclude the lane change maneuver (lag is less than the driver's acceptable lag). If the lag is accepted, the vehicle will be moved to the outside lane.

This is accomplished by creating an identical vehicle unit (a temporary entity) to the processed vehicle, in the new lane, having the same attributes of the old entity but under a new name (NB4 or SB1), then removing the original vehicle unit from the system. If the lag is rejected, the attempt to switch lanes is aborted, and the vehicle remains in the queue and control is transferred to the updating routines. However, the vehicle will attempt to switch lanes every time-step unit by entering either routine until it is successful or it starts moving.

16- Output routines:

These routines provide summary statistics of the arterial system performance. They are executed at the end of the simulation run. The routines utilize the following functions: maximum, minimum, means, standard deviation, and histograms.

The routine OUTPUT produces a complete report of traffic stream variates in each lane with separate report for the left-turning movements in either direction. Statistics of travel time, number of stops, stopped-delay, fuel consump-
tion, number of lane changes, and number of maximum deceleration utilized are provided.

The OUT.BM routine is an optional feature of the model. It is only provided if the user chooses to make extensive use of the Batch Means procedure as a variance reduction technique.

As previously mentioned, ARTSIM is capable of simulating traffic flow conditions along an arterial section without a TWLTL. This section reports the changes encountered by removing the TWLTL from the system. The basic changes occur only at the point where left-turning vehicles are to enter the TWLTL. Instead they would continue travelling in the inside lanes thereby introducing the possibility of a queue buildup. The TWLTL entry routines are omitted from the model. Turning vehicles are kept in their original sets and are only removed from these sets when a suitable gap is found in the opposing traffic.
Appendix B

ARTSIM LISTING OF ROUTINES

** THE FOLLOWING IS DEFINITION OF THE VARIABLES USED IN THE **
** PROGRAM. EACH VARIABLE CONSISTS OF A CHARACTER STRING AND **
** ENDS WITH A NUMBER. THIS NUMBER REPRESENTS THE LANE NUMBER. **
** THEREFORE, VARIABLES OF ONE LANE WILL BE DEFINED AND THE READER **
** CAN FOLLOW THE OTHER VARIABLES BY CHANGING THE NUMBER AFFILIATED **
** WITH THE VARIABLE ACCORDING TO THE LANE NUMBER. **

** NB3 VEHICLE GENERATED IN LANE #3 TRAVELING NORTH **
** LANE3 SET WHERE NB3 VEHICLES ARE STORED ACCORDING TO A DECLARED **
** DISCIPLINE **
** SB2 VEHICLE GENERATED IN LANE #2 TRAVELING SOUTH **
** LANE2 SET WHERE SB2 VEHICLES ARE STORED **
** NTWLTL SET WHERE LEFT-TURN VEHICLES OF TYPE NB3 ARE STORED WHEN **
** THEY ENTER THE TWLTL **
** STWLTL SET WHERE LEFT-TURN VEHICLES OF TYPE SB2 ARE STORED **

** AR3.TIME ARRIVAL TIME OF VEHICLE NB3 AT THE SYSTEM **
** X3 POSITION OF THE VEHICLE NB3 AT THE CURRENT SIMULATION TIME **
** TIME **
** V3 SPEED OF THE VEHICLE NB3 AT THE CURRENT SIMULATION TIME **
** A3 ACCELERATION OF NB3 **
** LAG3 THE LEFT-TURNER OF TYPE NB3 WILL NOT ACCEPT A LAG < LAG3 **
** GAP3 NB3 WILL NOT ACCEPT A GAP < GAP3 **
** LCLAG3 A STOPPED NB3 WILL NOT ACCEPT A LAG < LCLAG3 TO CHANGE **
** ITS LANE. **
** BL3 A FLAG FOR A NB3 WHO IS CHANGING ITS LANE AND MOVING **
** LATERALLY TO ITS NEW LANE **
** TENT3 TIME WHEN A NEW NB4 IS CREATED TO REPLACE NB3 **
** B3 A FLAG TO DECLARE THAT THE VEHICLE NB3 HAS ALREADY **
** STARTED CHANGING ITS LANE AND THERE IS NO NEED TO LOOK **
** FOR ANOTHER CHANCE TO CHANGE ITS LANE **
** TLC3 THE TIME A NB3 STARTED CHANGING ITS LANE. THIS VARIABLE **
** IS ASSOCIATED WITH B3 VARIABLE. **
** EXIT DISTANCE A NB3 MUST TRAVEL BEFORE EXITING FROM THE SYSTEM **
** GS3 THE SECTION OF THE ARTERIAL WHERE A LEFT-TURNER OF NB3 **
** TYPE WILL BE LOOKING FOR A GAP IN THE OPPOSING DIRECTION **
** TGT3 TARGET SPEED OF A NB3 **
** VMU3 MEAN SPEED INPUT IN THE NORTH DIRECTION **
** VSIG3 STANDARD DEVIATION OF SPEED IN THE NORTH DIRECTION **
** VOL3 INPUT TRAFFIC VOLUME IN LANE #3 **
** PRL3 PROBABILITY THIS NB3 WILL TURN LEFT **
** PRLC3 PROBABILITY THIS NB3 WILL CHANGE ITS LANE **
** PSLTM POSITION A LEFT-TURN NB3 SHOULD START ENTERING **
** THE MEDIAN LANE (TWLTL)
TSLTM  TIME THE LEFT-TURN VEHICLE NB3 STARTS ENTERING TW

FLG  A FLAG TO IDENTIFY A LEFT-TURNER FOUND AN ACCEPTABLE GAP

VMAXT  MAXIMUM SPEED OF A NB3 WHILE TURNING

R3  RADIUS OF A TURN

NNSTOP  NUMBER OF STOPS OF STRAIGHT-THROUGH NB3 VEHICLES

NSTDY  STOPPED-DELAY OF NB3 VEHICLES

NLTPWY  NUMBER OF DRIVeways WHERE NB3 VEHICLES WILL EXIT

TSYS  TIME SPENT BY LEFT-TURN VEHICLES 250-FT BEFORE EXITING

LPHI3  FUEL CONSUMED BY LEFT-TURN NB3 VEHICLES

TT3  TRAVEL TIME OF NB3 VEHICLE

X03  DISTANCE TRAVELLED BY NB3 IN THE SYSTEM

N3  NUMBER OF NB3 VEHICLES EXITED FROM THE SYSTEM

NL3  NUMBER OF NB3 VEHICLES WHO CHANGED THEIR LANE

PH31  FUEL CONSUMED BY STRAIGHT-THROUGH VEHICLES ON LANE #3

TSTOP  SIMULATION TIME IN SECONDS

WARM.UP  INITIALIZATION PERIOD FOR THE SYSTEM

SEGMENT  ARTERIAL SECTION LENGHT

NLTP  LEFT-TURN PERCENT FROM THE NORTH DIRECTION

MDEC  MAXIMUM DECELERATION

SL  ARRAY OF LEFT DRIVEWAY DISTANCES

C  SCANNING PERIOD IN SECONDS

******************************************************************************

NORMALLY MODE IS INTEGER

******************************************************************************

REQUIRED DEFINITIONS FOR BATCH MEANS

******************************************************************************

DEFINE BM.NUM.EST.BM.TPVS.BM.M AS VARIABLES
DEFINE BM.TPDEL.BM.TIMEO AS REAL VARIABLES
DEFINE BM.CNT.BM.BSZ.BM.NB AS 1-DIMENSIONAL ARRAYS
DEFINE BATCHES AND BM.TPARRAY AS 2-DIMENSIONAL REAL ARRAYS
DEFINE BM.OBS AS A 1-DIMENSIONAL REAL ARRAY MONITORED ON THE LEFT
DEFINE BM.SUMS AS A 1-DIMENSIONAL REAL ARRAY
DEFINE STUDENT.T AS A REAL FUNCTION

******************************************************************************

TEMPORARY ENTITIES

EVERY NB4 HAS A V4, A X4, AN A4, AN AR4.TIME, A TGTV4, A B4, A TENT4,
A TLC4, A LAGLC4, A PRLC4, A BL4, A R44 AND MAY BELONG TO A LANE4
EVERY NB3 HAS AN AR3.TIME, A V3, A X3, AN A3, A GAP3, A LAG3, A PRLT3,
A TGT3, A SRC, A PSLTM, A TSLT, A FLG, A VMAXT, A R3, AN EXIT, A GS3,
A B3, A TLC3, A LCLAG3, A PRLC3, A TST3, A TENT3, A BL3, A R33, A TR3,
AN ASENT, AN ASTIM AND MAY BELONG TO A LANE3 AND A NTWLT
EVERY SB1 HAS A VI, A XI, AN AI, AN AR1.TIME, A B1, A TLC1, A LAGLC1,
A BL1, A TENT1, A R11,
A PRLC1, A TGT1 AND MAY BELONG TO A LANE1
EVERY SB2 HAS A V2, A X2, AN A2, AN AR2.TIME, A TGTV2, A PRLT2, A R2,
AN EXIT2, A PSLT, A TSLT, A GAP2, A LAG2, A VMAX, A SRC2, A FLG2, A R22,
A GS2, A TLC2, A SENT2, A PRLC2, A B2, A TST2, A LCLG2, A TENT2, A BL2
AND MAY BELONG TO A LANE2 AND A STWLT
DEFINE GAP3, LAG3, PRTL3, A3, GAP2, LAG2, PRTL2, A2 AS REAL VARIABLES
DEFINE AR1.TIME, AR2.TIME, AR3.TIME, AR4.TIME, A1 as REAL VARIABLES
DEFINE V1, V2, V3, V4, TGT1, TGT2, TGT3, TGT4 AS REAL VARIABLES

DEFINE NTWLT AS A SET RANKED BY HIGH X3
DEFINE STWLT AS A SET RANKED BY HIGH X2
DEFINE LANE3 AS A SET RANKED BY HIGH X3
DEFINE LANE2 AS A SET RANKED BY HIGH X2
DEFINE LANE1 AS A SET RANKED BY HIGH X1
DEFINE LANE4 AS A SET RANKED BY HIGH X4

' DEFINITION OF ROUTINES

DEFINE TNSD AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1
DEFINE TEXP AS A ROUTINE GIVEN 1 ARGUMENT YIELDING 1
DEFINE CRF EQ AS A ROUTINE GIVEN 4 ARGUMENTS YIELDING 1
DEFINE SSDC AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1
DEFINE DECELERATION AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1
DEFINE ACCELERATION AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1
DEFINE NCHECK AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1
DEFINE SCHECK AS A ROUTINE GIVEN 2 ARGUMENTS YIELDING 1

'SYSTEM ATTRIBUTES

DEFINE TLC1, TLC4, PRLC1, PRLC4, A4, LAGLC1, LAGLC4, TCP, VMU1, VSIG1 AS REAL VARIABLES
DEFINE SL, SR AS 1-DIMENSIONAL ARRAYS

' EVENT NOTICES

EVENT NOTICES INCLUDE OUTPUT, GEN3, GEN1, GEN2, GEN4, INITIALIZ, OUT.BM
EVERY DECL HAS A C2    EVERY REM3 HAS A C3
EVERY ADJS2 HAS A C6    EVERY MANVR HAS A C7
EVERY SLTM4 HAS A C8    EVERY RMLT HAS A C9
EVERY ADJS1 HAS A C10   EVERY FLTLM HAS A C11
EVERY UPDT1 HAS A C12   EVERY ADJS3 HAS A C14
EVERY ADJS4 HAS A C15   EVERY FLTLM1 HAS A C16
EVERY LNCHT1 HAS A C19  EVERY LNCHT2 HAS A C20
EVERY LNCHT3 HAS A C21  EVERY LNCHT4 HAS A C22
EVERY ADJS7 HAS A C23   EVERY ADJS8 HAS A C24
EVERY ADJS5 HAS A C17   EVERY ADJS6 HAS A C18
EVERY WAIT HAS A C25    EVERY REM1 HAS A C27
EVERY REM4 HAS A C29    EVERY SLTM1 HAS A C30
EVERY SLTM2 HAS A C31   EVERY SLTM3 HAS A C32
EVERY TRVL1 HAS A C4    EVERY TRVL2 HAS A C5
EVERY TRVL3 HAS A C58   EVERY TRVL4 HAS A C40
EVERY FLTLM2 HAS A C26  EVERY FLTLM3 HAS A C28
EVERY SLOW HAS A C33    EVERY UPDT2 HAS A C34
EVERY UPDT3 HAS A C35  EVERY REM2 HAS A C36
EVERY REM5 HAS A C37  EVERY REM6 HAS A C38
EVERY WAIT1 HAS A C39  EVERY LNCH5 HAS A C44
EVERY TRVL5 HAS A C45  EVERY LNCH6 HAS A C41
EVERY LNCH7 HAS A C42  EVERY LNCH8 HAS A C43
EVERY LNCH HAS A C46  EVERY LNCH9 HAS A C47
EVERY WAIT3 HAS A C48  EVERY WAIT5 HAS A C49
EVERY WAIT2 HAS A C50  EVERY WAIT4 HAS A C51
EVERY ADJS9 HAS A C70
EVERY ADJS0 HAS A C71
EVERY TRVL6 HAS A C74  EVERY TRVL7 HAS A C75
EVERY FLTM4 HAS A C76  EVERY FLTM5 HAS A C77
EVERY FLTM6 HAS A C78  EVERY FLTM7 HAS A C79
EVERY REM7 HAS A C80  EVERY REM8 HAS A C81
EVERY WAIT8 HAS A C82  EVERY WAIT9 HAS A C83
EVERY MNVR1 HAS A C84  EVERY MNVR2 HAS A C85
EVERY WAIT6 HAS A C86  EVERY WAIT7 HAS A C87

DEFINE ST.TYPE AS AN ALPHA VARIABLE
DEFINE XD1,XD2,XD3,XD4,NLDWY,NRDWY AS VARIABLES
DEFINE VMU3,VSIG3,C,TT4,MDEC,TT1,TT2,TT3,NLTP,SLTP,T.SYS,TSYS2,
     LCLG2,LCLAG3,TENT1,TENT2,TENT3,TENT4 AS REAL VARIABLES
DEFINE N1,N2,N3,N4,NLT2,NLT3,NMDEC,NMDE1,CASE AS VARIABLES
DEFINE VOL1,VOL2,VOL3,VOL4,NNST0P,NNSSTOP,OPTION1 AS VARIABLES
DEFINE NSTDY,SSTDY,TST2,TST3 AS REAL VARIABLES
DEFINE NL1,NL2,NL3,NL4,NSTAT0P,NSTAT1 AS VARIABLES
DEFINE S12,S34,T.STOP,SEGMENT,MED.TRTMNT AS VARIABLES
DEFINE SECONDS TO MEAN UNITS
DEFINE K1,FUEL,K2,FUEL,PHI1,PHI2,PHI3,PHI4,LPHI2,LPHI3 AS REAL VARIABLES
DEFINE EXIT3.HISTOGRAM,EXIT2.HISTOGRAM AS VARIABLES
DEFINE WARM.UP AS A REAL VARIABLE

     AS THE MEAN,AND V.T.SYS AS THE VARIANCE OF T.SYS
TALLY T1.BAR AS THE MEAN,T1.MAX AS THE VARIANCE,T1.MIN AS THE
     MINIMUM OF T1
TALLY T2.BAR AS THE MEAN,T2.MAX AS THE VARIANCE,T2.MIN AS THE
     MINIMUM OF T2
     MINIMUM OF T3
     MINIMUM OF T4
TALLY MAX.T AS THE MAXIMUM,MIN.T AS THE MINIMUM,AVG.T AS THE MEAN,
     AND VAR.T AS THE VARIANCE OF TSYS2
TALLY X1.BAR AS THE MEAN OF XD1
TALLY X2.BAR AS THE MEAN OF XD2
TALLY X3.BAR AS THE MEAN OF XD3
TALLY X4.BAR AS THE MEAN OF XD4
TALLY P1.BAR AS THE MEAN,MX.P1 AS THE MAXIMUM,MI.P1 AS THE MINIMUM,
     V.P1 AS THE VARIANCE,S.P1 AS THE SUM OF PHI1
TALLY SST.BAR AS THE MEAN, SST.M AS THE MAXIMUM, SST.N AS THE MINIMUM, SST.V AS THE VARIANCE OF SSTDY
TALLY H.EX3(300 TO 1800 BY 50) AS THE HISTOGRAM OF EXIT3.HISTOGRAM
TALLY H.EX2(300 TO 1800 BY 50) AS THE HISTOGRAM OF EXIT2.HISTOGRAM
ACCUMULATE A3.LAN3 AS THE MEAN OF N.LANE3
ACCUMULATE A4.LAN4 AS THE MEAN OF N.LANE4
ACCUMULATE A2.LAN2 AS THE MEAN OF N.LANE2
ACCUMULATE A1.LAN1 AS THE MEAN OF N.LANE1

MAIN
READ ST.TYPE, CASE
READ SEGMENT, NLDWY, NRDWY, S12, S34
READ N.OUT, T.STOP, C, WARM.UP
READ VMU1, VSIG1, VOL1, VOL2, VOL3, VOL4, VMU3, VSIG3
READ LCP, NLTP, SLTP, MDEC
READ SEED1, SEED2, SEED3, SEED4, SEED5
RESERVE SL(*) AS NLDWY
RESERVE SR(*) AS NRDWY
READ SL
START NEW CARD
READ SR

LET BM.NUM.EST=4 LET BM.TPVS=0
LET BM.M=200 CALL BM.INIT
LET K1.FUEL = 0.0362
LET K2.FUEL = 0.746
PRINT 5 LINES WITH ST.TYPE THUS
SIMULATION OF MIDBLOCK TRAFFIC FLOW ON A TWO-WAY

****-LANE ARTERIAL
IF CASE=1 PRINT 1 LINE AS FOLLOWS
    CASE (1): WITH A TWLTL
ELSE PRINT 1 LINE AS FOLLOWS
    CASE (2): WITHOUT A TWLTL
ALWAYS
SKIP 2 LINES
PRINT 34 LINES WITH VMU3,VSIG3,VMU1,VSIG1,VOL1,VOL2,VOL3,VOL4,
    LCP,C,T.STOP,NLTP,SLTP,MDEC,S12,S34 THUS
    INPUT DATA

INPUT MEAN SPEED IN NORTH-BOUND = ***.** FT/SEC
INPUT STD.DEV IN NORTH-BOUND = ***.** FT/SEC
INPUT MEAN SPEED IN SOUTH-BOUND = ***.** FT/SEC
INPUT STD.DEV IN SOUTH-BOUND = ***.** FT/SEC
VOLUME IN LANE 1 = **** VEH/HR
VOLUME IN LANE 2 = **** VEH/HR
VOLUME IN LANE 3 = **** VEH/HR
VOLUME IN LANE 4 = **** VEH/HR
% OF DRIVERS CHANGE LANES = *.**
SCANNING TIME = **.** SECONDS
SIMULATION TIME / SUBRUN = ****.** SECONDS
% OF LEFT-TURN TRAFFIC FROM NORTH-BOUND = *.**
% OF LEFT-TURN TRAFFIC FROM SOUTH-BOUND = *.**
MAX DECELERATION = ***.** FT/SEC/SEC
DISTANCE BETWEEN SECTIONS 1 & 2 = **** FT
DISTANCE BETWEEN SECTIONS 3 & 4 = **** FT

SKIP 1 LINE
PRINT 6 LINES WITH SEGMENT,N.OUT,WARM.UP THUS
    LENGTH OF SIMULATED ARTERIAL = ********.** FT

NUMBER OF REQUESTED OUTPUTS (SUBRUNS) = ***
WARM UP PERIOD BEFORE COLLECTING DATA = ***.** SECONDS
PRINT 9 LINES WITH SEED1,SEED2,SEED3,SEED4,SEED5  THUS
RANDOM NUMBER SEED FOR VEHICULAR INTERARRIVAL = ************

RANDOM NUMBER SEED FOR TARGET SPEEDS = ************
RANDOM NUMBER SEED FOR LEFT-TURN PROBABILITY = ************
RANDOM NUMBER SEED FOR LANE-CHANGE PROBABILITY = ************
RANDOM NUMBER SEED FOR LEFT-TURN DESTINATION = ************

SKIP 2 LINES
PRINT 5 LINES WITH K1.FUEL,K2.FUEL  THUS
FUEL CONSUMPTION PARAMETERS

ROLLING RESISTANCE PARAMETER = **.****
FUEL FLOW RATE PARAMETER = **.****
LET NLTP = NLTP*(VOL3+VOL4)/VOL3
LET SLTP = SLTP*(VOL1+VOL2)/VOL2

SKIP 3 LINES
PRINT 4 LINES AS FOLLOWS
LEFT-HAND SIDE DRIVEWAYS

DRIVEWAY NUMBER  DISTANCE FROM ORIGIN
FOR I=1 TO NLDWY, PRINT 1 LINE WITH I,SL(I)  THUS
**  ****

SKIP 5 LINES
PRINT 4 LINES AS FOLLOWS
RIGHT-HAND SIDE DRIVEWAYS

DRIVEWAY NUMBER  DISTANCE FROM ORIGIN
FOR I=1 TO NRDWY, PRINT 1 LINE WITH I,SR(I)  THUS
**  ****

START NEW CARD
READ LAG
START NEW PAGE
PRINT 2 LINES AS FOLLOWS
LAG SIZE  PROBABILITY OF
(SEC)  ACCEPTING A LAG

SKIP 2 LINES
FOR EACH RANDOM.E IN LAG , DO
PRINT 1 LINE WITH RVALUE.A,PROB.A  THUS
**.***  **.****

SKIP 1 LINE
LOOP
READ GAP
SKIP 5 LINES
PRINT 2 LINES AS FOLLOWS
GAP SIZE PROBABILITY OF
(SEC) ACCEPTING A GAP
SKIP 2 LINES
FOR EACH RANDOM.E IN GAP, DO
PRINT 1 LINE WITH RVALUE.A,PROB.A
*** ***
** ****
SKIP 1 LINE
LOOP
IF VOL1=0 GO TO A ELSE
READ LANE.CHANGE
SKIP 5 LINES
PRINT 2 LINES AS FOLLOWS
LAG SIZE PROBABILITY OF ACCEPTING A LAG
(SEC) FOR A LANE CHANGE
SKIP 2 LINES
FOR EACH RANDOM.E IN LANE.CHANGE, DO
PRINT 1 LINE WITH RVALUE.A,PROB.A
*** ***
** ****
SKIP 1 LINE
LOOP
READ OPTION1
'A' IF VOL1 > 0 SCHEDULE A GEN1 NOW SCHEDULE A GEN4 NOW ALWAYS
SCHEDULE A GEN2 NOW
SCHEDULE A GEN3 NOW
SCHEDULE AN INITIALIZ IN WARM.UP SECONDS
START SIMULATION
STOP
END

EVENT INITIALIZ

THE PURPOSE OF THIS EVENT IS TO INITIALIZE ALL VARIABLES PRESENTED
IN THE FINAL REPORT. IT IS CALLED AFTER THE WARM.UP PERIOD OR AT
THE BEGINNING OF NEW SUBRUN WHEN 2 OR MORE OUTPUTS ARE REQUESTED.

RESET TOTALS OF T.SYS,TT1,TT2,TT3,TT4,TSYS2,XD1,XD2,XD3,XD4,
PHI1,PHI2,PHI3,PHI4,LPHI2,LPHI3,NSTDY,SSTDY
RESET TOTALS OF EXIT3.HISTOGRAM,EXIT2.HISTOGRAM
RESET TOTALS OF N.LANE1,N.LANE2,N.LANE3,N.LANE4
LET NNSTOP=0 LET NSSTOP=0
LET N1=0 LET N2=0 LET N3=0 LET N4=0
LET NL1=0 LET NL2=0 LET NL3=0 LET NL4=0
LET NSLTN=0 LET NLSLTS=0 LET NMDEC=0 LET NMDE1=0
CALL BM.INIT
SCHEDULE AN OUTPUT IN T.STOP SECONDS
RETURN END
EVENT GEN4

"" THE PURPOSE OF THIS EVENT IS TO GENERATE VEHICLES OF TYPE NB4 IN LANE #4 AND GENERATE ITS PERTINENT ATTRIBUTES.

DEFINE HDY,VEL,VL1 AS REAL VARIABLES
CREATE A NB4
LET AR4.TIME(NB4) = TIME.V
CALL TNSD(VMU3,VSIG3) YIELDING VEL
LET TGV4(NB4) = VEL
LET PRLC4(NB4) = RANDOM.F(SEED4)
IF PRLC4(NB4) <= LCP
    LET LAGLC4(NB4) = LANE.CHANGE
ALWAYS
FILE THIS NB4 IN THE LANE4
IF N.LANE4 = 1
    LET V4(NB4) = TGV4(NB4) GO TO A
ELSE IF VEL < V4(P.LANE4)
    LET V4(NB4) = VEL
ELSE LET VL1 = V4(P.LANE4)
    CALL SSDC(VL1,VEL) YIELDING S
    IF X4(P.LANE4) <= S
        LET V4(NB4) = V4(P.LANE4)
    ELSE LET V4(NB4) = VEL
    ALWAYS ALWAYS
'A' SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
CALL TEXP(V0L4) YIELDING HDY
SCHEDULE A GEN4 IN HDY SECONDS
RETURN END
EVENT GEN3

DEFINE HDY, VEL, VL1, K AS REAL VARIABLES
CREATE A NB3
LET AR3.TIME(NB3) = TIME.V
CALL TNSD(VMU3, VSIG3) YIELDING VEL
LET TGT(V3(NB3)) = VEL
LET PRLT3(NB3) = RANDOM.F(SEED3)
IF PRLT3(NB3) <= NLTP
    LET LAG3(NB3) = LAG LET GAP3(NB3) = GAP
    LET PRLC3(NB3) = 1.95 LET K = NLDY
    LET EXIT(NB3) = S12 + SL(I)
LET GS3(NB3) = SEGMENT-EXIT(NB3) + 17
ELSE LET PRLC3(NB3) = RANDOM.F(SEED4)
IF PRLC3(NB3) <= LCP LET LCLAG3(NB3) = LANE.CHA
ALWAYS ALWAYS
FILE THIS NB3 IN THE LANE3
IF X3(F.LANE3) = X3(NB3)
    LET V3(NB3) = TGT(V3(NB3)) GO TO A
ELSE IF VEL < V3(P.LANE3)
    LET V3(NB3) = VEL
ELSE LET VL1 = V3(P.LANE3)
    CALL SSDC(VL1, VEL) YIELDING S
    IF X3(P.LANE3) <= S
        LET V3(NB3) = V3(P.LANE3)
    ELSE LET V3(NB3) = VEL
ALWAYS ALWAYS
IF CASE = 1
    SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ELSE SCHEDULE AN ADJS9 GIVEN NB3 IN C SECONDS
ALWAYS
CALL TEXP(VOL3) YIELDING HDY
SCHEDULE A GEN3 IN HDY SECONDS
RETURN END
EVENT GEN1
DEFINE HDY,VEL,VL1 AS REAL VARIABLES
CREATE A SB1
LET AR1.TIME(SB1) = TIME.V
LET PRLC1(SB1) = RANDOM.F(SEED4)
IF PRLC1(SB1) <= LCP
  LET LAGLC1(SB1) = LANE.CHANGE
ALWAYS
CALL TNSD(VMU1,VSIG1) YIELDING VEL
LET TGT1(SB1) = VEL
FILE THIS SB1 IN THE LANE1
IF N.LANE1 = 1
  LET V1(SB1) = TGT1(SB1) GO TO A
ELSE IF VEL < V1(P.LANE1)
  LET V1(SB1)=VEL
ELSE LET VL1=V1(P.LANE1)
  CALL SSDC(VL1,VEL) YIELDING S
  IF X1(P.LANE1) <= S
    LET V1(SB1)=V1(P.LANE1)
  ELSE LET V1(SB1)=VEL
ALWAYS ALWAYS
'A' SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
CALL TEXP(VOL1) YIELDING HDY
SCHEDULE A GEN1 IN HDY SECONDS
RETURN  END
EVENT GEN2
DEFINE HDY, VEL, VL1, K AS REAL VARIABLES
CREATE A SB2
LET AR2.TIME(SB2) = TIME.V
CALL TNSD(VMU1, VSIG1) YIELDING VEL
LET TGTV2(SB2) = VEL
FILE THIS SB2 IN LANE2
LET PRLT2(SB2) = RANDOM.F(SEED3)
IF PRLT2(SB2) <= SLTP
  LET LAG2(SB2) = LAG LET GAP2(SB2) = GAP
  LET PRLC2(SB2) = 1.95 LET K = NRDWY
  LET I = UNIFORM.F(1.0, K, SEED5)
  LET EXIT2(SB2) = S34 + SR(I)
  LET GS2(SB2) = SEGMENT-EXIT2(SB2) + 17
ELSE LET PRLC2(SB2) = RANDOM.F(SEED4)
IF PRLC2(SB2) <= LCP LET LCLG2(SB2) = LANE.CHANGE
ALWAYS ALWAYS
IF N.LANE2 = 1
  LET V2(SB2) = TGTV2(SB2) GO TO A
ELSE IF VEL < V2(P.LANE2)
  LET V2(SB2) = VEL
ELSE LET VL1 = V2(P.LANE2)
  CALL SSDC(VL1, VEL) YIELDING S
  IF X2(P.LANE2) <= S
    LET V2(SB2) = V2(P.LANE2)
  ELSE LET V2(SB2) = VEL
ALWAYS ALWAYS
IF CASE = 1
'A' SCHEDULE A ADJS5 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE AN ADJS0 GIVEN SB2 IN C SECONDS
ALWAYS
  CALL TEXP(VOL2) YIELDING HDY
  SCHEDULE A GEN2 IN HDY SECONDS
RETURN END
EVENT ADJS3(SB1)

THE PURPOSES OF THIS EVENT ARE:
1- UPDATE THE POSITION AND SPEED OF VEHICLES OF TYPE SB1 UNDER FREE-FLOW CONDITIONS.
2- REMOVE THE VEHICLE FROM LANE #1 WHEN IT IS FLAGED BY SO TO EFFECT ITS LANE-CHANGE MANEUVER.
3- REMOVE THE SB1 VEHICLE FROM THE SYSTEM WHEN IT REACHES THE END OF THE ARTERIAL SECTION.
THIS EVENT IS SCHEDULED EVERY C SECONDS.

DEFINE ACC AS A REAL VARIABLE
IF X1(SB1)>=SEGMENT-200 AND R11=0
LET XD1 = X1(SB1) ADD 1 TO N1
LET TT1 = TIME.V - AR1.TIME(SB1)
    LET V = (XD1/TT1)/1.47 LET R11=1
    LET PHI1=K1.FUEL+(K2.FUEL/V)
ALWAYS
IF BL1(SB1)=1 LET A1(SB1)=0 GO TO C ELSE
IF TLCI(SB1) = 0 GO TO A
ELSE IF TIME.V-TLCI(SB1) >= 2.0
    REMOVE THIS SB1 FROM LANE1 ADD 1 TO NL1
    DESTROY THIS SB1 RETURN ELSE
'A'
IF X1(F.LANE1) = X1(SB1) GO TO B ELSE
IF X1(P.LANE1)-X1(SB1) <=200
    SCHEDULE AN ADJS4 GIVEN SB1 NOW RETURN ELSE
'B'
IF V1(SB1) >= TGTVI(SB1) LET A1(SB1)=0
ELSE LET A1(SB1)=TGTVI(SB1)-V1(SB1)
    CALL ACCELERATION(A1,V1) YIELDING ACC
    LET A1(SB1) = ACC
ALWAYS
'C'
LET X1(SB1)=X1(SB1)+V1(SB1)*C+0.5*A1(SB1)*C**2
LET V1(SB1)=V1(SB1)+A1(SB1)*C
IF TIME.V>=TLCI+2 AND B1=1 LET BL1=0 ALWAYS
IF TIME.V=TENTI+2 AND B1=0 LET BL1=0 ALWAYS
IF X1(SB1) >= SEGMENT
    REMOVE THIS SB1 FROM LANE1
    DESTROY THIS SB1
ELSE SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
ALWAYS
RETURN END
EVENT ADJS4(SB1)

**THIS EVENT IS SCHEDULED TO COMPUTE THE ACCELERATION USING THE CAR-FOLLOWING RULE. THE POSITION AND THE SPEED OF THE VEHICLE IS UPDATED EVERY C SECONDS.**

DEFINE K, ACC, VL2 AS REAL VARIABLES
LET S1 = X1(P.LANE1) + V1(P.LANE1) * C + 0.5 * A1(P.LANE1) * C ** 2
LET VL2 = V1(P.LANE1) + A1(P.LANE1) * C
CALL CRFEQ(VL2, V1, S1, X1) YIELDING K
IF V1(SB1) >= VL2 AND K > 0.0
    LET A1(SB1) = 0.0
ELSE LET A1(SB1) = K
ALWAYS
LET X1(SB1) = X1(SB1) + V1(SB1) * C + 0.5 * A1(SB1) * C ** 2
LET V1(SB1) = V1(SB1) + A1(SB1) * C
IF V1(SB1) < TGTV1(SB1) AND PRLC1(SB1) <= LCP AND B1(SB1) = 0
SCHEDULE A LNCH1 GIVEN SB1 NOW
ELSE SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
ALWAYS
RETURN  END
EVENT ADJS5(SB2)
DEFINE ACC AS A REAL VARIABLE
IF CASE = 2
SCHEDULE AN ADJS0 GIVEN SB2 NOW RETURN
ELSE
IF X2(SB2) < 0
PRINT 5 LINES AS FOLLOWS
A JAMMED FLOW CONDITION HAS BEEN REACHED. YOU HAVE TWO OPTIONS:
1- REDUCE THE TRAFFIC VOLUME AND/OR
2- INCREASE THE APPROACH LENGTHS.
SCHEDULE AN OUTPUT NOW RETURN
ELSE
IF X2(SB2) >= SEGMENT-200 AND R22=0
LET XD2 = X2(SB2) ADD 1 TO N2
LET TT2 = TIME.V-AR2.TIME(SB2)
LET V = (XD2/TT2)/1.47 LET R22=1
LET PHI2=K1.FUEL+(K2.FUEL/V)
ALWAYS
IF BL2(SB2)=1 LET A2(SB2)=0 GO TO C ELSE
IF TLC2(SB2) = 0 GO TO B
ELSE IF TIME.V-TLC2(SB2) >= 2.0
REMOVE THIS SB2 FROM LANE2 ADD 1 TO NL2
DESTROY THIS SB2 RETURN ELSE
'B'
IF X2(F.LANE2) = X2(SB2) GO TO A ELSE
IF X2(P.LANE2)-X2(SB2) <= 200
SCHEDULE AN ADJS6 GIVEN SB2 NOW RETURN ELSE
'A'
IF V2(SB2) >= TGT2(SB2) LET A2(SB2)=0
ELSE LET A2(SB2)=TGT2(SB2)-V2(SB2)
CALL ACCELERATION(A2,V2) YIELDING ACC
LET A2(SB2) = ACC
ALWAYS
'C'
LET X2(SB2)=X2(SB2)+V2(SB2)*TIME.V+0.5*A2(SB2)*TIME.V**2
LET V2(SB2)=V2(SB2)+A2(SB2)*TIME.V
IF TIME.V=TENT2+2 AND B2=0 LET BL2=0 ALWAYS
IF TIME.V=TLC2+2 AND B2=1 LET BL2=0 ALWAYS
IF X2(SB2) >= EXIT2(SB2)-250 AND PRLT2(SB2) <= SLTP
LET TSLT(SB2) = TIME.V
LET PSLT(SB2) = X2(SB2)
LET SRC2(SB2) = UNIFORM.F(40.,50.0,1)
SCHEDULE A TRVL1 GIVEN SB2 IN C SECONDS
ELSE IF X2(SB2) >= SEGMENT
REMOVE THIS SB2 FROM LANE2
DESTROY THIS SB2
ELSE SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS
ALWAYS
RETURN END
EVENT LNCH1(SB1)

"" THIS EVENT IS SCHEDULED TO CHECK THE LAG WHEN SWITCHING TO LANE 2
"" FROM LANE 1.
""

IF X1(SB1) <= 100
   SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS  RETURN
ELSE
   FOR EACH SB2 OF LANE2 WITH X2(SB2) <= X1(SB1)
   FIND THE FIRST CASE
   IF NONE, SCHEDULE A LNCH2 GIVEN SB1 NOW  RETURN
   ELSE IF V2(SB2)=0 AND X1(SB1)-X2(SB2) >= 30
   SCHEDULE A LNCH2 GIVEN SB1 NOW
   ELSE CALL SSOC(V1,V2) YIELDING S
   IF X1(SB1)-X2(SB2) < S
   "" LAG IS REJECTED.
   ""
      SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
   ELSE SCHEDULE A LNCH2 GIVEN SB1 NOW
   ALWAYS
RETURN  END
EVENT LNCH2(SB1)

THIS EVENT IS SCHEDULED TO CHECK THE SPEED AND THE CAR-FOLLOWING SITUATION FOR THE POTENTIAL NEW LEAD CAR.

DEFINE VL1 AS A REAL VARIABLE
CREATE A SB2
LET V2(SB2) = V1(SB1) LET X2(SB2) = X1(SB1)
LET AR2.TIME(SB2) = AR1.TIME(SB1) LET TGT2(SB2) = TGT1(SB1)
LET PRLC2(SB2) = RANDOM.F(SEED4)
IF PRLC2(SB2) <= LCP
LET LCLG2(SB2) = LANE.CHANGE ALWAYS
LET PRT2(SB2) = 1.95
LET EXIT2(SB2) = SEGMENT
LET BL2(SB2) = 1 LET TENT2(SB2) = TIME.V
FILE THIS SB2 IN LANE2

CHECK THE SPEED OF THE POTENTIAL NEW LEAD CAR.
IF V2(F.LANE2) = V2(SB2)
LET B1(SB1) = 1 LET BL1(SB1) = 1
LET TLC1(SB1) = TIME.V
SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS
ELSE IF V2(P.LANE2) <= V1(P.LANE1)
REMOVE THIS SB2 FROM LANE2
DESTROY THIS SB2
ELSE

CHECK THE CAR FOLLOWING SITUATION.
LET VL1 = V2(P.LANE2)
CALL SSDC(VL1, V2) YIELDING S
IF X2(P.LANE2) - X1(SB1) < S
REMOVE THIS SB2 FROM LANE2
DESTROY THIS SB2
ELSE LET B1(SB1) = 1 LET BL1(SB1) = 1
LET TLC1(SB1) = TIME.V
SCHEDULE A ADJS5 GIVEN SB2 IN C SECONDS
ALWAYS ALWAYS ALWAYS
SCHEDULE A ADJS3 GIVEN SB1 IN C SECONDS
RETURN END
EVENT ADJS7(NB4)

DEFINE ACC AS A REAL VARIABLE

IF X4(NB4)>=SEGMENT-200 AND R44=0
LET XD4 = X4(NB4) ADD 1 TO N4
LET TT4 = TIME.V-AR4.TIME(NB4)
LET V = (XD4/TT4)/1.47 LET R44=1
LET PHI4=K1.FUEL+(K2.FUEL/V)
ALWAYS
IF BL4(NB4)=1 LET A4(NB4)=0 GO TO C ELSE
IF TLC4(NB4) = 0 GO TO A
ELSE IF TIME.V-TLC4(NB4) >= 2.0
REMOVE THIS NB4 FROM LANE4 ADD 1 TO NL4
DESTROY THIS NB4 RETURN ELSE
'A' IF X4(F.LANE4) = X4(NB4) GO TO B ELSE
IF X4(P.LANE4)-X4(NB4) <= 200
SCHEDULE AN ADJS8 GIVEN NB4 NOW RETURN ELSE
'B' IF V4(NB4) >= TGT4(NB4) LET A4(NB4)=0
ELSE LET A4(NB4) = TGT4(NB4)-V4(NB4)
CALL ACCELERATION(A4,V4) YIELDING ACC
LET A4(NB4) = ACC
ALWAYS
'C' LET X4(NB4) = X4(NB4)+V4(NB4)*C+0.5*A4(NB4)*C**2
LET V4(NB4) = V4(NB4)+A4(NB4)*C
IF TIME.V=TENT4+2 AND B4=0 LET BL4=0 ALWAYS
IF TIME.V=TLC4+2 AND B4=1 LET BL4=0 ALWAYS
IF X4(NB4) >= SEGMENT
REMOVE THIS NB4 FROM LANE4
DESTROY THIS NB4
ELSE SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
ALWAYS
RETURN End
EVENT ADJS8(NB4)
DEFINE K,ACC,VL2 AS REAL VARIABLES
IF V4(P.LANE4) = 0
  SCHEDULE A WAIT6 GIVEN NB4 NOW RETURN
ELSE
  LET S1 = X4(P.LANE4)+V4(P.LANE4)*C+0.5*A4(P.LANE4)*C**2
  LET VL2 = V4(P.LANE4)+A4(P.LANE4)*C
  CALL CRFEQ(VL2,V4,S1,X4) YIELDING K
  IF V4(NB4) >= VL2 AND K > 0.0
    LET A4(NB4) = 0.0
  ELSE LET A4(NB4) = K
    ALWAYS
    LET X4(NB4) = X4(NB4)+V4(NB4)*C+0.5*A4(NB4)*C**2
    LET V4(NB4) = V4(NB4)+A4(NB4)*C
    IF V4(NB4) < TGT4(NB4) AND PRLC4(NB4) <= LCP AND B4(NB4) = 0
      SCHEDULE A LNCH3 GIVEN NB4 NOW
    ELSE SCHEDULE A LNCH4 GIVEN NB4 NOW RETURN
    ALWAYS
RETURN END

EVENT LNCH3(NB4)
IF X4(NB4) <= 100
  SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS RETURN
ELSE
  FOR EACH NB3 OF LANE3 WITH X3(NB3) < X4(NB4)
  FIND THE FIRST CASE
  IF NONE , SCHEDULE A LNCH4 GIVEN NB4 NOW RETURN
  ELSE IF V3(NB3)=0 AND X4(NB4)-X3(NB3) >= 30
    SCHEDULE A LNCH4 GIVEN NB4 NOW
  ELSE CALL SSDC(V4,V3) YIELDING S
    IF X4(NB4)-X3(NB3) < S
      SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
    ELSE SCHEDULE A LNCH4 GIVEN NB4 NOW
    ALWAYS
RETURN
END
EVENT LNCH4(NB4)
DEFINE VL1 AS A REAL VARIABLE
CREATE A NB3
LET TGT3(NB3) = TGT4(NB4) LET V3(NB3) = V4(NB4)
LET X3(NB3) = X4(NB4)
LET AR3.TIME(NB3) = AR4.TIME(NB4)
LET PRLC3(NB3) = RANDOM.F(SEED4)
LET PRLT3(NB3) = 1.95 LET EXIT(NB3) = SEGMENT
LET BL3(NB3) = 1 LET TENT3(NB3) = TIME.V
FILE THIS NB3 IN LANE3
IF V3(F.LANE3) = V3(NB3)
    LET B4(NB4) = 1 LET BL4(NB4) = 1
    LET TLC4(NB4) = TIME.V
    SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ELSE IF V3(P.LANE3) <= V4(P.LANE4)
    REMOVE THIS NB3 FROM LANE3
    DESTROY THIS NB3
ELSE LET VL1 = V3(P.LANE3)
    CALL SSDC(VL1, V3) YIELDING S
    IF X3(P.LANE3) - X4(NB4) < S
        REMOVE THIS NB3 FROM LANE3
        DESTROY THIS NB3
    ELSE LET B4(NB4) = 1 LET BL4(NB4) = 1
        LET TLC4(NB4) = TIME.V
        SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ALWAYS ALWAYS ALWAYS
SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
RETURN END
EVENT ADJS1(NB3)
  DEFINE ACC AS A REAL VARIABLE
  IF CASE = 2
    SCHEDULE AN ADJS9 GIVEN NB3 NOW RETURN
  ELSE
    IF X3(NB3) < 0
      PRINT 5 LINES AS FOLLOWS
      A JAMMED FLOW CONDITION HAS BEEN REACHED. YOU HAVE TWO OPTIONS:
      1- REDUCE THE TRAFFIC VOLUME AND/OR
      2- INCREASE THE APPROACH LENGTHS.
      SCHEDULE AN OUTPUT NOW RETURN
    ELSE
      IF X3(NB3) >= SEGMENT-200 AND R33=0
        LET XD3 = X3(NB3) ADD 1 TO N3
        LET TT3 = TIME.V - AR3.TIME(NB3)
        LET V = (XD3/TT3)*1.47 LET R33=1
        LET PHI3=K1.FUEL+(K2.FUEL/V)
      ALWAYS
      IF BL3(NB3)=1 LET A3(NB3)=0 GO TO C ELSE
      IF TLC3(NB3) = 0 GO TO B
      ELSE IF TIME.V-TLC3(NB3) >= 2.0
        REMOVE THIS NB3 FROM LANE3 ADD 1 TO NL3
        DESTROY THIS NB3 RETURN ELSE
      'B' IF X3(F.LANE3) = X3(NB3) GO TO A ELSE
      IF X3(P.LANE3)-X3(NB3) <= 200
        SCHEDULE AN ADJS2 GIVEN NB3 NOW RETURN ELSE
      'A' IF V3(NB3) >= TGTV3(NB3) LET A3(NB3)=0
        ELSE LET A3(NB3)=TGTv3(NB3)-V3(NB3)
        CALL ACCELERATION(A3,V3) YIELDING ACC
        LET A3(NB3) = ACC
      ALWAYS
      'C' LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
      LET V3(NB3)=V3(NB3)+A3(NB3)*C
      IF TIME.V>=TENT3+2 AND B3=0 LET BL3=0 ALWAYS
      IF TIME.V>=TLC3+2 AND B3=1 LET BL3=0 ALWAYS
      IF X3(NB3) >= EXIT(NB3)-250 AND PRLT3(NB3) <= NLTP
        LET TSLTM(NB3) = TIME.V
        LET PSLTM(NB3) = X3(NB3)
        LET SRC(NB3) = UNIFORM.F(40.,50.,1)
        SCHEDULE A SLTM1 GIVEN NB3 IN C SECONDS
      ELSE IF X3(NB3) >= SEGMENT
        REMOVE THIS NB3 FROM LANE3
        DESTROY THIS NB3
      ELSE SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
      ALWAYS ALWAYS
    RETURN END
EVENT ADJS6(SB2)
DEFINE K, ACC, VL2, B1, B3 AS REAL VARIABLES
LET ACC = A2(SB2)
LET VL1 = V2(P.LANE2)
IF VL1 <= 1
SCHEDULE A WAIT5 GIVEN SB2 NOW RETURN
ELSE
LET S1 = X2(P.LANE2) + V2(P.LANE2) * C + 0.5 * A2(P.LANE2) * C**2
LET VL2 = V2(P.LANE2) + A2(P.LANE2) * C
CALL CRFEQ(VL2, V2, S1, X2) YIELDING K
IF V2(SB2) >= VL2 AND K > 0.0
LET A2(SB2) = 0.0
ELSE LET B1 = MDEC + (2 * V2) / C
IF A2(P.LANE2) >= 0 LET A2(SB2) = K
ELSE
LET B3 = ((2 * MDEC) / C**2) * (S1 - X2 - V2 * C - 22 - (V2**2 / (2. * MDEC)) - VL2**2 / (2 * A2(P.LANE2)))
IF B1**2 + 4 * B3 < 0
SCHEDULE A WAIT5 GIVEN SB2 NOW RETURN
ELSE
LET A2(SB2) = -B1 / 2 + 0.5 * SQRT.F(B1**2 + 4 * B3)
LET A2(SB2) = MIN.F(K, A2)
LET A2(SB2) = MAX.F(-MDEC, A2)
ALWAYS ALWAYS
IF ACC = -MDEC AND A2(SB2) = -MDEC GO TO A ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
LET X2(SB2) = X2(SB2) + V2(SB2) * C + 0.5 * A2(SB2) * C**2
LET V2(SB2) = V2(SB2) + A2(SB2) * C
IF V2(SB2) < TGT2V2(SB2) AND PRLC2(SB2) < LCP AND B2(SB2) = 0
SCHEDULE A LNC7 GIVEN SB2 NOW
ELSE IF X2(SB2) >= EXIT2(SB2) - 250 AND PRLT2(SB2) <= SLTP
LET TSLT(SB2) = TIME.V
LET PSLT(SB2) = X2(SB2)
LET SRC2(SB2) = UNIFORM.F(40., 50., 1)
SCHEDULE A TRVL1 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS
ALWAYS ALWAYS
RETURN END
EVENT WAIT5(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
LET S1 = X2(P.LANE2)-X2(SB2)-20
IF S1 > 0
  LET A2(SB2) = -(V2(SB2)**2)/(2*S1)
ELSE LET A2(SB2) = -V2(SB2)/C
ALWAYS
  LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS 'A'
  LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
  LET V2(SB2) = V2(SB2)+A2(SB2)*C
IF X2(SB2) < X2(P.LANE2)-20
  SCHEDULE A ADJS5 GIVEN SB2 IN C SECONDS
ELSE IF INT.F(V2) = 0
  ADD 1 TO NSSSTOP LET V2(SB2)=0
  LET TST2(SB2) = TIME.V
  SCHEDULE A WAIT3 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE A WAIT5 GIVEN SB2 IN C SECONDS
ALWAYS ALWAYS
RETURN END

EVENT WAIT3(SB2)
IF X2(F.LANE2) = X2(SB2)
  LET SSTDY=TIME.V-TST2(SB2)+0.75
  SCHEDULE A ADJS5 GIVEN SB2 IN 0.75 SECONDS RETURN
ELSE IF PRLC2(SB2)<=LCP AND B2(SB2) = 0 AND X2(P.LANE2)-X2 <= 27
  SCHEDULE A LNCH GIVEN SB2 NOW
ELSE IF X2(P.LANE2)-X2(SB2) > 27
  LET SSTDY = TIME.V-TST2(SB2)
  SCHEDULE A ADJS5 GIVEN SB2 NOW
ELSE SCHEDULE A WAIT3 GIVEN SB2 IN C SECONDS
ALWAYS ALWAYS
RETURN END
EVENT ADJS2(NB3)
DEFINE K,ACC,B1,B5,VL2 AS REAL VARIABLES
LET ACC = A3(NB3)
LET VL1 = V3(P.LANE3)
IF VL1 <= 1
  SCHEDULE A WAIT4 GIVEN NB3 NOW RETURN
ELSE
LET S1 = X3(P.LANE3)+V3(P.LANE3)*C+0.5*A3(P.LANE3)*C**2
LET VL2 = V3(P.LANE3)+A3(P.LANE3)*C
CALL CRFEQ(VL2,V3,S1,X3) YIELDING K
IF V3(NB3) >= VL2 AND K > 0.0
  LET A3(NB3) = 0.0
ELSE LET B1 = MDEC+(2*V3)/C
IF A3(P.LANE3) >= 0 LET A3(NB3) = K
ELSE
LET B5= (((2*MDEC)/C**2)*(S1-X3-V3*C-22-(V3**2/(2.*MDEC))
  -VL2**2/(2*A3(P.LANE3)))
IF B1**2+4*B5 < 0
  SCHEDULE A WAIT4 GIVEN NB3 NOW RETURN
ELSE
  LET A3(NB3) = -B1/2+0.5*SQRT.F(B1**2+4*B5)
  LET A3(NB3) = MIN.F(K,A3)
  LET A3(NB3) = MAX.F(-MDEC,A3)
ALWAYS ALWAYS
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF X3(NB3) >= EXIT(NB3)-250 AND PRLT3(NB3) <= NLTP
  LET TSLTM(NB3) = TIME.V
  LET PSLTM(NB3) = X3(NB3)
  LET SRC(NB3) = UNIFORM.F(40.,50.,1)
  SCHEDULE A SLTM1 GIVEN NB3 IN C SECONDS
ELSE IF V3(NB3) < TGTV3(NB3) AND PRLC3(NB3) <= LCP AND B3=0
  SCHEDULE A LNCH5 GIVEN NB3 NOW
  ELSE SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ALWAYS ALWAYS
RETURN END
EVENT WAIT4(NB3)
DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
LET S = X3(P.LANE3) - X3(NB3) - 20
IF S > 0
LET A3(NB3) = -(V3(NB3)**2)/(2*S)
ELSE LET A3(NB3) = -V3(NB3)/C
ALWAYS
LET A3(NB3) = MAX.F(-MDEC, A3(NB3))
IF ACC = -MDEC AND A3(NB3) = -MDEC GO TO A
ELSE IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS 'A'
LET X3(NB3) = X3(NB3) + V3(NB3)*C + 0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3) + A3(NB3)*C
IF X3(NB3) < X3(P.LANE3) - 20
SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ELSE IF INT.F(V3) = 0 LET V3(NB3) = 0
LET TST3(NB3) = TIME.V + ADD 1 TO NNSTOP
SCHEDULE A WAIT2 GIVEN NB3 IN C SECONDS
ELSE SCHEDULE A WAIT4 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN
END

EVENT WAIT2(NB3)
IF X3(F.LANE3) = X3(NB3)
LET NSTDY = TIME.V - TST3(NB3) + 0.75
SCHEDULE AN ADJS1 GIVEN NB3 IN 0.75 SECONDS RETURN
ELSE IF PRLC3(NB3) <= LCP AND B3(NB3) = 0 AND X3(P.LANE3) - X3(NB3) <= 27
SCHEDULE A LNCH9 GIVEN NB3 NOW
ELSE IF X3(P.LANE3) - X3(NB3) > 27
LET NSTDY = TIME.V - TST3(NB3)
SCHEDULE AN ADJS1 GIVEN NB3 NOW
ELSE SCHEDULE A WAIT2 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN
END
EVENT SLTM1(NB3)
IF N.STWLT = 0
  LET ASENT(NB3) = X3(NB3)
  SCHEDULE A SLTM4 GIVEN NB3 NOW  RETURN
ELSE IF SEGMENT-EXIT2(F.STWLT) >= EXIT(NB3)
  LET ASENT(NB3) = X3(NB3)
  SCHEDULE A SLTM4 GIVEN NB3 NOW  RETURN
ELSE LET D = SEGMENT - X3(NB3)
  FOR EACH SB2 OF STWL WITH EXIT2 <= D
    FIND THE FIRST CASE
    IF FOUND, SCHEDULE A SLTM3 GIVEN NB3 NOW
    ELSE LET ASENT(NB3) = X3(NB3)
  SCHEDULE A SLTM4 GIVEN NB3 NOW
END

EVENT SLTM2(NB3)
; THE LEFT TURNER ENTERS THE TWLTL ON A REVERSE-CURVE PATH.

DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
IF EXIT(NB3)-X3(NB3) > 50
  LET A3(NB3) = 0  GO TO A
ELSE LET S=EXIT-X3-22
  IF S<=0 LET A3(NB3)=-V3/C
  ELSE LET A3(NB3) = -(V3(NB3)**2) / (2*S)
  ALWAYS
  LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A  ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF V3(NB3)=0 REMOVE THIS NB3 FROM LANE3
FILE THIS NB3 IN THE NTWLTL
SCHEDULE A REM4 GIVEN NB3 IN C SECONDS ELSE
IF X3(NB3) >= ASENT(NB3)+0.5*SRC(NB3)
  SCHEDULE A FLTM GIVEN NB3 IN C SECONDS
  REMOVE THIS NB3 FROM LANE3
  FILE THIS NB3 IN THE NTWLTL
ELSE SCHEDULE A SLTM2 GIVEN NB3 IN C SECONDS
  ALWAYS  ALWAYS
RETURN  END
EVENT SLTM3(NB3)
DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
LET S = EXIT(NB3)-X3(NB3)
IF S <= 12
   REMOVE THIS NB3 FROM LANE3
   FILE THIS NB3 IN THE NTWL
   SCHEDULE A DECLT GIVEN NB3 NOW
RETURN ELSE
LET A3(NB3) = -(V3(NB3)**2)/(2*S)
LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
FOR EACH SB2 OF STWL WITH X2 < SEGMENT - X3(NB3)
   FIND THE FIRST CASE
IF NONE , LET ASENT(NB3) = X3(NB3)
   SCHEDULE A SLTM4 GIVEN NB3 IN C SECONDS
ELSE IF EXIT2(SB2) <= SEGMENT-EXIT(NB3)
   LET ASENT(NB3) = X3(NB3)
   SCHEDULE A SLTM4 GIVEN NB3 IN C SECONDS
ELSE SCHEDULE A SLTM3 GIVEN NB3 IN C SECONDS
   ALWAYS ALWAYS
RETURN END

EVENT SLTM4(NB3)
DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
IF N.NTWLT = 0
   SCHEDULE A SLTM2 GIVEN NB3 NOW RETURN
ELSE IF EXIT(L.NTWLT) >= EXIT(NB3)
   SCHEDULE A SLTM2 GIVEN NB3 NOW RETURN
ELSE LET X = EXIT(NB3) LET D = X3(NB3)
   CALL NCHECK(X,D) YIELDING NLT
IF NLT = 1
   SCHEDULE A SLTM2 GIVEN NB3 NOW
ELSE LET S = EXIT(NB3)-X3(NB3)
   LET A3(NB3) = -(V3(NB3)**2)/(2*S)
   LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
   IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
   IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
SCHEDULE A SLTM1 GIVEN NB3 IN C SECONDS
   ALWAYS
RETURN END
EVENT FLTM(NB3)
DEFINE K,B,ACC,VL2 AS REAL VARIABLES
LET ACC = A3(NB3)
IF X3(F.NTWLT) = X3(NB3)
SCHEDULE A FLTM1 GIVEN NB3 NOW RETURN
ELSE IF EXIT(P.NTWLT) > EXIT(NB3)
SCHEDULE A FLTM1 GIVEN NB3 NOW RETURN
ELSE IF V3(P.NTWLT) = 0
SCHEDULE A WAIT GIVEN NB3 NOW RETURN ELSE
LET S1 = X3(P.NTWLT)+V3(P.NTWLT)*C+0.5*A3(P.NTWLT)*C**2
LET VL2 = V3(P.NTWLT)+A3(P.NTWLT)*C
CALL CRFEQ(VL2,V3,S1,X3) YIELDING K
IF V3(NB3) > 20
LET S = EXIT(NB3)-X3(NB3)-22
LET B = (20**2-V3(NB3)**2)/(2*S)
LET A3(NB3) = MIN.F(K,B)
LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
ELSE LET A3(NB3) = K
ALWAYS
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF X3(NB3) >= EXIT(NB3)-50
SCHEDULE A WAIT GIVEN NB3 IN C SECONDS
ELSE SCHEDULE A FLTM GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT WAIT(NB3)
  DEFINE ACC AS A REAL VARIABLE
  LET ACC = A3(NB3)
  IF X3(F.NTWLT) = X3(NB3)
    SCHEDULE A FLTMI GIVEN NB3 NOW RETURN
  ELSE IF EXIT(P.NTWLT) > EXIT(NB3)
    SCHEDULE A FLTMI GIVEN NB3 NOW RETURN
  ELSE IF FLG(P.NTWLT) = 1
    SCHEDULE A FLTMI GIVEN NB3 NOW RETURN
  ELSE LET S1 = X3(P.NTWLT)-X3(NB3)-22
  IF S1<0 LET A3(NB3)=-V3/C ELSE
    LET A3(NB3) = -(V3(NB3)**2)/(2*S1)
  ALWAYS
    LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
  IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
  IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
  'A'
    LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
    LET V3(NB3) = V3(NB3)+A3(NB3)*C
  IF X3(NB3) < X3(P.NTWLT)-22
    SCHEDULE A WAIT GIVEN NB3 IN C SECONDS
  ELSE SCHEDULE A REM4 GIVEN NB3 IN C SECONDS
    ADD 1 TO NSLTN LET V3(NB3)=0
  ALWAYS
  RETURN END

EVENT REM4(NB3)
  IF X3(F.NTWLT) = X3(NB3)
    SCHEDULE A FLTMI GIVEN NB3 IN 0.75 SECONDS RETURN
  ELSE IF FLG(P.NTWLT) = 1
    SCHEDULE A FLTMI GIVEN NB3 IN 0.75 SECONDS RETURN
  ELSE IF V3(P.NTWLT) = 0
    SCHEDULE A REM4 GIVEN NB3 IN C SECONDS
  ELSE IF X3(P.NTWLT)-X3(NB3) >= 27
    SCHEDULE A FLTMI GIVEN NB3 IN C SECONDS
  ELSE SCHEDULE A REM4 GIVEN NB3 IN C SECONDS
  ALWAYS
  RETURN END
EVENT FLTM1(NB3)

THIS EVENT IS SCHEDULED WHEN THE LEFT TURNER IS THE ONLY ONE IN THE TWLTL OR IT IS THE FIRST VEHICLE IN THE SET.

DEFINE ACC, DEC AS REAL VARIABLES
LET DEC = A3(NB3)
LET S = EXIT(NB3) - 32 - X3(NB3)
IF S <= 0 AND V3(NB3) > 0
   SCHEDULE A DECLT GIVEN NB3 NOW RETURN ELSE
LET R3(NB3) = 50
LET VMAXT(NB3) = SQRT.F(9.66*R3(NB3))
IF V3(NB3) <= VMAXT(NB3)
   LET A3(NB3) = VMAXT(NB3) - V3(NB3)
   CALL ACCELERATION(A3, V3) YIELDING ACC
   LET A3(NB3) = ACC
ELSE LET A3(NB3) = (VMAXT(NB3)**2 - V3(NB3)**2) / (2*S)
   LET A3(NB3) = MAX.F(-MDEC, A3(NB3))
ALWAYS
IF DEC = -MDEC AND A3(NB3) = -MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
A
LET X3(NB3) = X3(NB3) + V3(NB3)*C + 0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3) + A3(NB3)*C
IF X3(NB3) >= EXIT(NB3) - 50
   SCHEDULE A RMVLT GIVEN NB3 NOW
ELSE SCHEDULE A FLTM1 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT RMVLT(NB3)

" THIS EVENT IS SCHEDULED TO CHECK THE OPPOSING TRAFFIC IN LANE 1
" BY A LEFT TURNER.

DEFINE T1 AS A REAL VARIABLE
IF VOL1 = 0
    SCHEDULE AN UPDT1 GIVEN NB3 NOW RETURN
ELSE
    FOR EACH SB1 OF LANE1 WITH X1 < GS3(NB3)
        FIND THE FIRST CASE
        IF NONE , SCHEDULE AN UPDT1 GIVEN NB3 NOW
        ELSE LET T1 = (GS3(NB3)-X1(SB1))/V1(SB1)
        IF V3(NB3) = 0
            IF GAP3(NB3) > T1
                " THIS GAP IS REJECTED. LOOK FOR ANOTHER ONE AFTER 1 SCANNING TIME.
                SCHEDULE A RMVLT GIVEN NB3 IN C SECONDS
                RETURN
            ELSE SCHEDULE AN UPDT1 GIVEN NB3 NOW
            " GAP IS ACCEPTED. CHECK GAPS IN LANE2
        ELSE IF LAG3(NB3) > T1
            " LAG IS REJECTED. WAIT FOR ANOTHER LAG.
            SCHEDULE A DECLT GIVEN NB3 IN C SECONDS
            ELSE SCHEDULE AN UPDT1 GIVEN NB3 NOW
            ALWAYS ALWAYS ALWAYS
    RETURN  END
EVENT UPDT1(NB3)

**\'\' THIS EVENT IS SCHEDULED TO CHECK THE OPPOSING TRAFFIC GAPS IN LANE 2 \n**\'\' BY A LEFT TURNER. **\'\'\n
DEFINE T1 AS A REAL VARIABLE FOR EACH SB2 OF LANE2 WITH X2 < GS(NB3)
FIND THE FIRST CASE IF NONE, SCHEDULE A MANVR GIVEN NB3 IN C SECONDS ELSE IF V2(SB2)=0
SCHEDULE A MANVR GIVEN NB3 IN C SECONDS ELSE LET T1 = (GS(NB3)-X2(SB2))/V2(SB2)
IF V3(NB3) = 0
IF GAP3(NB3) > T1
**\'\' THIS GAP IS REJECTED. LOOK FOR ANOTHER ONE AFTER 1 SCANNING TIME. \n**\'\' SCHEDULE A RMVLT GIVEN NB3 IN C SECONDS RETURN ELSE SCHEDULE A MANVR GIVEN NB3 IN C SECONDS \n**\'\' THIS GAP IS ACCEPTED. START A LEFT TURN MANEUVER. \n**\'\' ELSE IF LAG3(NB3) > T1 \n**\'\' LAG IS REJECTED. WAIT FOR ANOTHER LAG. \n**\'\' SCHEDULE A DECLT GIVEN NB3 IN C SECONDS \n**\'\' ALWAYS ALWAYS ALWAYS \n**\'\' LET R3(NB3) = EXIT(NB3)-X3(NB3)+6 \n**\'\' IF R3<18 LET R3=18 ALWAYS \n**\'\' 18 FT = 1.5 LANE WIDTH \nRETURN END
EVENT MANVR(NB3)

" THIS EVENT IS SCHEDULED WHEN THE VEHICLE MAKES A LEFT TURN AND CLEAR
" TWLT LANE OR LANE 3.
""

DEFINE VT,ACC,T AS REAL VARIABLES

IF CASE = 2
    SCHEDULE A MNVR1 GIVEN NB3 NOW RETURN
ELSE
    IF V3(NB3) = 0 ADD 1 TO NSLTN
    SCHEDULE A REM1 GIVEN NB3 IN 0.75 SECONDS RETURN
ELSE LET FLG(NB3)=1
    LET VMAXT(NB3) = SQRT.F(9.66*R3(NB3))
    LET S = EXIT(NB3)+40
    LET A3(NB3) = VMAXT(NB3) - V3(NB3)
    CALL ACCELERATION(A3,V3) YIELDING ACC
    LET A3(NB3) = ACC
    LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
    LET V3(NB3) = V3(NB3)+A3(NB3)*C
    IF X3(NB3) < S
        SCHEDULE A MANVR GIVEN NB3 IN C SECONDS
    ELSE SCHEDULE A REM 3 GIVEN NB3 NOW
    ALWAYS
RETURN END

EVENT REM1(NB3)

LET FLG(NB3) = 1
LET S = EXIT(NB3)+40
LET VMAXT=SQR.T.F(9.66*R3)
IF V3>VMAXT LET A3=0 ELSE LET A3=4.85 ALWAYS
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF X3(NB3) >= S
    SCHEDULE A REM 3 GIVEN NB3 NOW
ELSE SCHEDULE A REM 1 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT DECLT(NB3)

" THIS EVENT IS SCHEDULED WHEN A LEFT TURNER IS AT THE START-FREE-TURN POINT AND HAS NOT FOUND AN ACCEPTABLE LAG. HE STARTS TO DECELERATE."

DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
IF X3(NB3) >= EXIT(NB3)-12
LET A3(NB3) = 0.0 LET V3(NB3)=0
ELSE LET S = EXIT(NB3)-X3(NB3)-12
LET A3(NB3) = -(V3(NB3)**2)/(2*S)
LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
ALWAYS
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3) + V3(NB3)*C + 0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3) +A3(NB3)*C
SCHEDULE A RMVLT GIVEN NB3 NOW
RETURN END
EVENT REM3(NB3)

DEFINE VBAR AS A REAL VARIABLE
LET T.SYS = TIME.V-TSLTM(NB3)
LET DIST = X3(NB3)-PSLTM(NB3)
LET VBAR=(DIST/T.SYS)/1.47
LET LPHI3=K1.FUEL+(K2.FUEL/VBAR)
LET EXIT3.HISTOGRAM=EXIT(NB3)
REMOVE THIS NB3 FROM THE NTWLT
LET BM.0BS(3)=T.SYS
DESTROY THIS NB3 ADD 1 TO NLT3
RETURN END

EVENT LNCH5(NB3)

IF X3(NB3)<= 100
SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS RETURN
ELSE
FOR EACH NB4 OF LANE4 WITH X4 < X3(NB3)
FIND THE FIRST CASE
IF NONE , SCHEDULE A LNCH6 GIVEN NB3 NOW
ELSE CALL SSDC(V3,V4) YIELDING S
IF X3(NB3)-X4(NB4) < S
SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
ELSE SCHEDULE A LNCH6 GIVEN NB3 NOW
ALWAYS ALWAYSS
RETURN END
EVENT LNCH6(NB3)
CREATE A NB4
LET TGV4(NB4) = TGV3(NB3) LET V4(NB4)=V3(NB3)
LET X4(NB4) = X3(NB3)
LET BL4(NB4)=1 LET TENT4(NB4)=TIME.V
LET AR4.TIME(NB4) = AR3.TIME(NB3)
LET PRLC4(NB4)= 0.95
FILE THIS NB4 IN THE LANE4
IF V4(F.LANE4) = V4(NB4)
  LET B3(NB3) = 1 LET BL3(NB3)=1
  LET TLC3(NB3) = TIME.V
  SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
ELSE IF V4(P.LANE4) <= V3(P.LANE3)
  REMOVE THIS NB4 FROM LANE4
  DESTROY THIS NB4
ELSE LET VL1 = V4(P.LANE4)
  CALL SSDC(VL1,V4) YIELDING S
  IF X4(P.LANE4)-X3(NB3) < S
    REMOVE THIS NB4 FROM LANE4
    DESTROY THIS NB4
  ELSE LET B3(NB3) = 1 LET BL3(NB3)=1
    LET TLC3(NB3) = TIME.V
    SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
ALWAYS ALWAYS ALWAYS
SCHEDULE AN ADJS1 GIVEN NB3 IN C SECONDS
RETURN END

EVENT LNCH7(SB2)
IF X2(SB2) <= 100
  SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS RETURN
ELSE
  FOR EACH SB1 OF LANE1 WITH X1 < X2(SB2)
    FIND THE FIRST CASE
  IF NONE , SCHEDULE A LNCH8 GIVEN SB2 NOW
  ELSE CALL SSDC(V2,V1) YIELDING S
    IF X2(SB2)-X1(SB1) < S
      SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS
      ELSE SCHEDULE A LNCH8 GIVEN SB2 NOW
      ALWAYS ALWAYS
RETURN END
EVENT LNCH8(SB2)
DEFINE VL1 AS A REAL VARIABLE
CREATE A SB1
LET X1(SB1) = X2(SB2)
LET TGTV1(SB1) = TGTV2(SB2) LET V1(SB1)=V2(SB2)
LET AR1.TIME(SB1) = AR2.TIME(SB2)
LET PRLC1(SB1) = 0.95
LET BL1(SB1)=1 LET TENT1(SB1)=TIME.V
FILE THIS SB1 IN THE LANE1
IF V1(F.LANE1) = V1(SB1)
   LET B2(SB2) = 1 LET BL2(SB2)=1
   LET TLC2(SB2) = TIME.V
   SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
ELSE IF V1(P.LANE1) <= V2(P.LANE2)
   REMOVE THIS SB1 FROM LANE1
   DESTROY THIS SB1
ELSE LET VL1 = VI(P.LANE1)
   CALL SSDC(VL1,V1) YIELDING S
   IF X1(P.LANE1)-X1(SB1) < S
      REMOVE THIS SB1 FROM LANE1
      DESTROY THIS SB1
   ELSE LET B2(SB2) = 1 LET BL2(SB2)=1
      LET TLC2(SB2) = TIME.V
      SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
      ALWAYS ALWAYS ALWAYS
      SCHEDULE AN ADJS5 GIVEN SB2 IN C SECONDS
      RETURN END

EVENT TRVL1(SB2)
IF N.NTWLT = 0
   LET SENT2(SB2) = X2(SB2)
   SCHEDULE A TRVL5 GIVEN SB2 NOW RETURN
ELSE IF EXIT(F.NTWLT) <= SEGMENT-EXIT2(SB2)
   LET SENT2(SB2) = X2(SB2)
   SCHEDULE A TRVL5 GIVEN SB2 NOW RETURN
   ELSE LET D = SEGMENT-X2(SB2)
      FOR EACH NB3 OF NTWL WITH EXIT <= D
         FIND THE FIRST CASE
         IF FOUND , SCHEDULE A TRVL3 GIVEN SB2 NOW
         ELSE SCHEDULE A TRVL5 GIVEN SB2 NOW
      ALWAYS
      RETURN END
EVENT TRVL2(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
IF EXIT2(SB2)-X2(SB2) > 50
   LET A2(SB2) = 0  GO TO A
ELSE LET S1=EXIT2-X2-22
IF S1<0  LET A2(SB2)=-V2/C
ELSE LET A2(SB2)=-(V2**2)/(2*S1)
ALWAYS
   LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
'A'
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
IF V2(SB2)=0 REMOVE THIS SB2 FROM LANE2
FILE THIS SB2 IN THE STWLT
SCHEDULE A REM6 GIVEN SB2 IN C SECONDS  ELSE
IF X2(SB2) >=SENT2(SB2)+0.5*SRC2(SB2)
   REMOVE THIS SB2 FROM THE LANE2
   FILE THIS SB2 IN THE STWLT
   SCHEDULE A FLTM2 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE A TRVL2 GIVEN SB2 IN C SECONDS
ALWAYS  ALWAYS
RETURN END

EVENT TRVL3(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
LET S = EXIT2(SB2)-X2(SB2)
IF S <= 12
   REMOVE THIS SB2 FROM LANE2
   FILE THIS SB2 IN THE STWLT
   SCHEDULE A SLOW GIVEN SB2 NOW
RETURN ELSE
LET A2(SB2) = -(V2(SB2)**2)/(2*S)
LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
'A'
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
FOR EACH NB3 OF NTWL WITH X3 < SEGMENT-X2(SB2)
   FIND THE FIRST CASE
IF NONE , LET SENT2(SB2) = X2(SB2)
   SCHEDULE A TRVL5 GIVEN SB2 IN C SECONDS
ELSE IF EXIT(NB3) <= SEGMENT - EXIT2(SB2)
   LET SENT2(SB2) = X2(SB2)
   SCHEDULE A TRVL5 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE A TRVL3 GIVEN SB2 IN C SECONDS
ALWAYS  ALWAYS
RETURN END
EVENT TRVL5(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
IF N.STWLT = 0
   SCHEDULE A TRVL2 GIVEN SB2 NOW RETURN
ELSE IF EXIT2(L.STWLT) >= EXIT2(SB2)
   SCHEDULE A TRVL2 GIVEN SB2 NOW RETURN
ELSE LET X = EXIT2(SB2) LET D = X2(SB2)
   CALL SCHECK(X,D) YIELDING SLT
   IF SLT = 1
      SCHEDULE A TRVL2 GIVEN SB2 NOW
   ELSE LET S = EXIT2(SB2)-X2(SB2)
      LET A2(SB2) = -(V2(SB2)**2)/(2*S)
      LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
      IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
      LET A2(SB2) = K
      ALWAYS
   IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
   IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
   'A'
   LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
   LET V2(SB2) = V2(SB2)+A2(SB2)*C
   SCHEDULE A TRVL1 GIVEN SB2 IN C SECONDS
   ALWAYS
RETURN END

EVENT FLTM2(SB2)
DEFINE K,B,ACC,VL2 AS REAL VARIABLES
LET ACC=A2(SB2)
IF X2(F.STWLT) = X2(SB2)
   SCHEDULE A FLTM3 GIVEN SB2 NOW RETURN
ELSE IF EXIT2(P.STWLT) > EXIT2(SB2)
   SCHEDULE A FLTM3 GIVEN SB2 NOW RETURN
ELSE IF V2(P.STWLT) = 0
   SCHEDULE A WAIT1 GIVEN SB2 NOW RETURN ELSE
   LET S1 = X2(P.STWLT)+V2(P.STWLT)*C+0.5*A2(P.STWLT)*C**2
   LET VL2=V2(P.STWLT)+A2(P.STWLT)*C
   CALL CRFEQ(VL2,V2,S1,X2) YIELDING K
   IF V2(SB2) > 20
      LET B = (20**2-V2(SB2)**2)/(2*S)
      LET A2(SB2) = MIN.F(K,B)
      LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
      ELSE LET A2(SB2) = K
      ALWAYS
   IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
   IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
   'A'
   LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
   LET V2(SB2) = V2(SB2)+A2(SB2)*C
   IF X2(SB2) >= EXIT2(SB2)—50
      SCHEDULE A WAIT1 GIVEN SB2 IN C SECONDS
   ELSE SCHEDULE A FLTM2 GIVEN SB2 IN C SECONDS
   ALWAYS
RETURN END
EVENT WAIT1(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
IF X2(F.STWLTL) = X2(SB2)
    SCHEDULE A FLTM3 GIVEN SB2 NOW  RETURN
ELSE IF EXIT2(P.STWLTL) > EXIT2(SB2)
    SCHEDULE A FLTM3 GIVEN SB2 NOW  RETURN
ELSE IF FLG2(P.STWLTL) = 1
    SCHEDULE A FLTM3 GIVEN SB2 NOW  RETURN
ELSE LET S1 = X2(P.STWLTL) - X2(SB2) - 22
    IF S1 <= 0 LET A2(SB2) = -V2/C
    ELSE LET A2(SB2) = -(V2(SB2)**2)/(2*S1)
    ALWAYS
    LET A2(SB2) = MAX.F(-MDEC, A2(SB2))
    IF ACC = -MDEC AND A2(SB2) = -MDEC GO TO A
    ELSE IF A2(SB2) = -MDEC ADD 1 TO NMDE1
    ALWAYS
    LET X2(SB2) = X2(SB2) + V2(SB2)*C + 0.5*A2(SB2)*C**2
    LET V2(SB2) = V2(SB2) + A2(SB2)*C
    IF X2(SB2) < X2(P.STWLTL) - 22
        SCHEDULE A WAIT1 GIVEN SB2 IN C SECONDS
    ELSE SCHEDULE A REM6 GIVEN SB2 IN C SECONDS
        ADD 1 TO NSLTS
    LET V2(SB2) = 0
    ALWAYS
RETURN  END

EVENT REM6(SB2)
IF X2(F.STWLTL) = X2(SB2)
    SCHEDULE A FLTM3 GIVEN SB2 IN 0.75 SECONDS  RETURN
ELSE IF FLG2(P.STWLTL) = 1
    SCHEDULE A FLTM3 GIVEN SB2 IN 0.75 SECONDS  RETURN
ELSE IF V2(P.STWLTL) = 0
    SCHEDULE A REM6 GIVEN SB2 IN C SECONDS
ELSE IF X2(P.STWLTL) - X2(SB2) >= 27
    SCHEDULE A FLTM2 GIVEN SB2 IN C SECONDS
    ELSE SCHEDULE A REM6 GIVEN SB2 IN C SECONDS
    ALWAYS
RETURN  END
DEFINE ACC, DEC AS REAL VARIABLES
LET DEC = A2(SB2)
IF V2(SB2) = 0 GO TO A ELSE
LET S = EXIT2(SB2)-32-X2(SB2)
IF S <= 0 GO TO B ELSE
'A'
LET R2(SB2) = 50
LET VMAX(SB2) = SQRT.F(9.66*R2(SB2))
IF V2(SB2) <= VMAX(SB2)
LET A2(SB2) = VMAX(SB2)-V2(SB2)
CALL ACCELERATION(A2,V2) YIELDING ACC
LET A2(SB2) = ACC
ELSE LET A2(SB2) = (VMAX(SB2)**2-V2(SB2)**2)/(2*S)
LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
 Always
IF DEC=-MDEC AND A2(SB2)=-MDEC GO TO C ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
'C'
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
'B'
IF X2(SB2) >= EXIT2(SB2)-50
SCHEDULE AN UPDT2 GIVEN SB2 NOW
ELSE SCHEDULE A FLTM3 GIVEN SB2 IN C SECONDS
 Always
RETURN END
EVENT FLTM3(SB2)
DEFINE ACC, DEC AS REAL VARIABLES
LET DEC = A2(SB2)
IF V2(SB2) = 0 GO TO A ELSE
LET S = EXIT2(SB2)-32-X2(SB2)
IF S <= 0 GO TO B ELSE
'A'
LET R2(SB2) = 50
LET VMAX(SB2) = SQRT.F(9.66*R2(SB2))
IF V2(SB2) <= VMAX(SB2)
LET A2(SB2) = VMAX(SB2)-V2(SB2)
CALL ACCELERATION(A2,V2) YIELDING ACC
LET A2(SB2) = ACC
ELSE LET A2(SB2) = (VMAX(SB2)**2-V2(SB2)**2)/(2*S)
LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
 Always
IF DEC=-MDEC AND A2(SB2)=-MDEC GO TO C ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
'C'
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
'B'
IF X2(SB2) >= EXIT2(SB2)-50
SCHEDULE AN UPDT2 GIVEN SB2 NOW
ELSE SCHEDULE A FLTM3 GIVEN SB2 IN C SECONDS
 Always
RETURN END
EVENT UPDT2(SB2)
DEFINE T1 AS A REAL VARIABLE
IF VOL4 = 0
SCHEDULE AN UPDT3 GIVEN SB2 NOW RETURN
ELSE
FOR EACH NB4 OF LANE4 WITH X4 < GS2(SB2)
FIND THE FIRST CASE
IF NONE , SCHEDULE AN UPDT3 GIVEN SB2 NOW RETURN
ELSE IF V4(NB4)=0
SCHEDULE AN UPDT3 GIVEN SB2 NOW
ELSE LET T1 = (GS2(SB2)-X4(NB4))/V4(NB4)
IF V2(SB2) = 0
IF GAP2(SB2) > T1
SCHEDULE AN UPDT2 GIVEN SB2 IN C SECONDS
RETURN
ELSE SCHEDULE AN UPDT3 GIVEN SB2 NOW
ELSE IF LAG2(SB2) > T1
SCHEDULE A SLOW GIVEN SB2 IN C SECONDS
ELSE SCHEDULE AN UPDT3 GIVEN SB2 NOW
 Always
RETURN END
EVENT UPDT3(SB2)
DEFINE T1 AS A REAL VARIABLE
FOR EACH NB3 OF LANE3 WITH X3 < GS2(SB2)
FIND THE FIRST CASE
IF NONE , SCHEDULE A TRVL4 GIVEN SB2 IN C SECONDS
ELSE IF V3(NB3)=0
 SCHEDULE A TRVL4 GIVEN SB2 IN C SECONDS
ELSE LET T1 = (GS2(SB2)-X3(NB3))/V3(NB3)
 IF V2(SB2) = 0
 IF GAP2(SB2) > T1
 SCHEDULE AN UPDT2 GIVEN SB2 IN C SECONDS
 RETURN
 ELSE SCHEDULE A TRVL4 GIVEN SB2 IN C SECONDS
 ELSE IF LAG2(SB2) > T1
 SCHEDULE A SLOW GIVEN SB2 IN C SECONDS
 ELSE SCHEDULE A TRVL4 GIVEN SB2 IN C SECONDS
 ALWAYS
 ALWAYS
 ALWAYS
 ALWAYS
 LET R2(SB2) = EXIT2(SB2)-X2(SB2)+6
 IF R2<18 LET R2=18 ALWAYS
 18 FT = 1.5 LANE WIDTH
 RETURN END
EVENT TRVL4(SB2)
DEFINE VT,ACC,T AS REAL VARIABLES
IF CASE =2
 SCHEDULE A MNVR2 GIVEN SB2 NOW RETURN
 ELSE
 IF V2(SB2) = 0 ADD 1 TO NSLTS
 SCHEDULE A REM5 GIVEN SB2 IN 0.75 SECONDS RETURN
 ELSE LET FLG2(SB2) = 1
 LET S = EXIT2(SB2)+40
 LET VMAX(SB2) = SQRT.F(9.66*R2(SB2))
 LET A2(SB2) = VMAX(SB2)-V2(SB2)
 CALL ACCELERATION(A2,V2) YIELDING ACC
 LET A2(SB2) = ACC
 LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
 LET V2(SB2) = V2(SB2)+A2(SB2)*C
 IF X2(SB2) <S
 SCHEDULE A TRVL4 GIVEN SB2 IN C SECONDS
 ELSE SCHEDULE A REM2 GIVEN SB2 NOW
 ALWAYS
 RETURN END
EVENT REM5(SB2)
LET FLG2(SB2) = 1
LET S = EXIT2(SB2)+40
LET VMAX =SQRT.F(9.66*R2)
 IF V2>VMAX LET A2=0 ELSE LET A2=4.85 ALWAYS
 LET X2(SB2)=X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
 LET V2(SB2)=V2(SB2)+A2(SB2)*C
 IF X2(SB2) >= S
 SCHEDULE A REM2 GIVEN SB2 NOW
 ELSE SCHEDULE A REM5 GIVEN SB2 IN C SECONDS
 ALWAYS
 RETURN END
EVENT SLOW(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
IF X2(SB2) >= EXIT2(SB2)-12
LET A2(SB2) = 0 LET V2(SB2)=0
ELSE LET S = EXIT2(SB2)-X2(SB2)-12
LET A2(SB2) = -(V2(SB2)**2)/(2*S)
LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
ALWAYS
IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
'A'
LET X2(SB2)=X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2)=V2(SB2)+A2(SB2)*C
SCHEDULE AN UPDT2 GIVEN SB2 NOW
RETURN END

EVENT REM2(SB2)
DEFINE VBAR AS A REAL VARIABLE
LET TSYS2 = TIME.V-TSLT(SB2)
LET DIST2 = X2(SB2)-PSLT(SB2)
LET VBAR = (DIST2/TSYS2)/1.47
LET LPHI2= K1.FUEL+(K2.FUEL/VBAR)
LET EXIT2.HIST0GRAM=EXIT2(SB2)
REMOVE THIS SB2 FROM THE STWL'T
DESTROY THIS SB2
LET BM.0BS(4)=TSYS2 ADD 1 TO NLT2
RETURN END

EVENT LNCH(SB2)
DEFINE T AS A REAL VARIABLE
FOR EACH SB1 OF LANE1 WITH X1 < X2(SB2)-27
FIND THE FIRST CASE
IF NONE , GO TO A
ELSE IF V1(SB1)= 0 GO TO A
ELSE LET T = (X2(SB2)-X1(SB1))/V1(SB1)
IF LCLG2(SB2) >  T
SCHEDULE A WAIT3 GIVEN SB2 IN C SECONDS
ELSE
'C'
CREATE A SB1 ADD 1 TO NL2
LET AR1.TIME(SB1) = AR2.TIME(SB2)
LET V1(SB1) = V2(SB2)
LET X1(SB1) = X2(SB2)
LET TGTV1(SB1) = TGTV2(SB2)
LET PRLC1(SB1) = RANDOM.F(SEED4)
FILE THIS SB1 IN LANE1
LET SSTDY = TIME.V-TST2(SB2)
REMOVE THIS SB2 FROM LANE2
DESTROY THIS SB2
SCHEDULE AN ADJS3 GIVEN SB1 IN C SECONDS
ALWAYS
RETURN END
EVENT LNCH9(NB3)
DEFINE T AS A REAL VARIABLE
FOR EACH NB4 OF LANE4 WITH X4 < X3(NB3) - 27
FIND THE FIRST CASE
IF NONE, GO TO A
ELSE IF V4(NB4) = 0 GO TO A
ELSE LET T = (X3(NB3) - X4(NB4))/V4(NB4)
IF LCLAG3(NB3) > T
SCHEDULE A WAIT2 GIVEN NB3 IN C SECONDS
ELSE
' A '
CREATE A NB4
LET AR4.TIME(NB4) = AR3.TIME(NB3)
LET TGT4V4(NB4) = TGT3V3(NB3)
LET X4(NB4) = X3(NB3)
LET V4(NB4) = V3(NB3)
LET PRLC4(NB4) = RANDOM.F(SEED4)
FILE THIS NB4 IN LANE4
LET NSTDY = TIME.V - TST3(NB3)
REMOVE THIS NB3 FROM LANE3
DESTROY THIS NB3 ADD 1 TO NL3
SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
ALWAYS
RETURN END
ROUTINE SSDC(VL, VF) YIELDING S
" THIS ROUTINE IS DESIGNED TO CHECK THE SAFE SPACE HEADWAY. 
" VL = THE SPEED OF THE LEADER 
" VF = THE SPEED OF THE FOLLOWER 
" S = SAFE SPACE HEADWAY 
" B = FACTOR ACCOUNTS FOR THE DIFFERENCE BETWEEN VF&VL 

DEFINE B, VL, VF AS REAL VARIABLES
IF VL - VF <= 10 LET B = 0.1
ELSE LET B = 0
ALWAYS
LET S = 27 + 0.75*VF + B*0.75*(VL-VF)**2
RETURN END
ROUTINE TEXP(FLOW) YIELDING HDY
DEFINE P, TOH, BETA, HDY, K1, K2 AS REAL VARIABLES
LET P = RANDOM.F(SEED1)
LET BETA = FLOW/3600
LET TOH = 0.75
IF P = 0 LET HDY = TOH
ALWAYS
LET K1 = 1 - P
IF K1 = 0 LET HDY = 36
ELSE
LET K2 = (1/BETA) - TOH
LET HDY = TOH - K2*(LOG.E.F(K1))
ALWAYS
RETURN END
ROUTINE TNSD(MU,SIG) YIELDING DSP
'' THIS ROUTINE IS DESIGNED TO GENERATE SPEEDS FROM A TRUNCATED
'' NORMAL DISTRIBUTION.
' DEFINE MU,SIG,DSP AS REAL VARIABLES
'A' LET DSP=NORMAL.F(MU,SIG,SEED2)
IF DSP < (MU-2*SIG) GO TO A
ALWAYS IF DSP > (MU+2*SIG) GO TO A
ALWAYS
RETURN END

ROUTINE CRFEQ(VELP,VEL,D,DC) YIELDING K
''VELP =VEL3(P_LANE3) VELOCITY OF THE LEADER AT THE END OF THE
'' SCANNING TIME,
''VEL =VEL3(NB3) VELOCITY OF THE FOLLOWER AT THE BEGINNING OF THE
'' SCANNING TIME,
''D =POSITION OF THE LEADER AT THE END OF SCANNING TIME.
''DC =POSITION OF THE FOLLOWER AT THE BEGINNING OF SCANNING TIME.
''K =ACCELERATION OF THE FOLLOWER TO KEEP A SAFE SPACE HEADWAY.
DEFINE A,B,K,DEC,ACC,VEL,VELP AS REAL VARIABLES
IF VELP-VEL <= 10 LET B=0.1
ELSE LET B=0
ALWAYS
LET A=2*(D-DC-27-VEL*(C+0.75)-B*0.75*(VELP-VEL)**2)/
    (C**2+2*0.75*C)
IF A < 0
    CALL DECELERATION(A,VEL) YIELDING DEC
    LET K=DEC
ELSE IF A >= 0
    CALL ACCELERATION(A,VEL) YIELDING ACC
    LET K=ACC
ALWAYS ALWAYS
RETURN END

ROUTINE ACCELERATION(ACCF,VF) YIELDING ACC
DEFINE ACCF,ACC,VF AS REAL VARIABLES
IF VF <= 60
    LET ACC=MIN.F(4.85,ACCF)
ELSE LET ACC=MIN.F(3.00,ACCF)
ALWAYS
RETURN END

ROUTINE NCHECK(X,D) YIELDING NLT
'B' FOR EACH NB3 OF NTWL WITH EXIT = X
    FIND THE FIRST CASE
    IF NONE, GO TO A
ELSE IF X3(NB3)-X3(S.NTWLT)>= 100 AND D-X3(S.NTWLT) >= 17
    LET NLT=1 ELSE
'A' FOR EACH NB3 OF NTWL WITH EXIT < X
    FIND THE FIRST CASE
    IF EXIT(NB3) <= D+17 LET NLT=1
ELSE LET NLT=0
ALWAYS ALWAYS
RETURN END
ROUTINE SCHECK(X,D) YIELDING SLT
'B' FOR EACH SB2 OF STWLTL WITH EXIT2 = X
FIND THE FIRST CASE
IF NONE , GO TO A
ELSE IF X2(SB2)-X2(S.STWLTL) >= 100 AND D-X2(S.STWLTL) >= 17
   LET SLT = 1 ELSE
'A' FOR EACH SB2 OF STWLTL WITH EXIT2 < X
FIND THE FIRST CASE
IF EXIT2(SB2) <= D+17 LET SLT=1
ELSE LET SLT = 0
ALWAYS ALWAYS
RETURN END

ROUTINE DECELERATION(DECF,VF) YIELDING DEC
DEFINE DECF,DEC,VF AS REAL VARIABLES
IF VF <= 45
   LET DEC  = MAX.F(-7.8,DECF)
ELSE IF VF <= 60
   LET DEC  = MAX.F(-6.6,DECF)
ELSE LET DEC  = MAX.F(-4.85,DECF)
ALWAYS ALWAYS
RETURN END

EVENT OUTPUT
SCHEDULE AN OUT.BM NOW
START NEW PAGE
ADD 1 TO NOUT
SKIP 10 LINES
PRINT 2 LINES WITH NOUT,(TIME.V-WARM.UP)/60 THUS
RESULTS OF SUBRUN NO. *** AT SIMULATION TIME *****.** MINUTES
===============================================================================
START NEW PAGE
IF VOL1=0 GO TO E ELSE
PRINT 5 LINES AS FOLLOWS
  STATISTICS OF LANE NO. 1

  PRINT 19 LINES WITH N1,X1.BAR,T1.BAR,X1.BAR/T1.BAR,T1.MAX,
   P1.BAR,MX,P1,M1,P1,V,P1,S,P1 THUS
NUMBER OF VEHICLES EXISTED IN LANE 1 = **** VEHICLES
AVERAGE DISTANCE TRAVELLED IN LANE 1 = **** FT
AVERAGE TIME SPENT IN LANE 1 = ***.** SECONDS
AVERAGE RUNNING SPEED IN LANE 1 = ***.** FT/SEC
VARIANCE OF TIME SPENT IN LANE # 1 = *****.**
AVERAGE FUEL CONSUMPTION RATE = *.**** GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = *.**** GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = *.**** GALLONS/VEHICLE-MILE

VARIANCE OF FUEL CONSUMPTION = **.*****

SUM OF FUEL CONSUMPTION RATE = ***.**** GALLONS/MILE

NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 1 = *** VEHICLES

AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = *****

STRAIGHT-THROUGH VEHICLES

PRINT 21 LINES WITH N2,X2.BAR,T2.BAR,X2.BAR/T2.BAR,T2.MAX,
P2.BAR,MX.P2,MI.P2,V.P2,S.P2,NSSTOP

NUMBER OF VEHICLES EXISTED IN LANE 2 = **** VEHICLES

AVERAGE DISTANCE TRAVELLED IN LANE 2 = **** FT

AVERAGE TIME SPENT IN LANE 2 = ***.** SECONDS

AVERAGE RUNNING SPEED IN LANE 2 = ***.** FT/SEC

VARIANCE OF TIME SPENT IN LANE #2 = *****.***

AVERAGE FUEL CONSUMPTION RATE = *.***** GALLONS/VEHICLE-MILE

MAXIMUM FUEL CONSUMPTION RATE = *.***** GALLONS/VEHICLE-MILE

MINIMUM FUEL CONSUMPTION RATE = *.***** GALLONS/VEHICLE-MILE

VARIANCE OF FUEL CONSUMPTION = **.*****

SUM OF FUEL CONSUMPTION RATE = ***.**** GALLONS/MILE

NUMBER OF STOPS IN LANE 2 = ***

AVERAGE STOPPED-DELAY TIME = ***.** SECONDS

MAXIMUM STOPPED-DELAY TIME = ***.** SECONDS

MINIMUM STOPPED-DELAY TIME = ***.** SECONDS

VARIANCE STOPPED-DELAY TIME = ********.**
NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 2 = *** VEHICLES

NO. OF MAX DECELERATION USED BY VEHICLES IN LANE 2 = ***
   (INCLUDING LEFT-TURN VEHICLES)
PRINT 2 LINES WITH A2.LAN2
AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = *****

PRINT 5 LINES AS FOLLOWS
STATISTICS OF LANE NO. 3

STRAIGHT-THROUGH VEHICLES

PRINT 21 LINES WITH N3,X3,BAR,T3.BAR,X3.BAR/T3.BAR,T3.MAX,
P3.BAR,MX.P3,MI.P3,V.P3,S,P3,NNSTOP
NUMBER OF VEHICLES EXISTED IN LANE 3 = **** VEHICLES

AVERAGE DISTANCE TRAVELLED IN LANE 3 = **** FT
AVERAGE TIME SPENT IN LANE 3 = ***.** SECONDS
AVERAGE RUNNING SPEED IN LANE 3 = ***.** FT/SEC

VARIANCE OF TIME SPENT IN LANE # 3 = *****.***
AVERAGE FUEL CONSUMPTION RATE = **.**** GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = **.**** GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = **.**** GALLONS/VEHICLE-MILE

VARIANCE OF FUEL CONSUMPTION = **.*****
SUM OF FUEL CONSUMPTION RATE=**.***** GALLONS/MILE

NUMBER OF STOPS IN LANE 3 = ***
PRINT 13 LINES WITH ST.BAR,ST.M,ST.MI,ST.V,NL3,NMDEC
AVERAGE STOPPED-DELAY TIME = ***.** SECONDS
MAXIMUM STOPPED-DELAY TIME = ***.** SECONDS
MINIMUM STOPPED-DELAY TIME = ***.** SECONDS
VARIANCE STOPPED-DELAY TIME = ******.**

NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 3 = *** VEHICLES
NO. OF MAX DECELERATION USED BY VEHICLES IN LANE 3 = ***
   ( INCLUDING LEFT-TURN VEHICLES )
PRINT 2 LINES WITH A3.LAN3 THUS

AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = *****
   IF VOL4=0 GO TO F ELSE
   START NEW PAGE
   PRINT 5 LINES AS FOLLOWS
   STATISTICS OF LANE NO. 4

   STRAIGHT-THROUGH VEHICLES
   PRINT 19 LINES WITH N4,X4.BAR,T4.BAR,X4.BAR/T4.BAR,T4.MAX,
      P4.BAR,MX.P4,MI.P4,V.P4,S.P4 THUS
   NUMBER OF VEHICLES EXISTED IN LANE 4 = **** VEHICLES
   AVERAGE DISTANCE TRAVELLED IN LANE 4 = **** FT
   AVERAGE TIME SPENT IN LANE 4 = ***.** SECONDS
   AVERAGE RUNNING SPEED IN LANE 4 = ***.** FT/SEC
   VARIANCE OF TIME SPENT IN LANE # 4 = *****.***
   AVERAGE FUEL CONSUMPTION RATE = *.**** GALLONS/VEHICLE-MILE
   MAXIMUM FUEL CONSUMPTION RATE = *.***** GALLONS/VEHICLE-MILE
   MINIMUM FUEL CONSUMPTION RATE = *.***** GALLONS/VEHICLE-MILE
   VARIANCE OF FUEL CONSUMPTION = **.*****
   SUM OF FUEL CONSUMPTION RATE=****.**** GALLONS/MILE
   PRINT 2 LINES WITH NL4 THUS
   NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 4 = *** VEHICLES
   PRINT 2 LINES WITH A4.LAN4 THUS

   AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = *****
   'F' START NEW PAGE
   PRINT 3 LINES AS FOLLOWS
   STATISTICS OF LEFT-TURN VEHICLES FROM LANE 2

   PRINT 21 LINES WITH NLT2,MAX.T,MIN.T,AVG.T,VAR.T,MAX.L2,
      MIN.L2,AVG.L2,VAR.L2,S.L2,NSLTS THUS
   NUMBER OF LEFT-TURN VEHICLES = *** VEHICLES

   MAXIMUM TIME SPENT IN THE SYSTEM = ***.** SECONDS
MINIMUM TIME SPENT IN THE SYSTEM = ***.** SECONDS
MEAN TIME SPENT IN THE SYSTEM = ***.** SECONDS
VARIANCE OF TIME SPENT IN SYSTEM = *****.**
MAXIMUM FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE
AVERAGE FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = ********.******
SUM OF FUEL CONSUMPTION = *****.*** GALLONS/MILE
NUMBER OF STOPS = ***

SKIP 2 LINES
PRINT 5 LINES AS FOLLOWS
HISTOGRAM OF DESTINATIONS

DESTINATION(FT) FREQUENCY(VEHICLES)

FOR K=1 TO 30 , DO
IF H.EX2(K)=0 GO TO C ELSE
PRINT 2 LINES WITH K*50+250,K*50+300,H.EX2(K) THUS
*****="EXIT"****

'C' LOOP
IF H.EX2(31)=0 GO TO D ELSE
PRINT 1 LINE WITH H.EX2(31) THUS
1800="EXIT"****

'D' START NEW PAGE
PRINT 3 LINES AS FOLLOWS
STATISTICS OF LEFT-TURN VEHICLES FROM LANE 3

PRINT 21 LINES WITH NLT3,MAX.T.SYS,MINT.SYS,AT.SYS,V.T.SYS,MAX.L3,
MIN.L3,AVG.L3,VAR.L3,S.L3,NSTN THUS
NUMBER OF LEFT-TURN VEHICLES = *** VEHICLES

MAXIMUM TIME SPENT IN THE SYSTEM = ***.** SECONDS
MINIMUM TIME SPENT IN THE SYSTEM = ***.** SECONDS
MEAN TIME SPENT IN THE SYSTEM = ***.** SECONDS
VARIANCE OF TIME SPENT IN SYSTEM = *****.**

MAXIMUM FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE

MINIMUM FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE

AVERAGE FUEL CONSUMPTION = ***.***** GALLONS/VEHICLE-MILE

VARIANCE OF FUEL CONSUMPTION = **********.*****

SUM OF FUEL CONSUMPTION = *****.*** GALLONS/MILE

NUMBER OF STOPS = ***

SKIP 2 LINES
PRINT 5 LINES AS FOLLOWS
HISTOGRAM OF DESTINATIONS

DESTINATION(FT) FREQUENCY(VEHICLES)

FOR I=1 TO 30, DO
IF H.EX3(I)=0 GO TO A ELSE
PRINT 2 LINES WITH I*50+250, I*50+300, H.EX3(I) THUS
*****<="EXIT"<**** ****

'A' LOOP
IF H.EX3(31)=0 GO TO B ELSE
PRINT 1 LINE WITH H.EX3(31) THUS
1800<="EXIT" ****

'B' RETURN END

EVENT ADJS0(SB2)
DEFINE ACC AS A REAL VARIABLE
IF X2(SB2) >= SEGMENT-200 AND R22=0
LET XD2=X2(SB2) LET R22=1 ADD 1 TO N2
LET TT2=TIME.V-AR2.TIME(SB2)
LET VBAR = (XD2/TT2)/1.47
LET PHI2 = K1.FUEL+(K2.FUEL/VBAR)
ALWAYS
IF BL2(SB2)=1 LET A2(SB2)=0 GO TO C ELSE
IF TLC2(SB2) = 0 GO TO B
ELSE IF TIME.V-TLC2(SB2) >= 2.0
REMOVE THIS SB2 FROM LANE2 ADD 1 TO NL2
DESTROY THIS SB2 RETURN ELSE

'B' IF X2(F.LANE2) = X2(SB2) GO TO A
ELSE
IF X2(P.LANE2)-X2(SB2) <= .200
SCHEDULE AN ADJ12 GIVEN SB2 NOW
RETURN ELSE
'A' IF V2(SB2) >= TGT(SB2) LET A2(SB2)=0
ELSE LET A2(SB2)=TGTV(SB2)-V2(SB2)
CALL ACCELERATION(A2,V2) YIELDING ACC
LET A2(SB2) = ACC
ALWAYS

'C'
LET X2(SB2)=X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2)=V2(SB2)+A2(SB2)*C
IF TIME.V>=TENT2+2 AND B2=0 LET BL2=0 ALWAYS
IF TIME.V>=TLC2+2 AND B2=1 LET BL2=0 ALWAYS
IF X2(SB2) >= EXIT2(SB2)-250 AND PRLT2(SB2) <= SLTP
   LET TSLT(SB2) = TIME.V
   LET PSLT(SB2) = X2(SB2)
   SCHEDULE A FLTM6 GIVEN SB2 IN C SECONDS RETURN
ELSE IF X2(SB2) >= SEGMENT
   REMOVE THIS SB2 FROM LANE2
   DESTROY THIS SB2
ELSE SCHEDULE AN ADJSO GIVEN SB2 IN C SECONDS
ALWAYS
RETURN END

EVENT WAIT6(NB4)
LET S1 = X4(P.LANE4)-X4(NB4)-20
IF S1 > 0
   LET A4(NB4) = -(V4**2)/(2*S1)
ELSE LET A4(NB4) = -V4/C
ALWAYS
LET A4(NB4) = MAX.F(-MDEC,A4)
LET X4(NB4) = X4(NB4)+V4(NB4)*C+0.5*A4(NB4)*C**2
LET V4(NB4) = V4(NB4)+A4(NB4)*C
IF X4(NB4) < X4(P.LANE4)-20
   SCHEDULE AN ADJS7 GIVEN NB4 IN C SECONDS
ELSE IF INT.F(V4) = 0
   LET V4(NB4) = 0
   SCHEDULE A WAIT7 GIVEN NB4 IN C SECONDS
ELSE SCHEDULE A WAIT6 GIVEN NB4 IN C SECONDS
ALWAYS ALWAYS
RETURN END

EVENT WAIT7(NB4)
IF X4(F.LANE4) = X4(NB4)
   SCHEDULE AN ADJS7 GIVEN NB4 IN 0.75 SECONDS
ELSE IF X4(P.LANE4)-X4(NB4) > 27
   SCHEDULE A ADJS7 GIVEN NB4 IN C SECONDS
ELSE SCHEDULE A WAIT7 GIVEN NB4 IN C SECONDS
ALWAYS ALWAYS
RETURN END
EVENT ADJS9(NB3)

DEFINE ACC AS A REAL VARIABLE

IF X3 < 0
FOR EACH NB3 OF LANE3
PRINT 1 DOUBLE LINE WITH V3,X3,A3,TGTV3,PRLT3,PRLC3,TLC3,BL3,
AR3,TIME,TIME.V

V3=*** X3=**** A3=***.** TG3=** PLT3=*.** PLC3=*.** TLC3=***.**
BL3=** AR3=****.** TIM=****.**
SCHEDULE AN OUTPUT NOW RETURN ELSE

IF X3(NB3)>=SEGMENT-200 AND R33=0
LET TT3 = TIME.V-AR3.TIME
LET XD3 = X3(NB3) LET R33=1 ADD 1 TO N3
LET VB3AR = (XD3/TT3)/1.47
LET PHI3 = K1.FUEL+(K2.FUEL/VB3AR)
ALWAYS
IF BL3(NB3)=1 LET A3(NB3)=0 GO TO C ELSE
IF TLC3(NB3) = 0 GO TO B
ELSE IF TIME.V-TLC3(NB3)>= 2.0
REMOVE THIS NB3 FROM LANE3 ADD 1 TO NL3
DESTROY THIS NB3 RETURN ELSE

'B' IF X3(F.LANE3) = X3(NB3) GO TO A ELSE
IF X3(P.LANE3)-X3(NB3) <=200
SCHEDULE AN ADJS9 GIVEN NB3 NOW RETURN ELSE

'A' IF V3(NB3) >= TGTV3(NB3) LET A3(NB3)=0
ELSE LET A3(NB3)=TGTV3(NB3)-V3(NB3)
CALL ACCELERATION(A3,V3) YIELDING ACC
LET A3(NB3) = ACC
ALWAYS

'C'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3)=V3(NB3)+A3(NB3)*C
IF TIME.V=TENT3+2 AND B3=0 LET BL3=0 ALWAYS
IF TIME.V=TLCT3+2 AND B3=1 LET BL3=0 ALWAYS
IF X3(NB3) >= EXIT(NB3)-250 AND PRLT3(NB3) <= NLTP
LET PSLTM(NB3) = X3(NB3)
LET TSLTM(NB3) = TIME.V
SCHEDULE A FLTM4 GIVEN NB3 IN C SECONDS RETURN
ELSE IF X3(NB3) >= SEGMENT
REMOVE THIS NB3 FROM LANE3
DESTROY THIS NB3
ELSE SCHEDULE AN ADJS9 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT ADJ12(SB2)
DEFINE K,ACC,VL2 AS REAL VARIABLES
LET ACC=A2(SB2)
LET VL1 = V2(P.LANE2)
IF VL1 <= 1
    SCHEDULE A WAIT5 GIVEN SB2 NOW RETURN ELSE
    LET S1=X2(P.LANE2)+V2(P.LANE2)*C+0.5*A2(P.LANE2)*C**2
    LET VL2=V2(P.LANE2)+A2(P.LANE2)*C
    CALL CRFEQ(VL2,V2,S1,X2) YIELDING K
    IF V2(SB2) >= VL2 AND K > 0.0
        LET A2(SB2) = 0.0
    ELSE LET A2(SB2) = K
    ALWAYS
    'A'
    LET X2(SB2)=X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
    LET V2(SB2)=V2(SB2)+A2(SB2)*C
    IF INT.F(V2) <= 0
        LET V2(SB2) = 0 ADD 1 TO NSSTOP LET TST2(SB2)=TIME.V
        SCHEDULE A WAIT3 GIVEN SB2 IN C SECONDS RETURN ELSE
    IF X2(SB2) >= EXIT2(SB2)-250 AND PRLT2(SB2) <= SLTP
        LET PSLT(SB2) = X2(SB2)
        LET TSLT(SB2) = TIME.V
        SCHEDULE A FLT6 GIVEN SB2 IN C SECONDS
    ELSE IF V2(SB2) < TGTV2(SB2) AND PRLC2(SB2) <= LCP AND B2(SB2)=0
        SCHEDULE A LNCH7 GIVEN SB2 NOW
    ELSE SCHEDULE A ADJSO GIVEN SB2 IN C SECONDS
    ALWAYS ALWAYS
RETURN END

EVENT ADJ11(NB3)
DEFINE K,ACC,VL2,B1,B5 AS REAL VARIABLES
LET ACC = A3(NB3)
LET VL1 = V3(P.LANE3)
IF VL1 <= 1
    SCHEDULE A WAIT4 GIVEN NB3 NOW RETURN ELSE
    LET S1 = X3(P.LANE3)+V3(P.LANE3)*C+0.5*A3(P.LANE3)*C**2
    LET VL2 = V3(P.LANE3)+A3(P.LANE3)*C
    CALL CRFEQ(VL2,V3,S1,X3) YIELDING K
    IF V3(NB3) >= VL2 AND K > 0.0
        LET A3(NB3) = 0.0
    ELSE LET B1 = MDEC+(2*V3)/C
        IF A3(P.LANE3) >= 0 LET A3(NB3) = K
        ELSE
            LET B5 = ((2*MDEC)/C**2)*(S1-X3-V3*C-22-(V3**2/(2.*MDEC))
                -VL2**2/(2*A3(P.LANE3)))
            IF B1**2+4*B5 < 0
                SCHEDULE A WAIT4 GIVEN NB3 NOW RETURN ELSE
            LET A3(NB3) = -B1/2+0.5*SQRT.F(B1**2+4*B5)
            LET A3(NB3) = MIN.F(K,A3)
            LET A3(NB3) = MAX.F(-MDEC,A3)
        ALWAYS ALWAYS
RETURN END
IF ACC = -MDEC AND A3(NB3) = -MDEC GO TO A ELSE
  IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
  LET X3(NB3) = X3(NB3) + V3(NB3) * C + 0.5 * A3(NB3) * C^2
  LET V3(NB3) = V3(NB3) + A3(NB3) * C
  IF INT.F(V3) <= 0
    LET V3(NB3) = 0 ADD 1 TO NNSTOP LET TST3(NB3) = TIME.V
    SCHEDULE A WAIT2 GIVEN NB3 IN C SECONDS RETURN ELSE
    IF X3(NB3) >= EXIT(NB3) - 250 AND PRLT3(NB3) <= NLTP
      LET TSLTM(NB3) = TIME.V
      LET PSLTM(NB3) = X3(NB3)
      SCHEDULE A FLTLM4 GIVEN NB3 IN C SECONDS
    ELSE IF PRLC3(NB3) <= LCP AND V3(NB3) < TGTV3(NB3)
    AND B3(NB3) = 0
      SCHEDULE A LNCH5 GIVEN NB3 NOW
    ELSE SCHEDULE A ADJS9 GIVEN NB3 IN C SECONDS
    ALWAYS ALWAYS
    RETURN END
EVENT WAIT4(NB3)
  DEFINE ACC AS A REAL VARIABLE
  LET ACC = A3(NB3)
  LET S = X3(P.LANE3) - X3(NB3) - 20
  IF S > 0
    LET A3(NB3) = -(V3(NB3)^2)/(2*S)
  ELSE LET A3(NB3) = -V3(NB3)/C
    ALWAYS
    LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
  IF ACC = -MDEC AND A3(NB3) = -MDEC GO TO A ELSE
  IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
  LET X3(NB3) = X3(NB3) + V3(NB3) * C + 0.5 * A3(NB3) * C^2
  LET V3(NB3) = V3(NB3) + A3(NB3) * C
  IF X3(NB3) < X3(P.LANE3) - 20
    SCHEDULE A ADJS9 GIVEN NB3 IN C SECONDS
  ELSE IF INT.F(V3) = 0 LET V3(NB3) = 0
    LET TST3(NB3) = TIME.V ADD 1 TO NNSTOP
    SCHEDULE A WAIT2 GIVEN NB3 IN C SECONDS
  ELSE SCHEDULE A WAIT4 GIVEN NB3 IN C SECONDS
    ALWAYS ALWAYS
    RETURN END
EVENT FLTM4(NB3)

THE PURPOSE OF THIS EVENT IS TO COMPUTE THE ACCELERATION OF
A LEFT-TURN VEHICLE OF TYPE NB3 IN THE CASE WITHOUT TWTL.

DEFINE B,ACC,VL2,K AS REAL VARIABLES
LET K=A3(NB3)
IF X3(F,LANE3) = X3(NB3)
    SCHEDULE A FLTM5 GIVEN NB3 NOW RETURN
ELSE IF X3(P,LANE3) > EXIT(NB3)+20
    SCHEDULE A FLTM5 GIVEN NB3 NOW RETURN ELSE
IF V3(P,LANE3) <= 1
    SCHEDULE A WAIT8 GIVEN NB3 NOW RETURN ELSE
LET S1=X3(P,LANE3)+V3(P,LANE3)*C+0.5*A3(P.LANE3)*C**2
LET VL2=V3(P,LANE3)+A3(P,LANE3)*C
CALL CRFEQ(VL2,V3,S1,X3) YIELDING ACC
IF X3(NB3) >= EXIT(NB3)-ST.SD AND V3 > 20
    LET A3(NB3) = -(V3(NB3)**2)/(2*(EXIT-X3-17))
    LET A3(NB3) = MAX.F(-MDEC,A3)
    LET A3(NB3) = MIN.F(A3,ACC)
ELSE IF V3(NB3) > TGT(3(NB3) AND ACC > 0
    LET A3(NB3) = 0
ELSE LET A3(NB3) = ACC
ALWAYS ALWAYS
IF K =-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
LET VL1 = V3(NB3)
IF VL1 <= 0
    LET V3(NB3) = 0 ADD 1 TO NSLTN
    LET A3(NB3) = 0
    SCHEDULE A REM7 GIVEN NB3 IN C SECONDS RETURN ELSE
IF X3(NB3) >= EXIT(NB3)-50
    SCHEDULE A WAIT8 GIVEN NB3 IN C SECONDS
ELSE SCHEDULE A FLTM4 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT WAIT8(NB3)

' ' THIS EVENT IS CALLED WHEN THE LEADER OF A LEFT-TURNER IS STOPPED.

DEFINE ACC AS A REAL VARIABLE
LET ACC = A3(NB3)
LET S1 = X3(P.LANE3)-X3(NB3)-20
IF S1 > 0
  LET A3(NB3) = -(V3(NB3)**2)/(2*S1)
ELSE LET A3(NB3) = -V3(NB3)/C
ALWAYS
  LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
IF ACC=-MDEC AND A3(NB3)=-MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC ALWAYS
'A'
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF X3(NB3) < X3(P.LANE3)-20
  SCHEDULE A FLTM4 GIVEN NB3 IN C SECONDS
ELSE IF INT.F(V3) = 0
  LET V3(NB3)=0 ADD 1 TO NSLTN
  SCHEDULE A REM7 GIVEN NB3 IN C SECONDS
  ELSE SCHEDULE A WAIT8 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END

EVENT REM7(NB3)

' ' THIS EVENT IS SCHEDULED FOR A STOPPED-LEFT-TURNER. THE VEHICLE STARTS MOVING WHEN :
' ' 1- IT BECOMES THE FIRST IN THE LANE
' ' 2- ITS LEADER HAS BECOME BEYOND ITS EXIT
' ' 3- THE HEADWAY DISTANCE BECOMES > 27 FT

IF X3(F.LANE3) = X3(NB3)
  SCHEDULE A FLTM5 GIVEN NB3 IN 0.75 SECONDS RETURN
ELSE IF X3(P.LANE3) > EXIT(NB3)+22
  SCHEDULE A FLTM5 GIVEN NB3 IN 0.75 SECONDS RETURN
ELSE IF V3(P.LANE3) = 0
  SCHEDULE A REM7 GIVEN NB3 IN C SECONDS
ELSE IF X3(P.LANE3)-X3(NB3) >= 27
  SCHEDULE A FLTM4 GIVEN NB3 NOW
  ELSE SCHEDULE A REM7 GIVEN NB3 IN C SECONDS
ALWAYS
RETURN END
EVENT FLTM5(NB3)

" THIS EVENT IS SCHEDULED WHEN THE LEADER IS NOT A LEFT TURNER.

DEFINE K,ACC,V11 AS REAL VARIABLES
LET K = A3(NB3)
LET S = EXIT(NB3)-50-X3(NB3)
LET R(NB3) = 50
LET VMAXT(NB3) = SQRT.F(9.66*R(NB3))
IF V3(NB3) <= VMAXT(NB3)
  LET A3(NB3) = VMAXT(NB3)-V3(NB3)
  CALL ACCELERATION(A3,V3) YIELDING ACC
LET A3(NB3) = ACC
ELSE LET A3(NB3) = (VMAXT(NB3)**2-V3(NB3)**2)/(2*S)
  LET A3(NB3) = MAX.F(-MDEC,A3(NB3))
\Aways
IF K = -MDEC AND A3(NB3) = -MDEC GO TO A ELSE
IF A3(NB3) = -MDEC ADD 1 TO NMDEC \Aways
\A
LET X3(NB3) = X3(NB3)+V3(NB3)*C+0.5*A3(NB3)*C**2
LET V3(NB3) = V3(NB3)+A3(NB3)*C
IF X3(NB3) >= EXIT(NB3)-50
  SCHEDULE A RMVL5 GIVEN NB3 NOW
ELSE SCHEDULE A FLTM5 GIVEN NB3 IN C SECONDS
\Aways
\RETURN
\END

EVENT MNVR1(NB3)

" THIS EVENT IS SCHEDULED WHEN THE VEHICLE MAKES A LEFT TURN AND CLEAR LANE3.

DEFINE VT,ACC,T AS REAL VARIABLES
REMOVE THIS NB3 FROM LANE3
FILE THIS NB3 IN NTWL5
IF V3(NB3) = 0
  ADD 1 TO NSLTN
  SCHEDULE A RM1 GIVEN NB3 IN 0.75 SECONDS
\RETURN
ELSE
  SCHEDULE A TRVL6 GIVEN NB3 NOW
\RETURN
\END
EVENT TRVL6(NB3)

\[\text{THIS EVENT UPDATES THE POSITION AND SPEED OF A LEFT-TURNER WHO} \]
\[\text{FOUND AN ACCEPTABLE GAP BEFORE STOPPING.} \]

\[
\text{DEFINE ACC AS A REAL VARIABLE} \\
\text{LET } S = \text{EXIT}(NB3)+40 \\
\text{LET } V_{\text{MAX}}(NB3) = \sqrt{9.66 \times R3(NB3)} \\
\text{LET } A3(NB3) = V_{\text{MAX}}(NB3) - V3(NB3) \\
\text{CALL ACCELERATION(A3,V3) YIELDING ACC} \\
\text{LET } A3(NB3) = \text{ACC} \\
\text{LET } X3(NB3) = X3(NB3)+V3(NB3) \times C+0.5 \times A3(NB3) \times C^2 \\
\text{LET } V3(NB3) = V3(NB3)+A3(NB3) \times C \\
\text{IF } X3(NB3) < S \\
\text{SCHEDULE A TRVL6 GIVEN NB3 IN C SECONDS} \\
\text{ELSE SCHEDULE A REM3 GIVEN NB3 NOW} \\
\text{ALWAYS} \\
\text{RETURN} \\
\]

EVENT FLTM6(SB2)

\[
\text{DEFINE K,B,VL2,ACC AS REAL VARIABLES} \\
\text{LET } \text{ACC}=A2(SB2) \\
\text{IF } X2(\text{F.LANE}2) = X2(SB2) \\
\text{SCHEDULE A FLTM7 GIVEN SB2 NOW} \quad \text{RETURN} \\
\text{ELSE IF } X2(\text{P.LANE}2) > \text{EXIT2}(SB2)+20 \\
\text{SCHEDULE A FLTM7 GIVEN SB2 NOW} \quad \text{RETURN} \\
\text{ELSE LET } VL1 = V2(\text{P.LANE}2) \\
\text{IF } VL1 \leq 1 \\
\text{SCHEDULE A WAIT9 GIVEN SB2 NOW} \quad \text{RETURN} \\
\text{ELSE IF } X2(\text{P.LANE}2)-X2(SB2) \leq 27 \\
\text{SCHEDULE A WAIT9 GIVEN SB2 NOW} \quad \text{RETURN} \quad \text{ELSE} \\
\text{LET } S1=X2(\text{P.LANE}2)+V2(\text{P.LANE}2) \times C+0.5 \times A2(\text{P.LANE}2) \times C^2 \\
\text{LET } VL2=V2(\text{P.LANE}2)+A2(\text{P.LANE}2) \times C \\
\text{CALL CRFEQ(VL2,V2,S1,X2) YIELDING K} \\
\text{LET } ST.SD = (\text{TGT}2(\text{SB2}) \times 2)/(2 \times 32.2 \times 0.16) \\
\text{IF } X2(\text{SB2}) > \text{EXIT2}-ST.SD \text{ AND } V2(\text{SB2}) > 20 \\
\text{LET } S = \text{EXIT2}(\text{SB2})-X2(\text{SB2})-i7 \\
\text{LET } B = -(V2(\text{SB2}) \times 2)/(2 \times S) \\
\text{LET } A2(\text{SB2}) = \text{MAX}.F(-\text{MDEC},B) \\
\text{LET } A2(\text{SB2}) = \text{MIN}.F(A2,K) \\
\text{ELSE IF } V2(\text{SB2}) > \text{TGT}2(\text{SB2}) \text{ AND } K > 0 \\
\text{LET } A2(\text{SB2}) = 0 \\
\text{ELSE LET } A2(\text{SB2}) = K \\
\text{ALWAYS} \\
\text{ALWAYS} \\
\text{IF } \text{ACC}=-\text{MDEC} \text{ AND } A2(\text{SB2})=-\text{MDEC} \text{ GO TO A ELSE} \\
\text{IF } A2(\text{SB2}) = -\text{MDEC} \text{ ADD 1 TO NMDE1 ALWAYS} \\
\text{LET } X2(\text{SB2}) = X2(\text{SB2})+V2(\text{SB2}) \times C+0.5 \times A2(\text{SB2}) \times C^2 \\
\text{LET } V2(\text{SB2}) = V2(\text{SB2})+A2(\text{SB2}) \times C \\
\text{IF } X2(\text{SB2}) > \text{EXIT2}(\text{SB2})-50 \\
\text{SCHEDULE A WAIT9 GIVEN SB2 IN C SECONDS} \\
\text{ELSE SCHEDULE A FLTM6 GIVEN SB2 IN C SECONDS} \\
\text{ALWAYS} \\
\text{RETURN} \\
\]
EVENT WAIT9(SB2)
DEFINE ACC AS A REAL VARIABLE
LET ACC=A2(SB2)
    LET S1 = X2(P.LANE2)-X2(SB2)-20
    IF S1 > 0
    LET A2(SB2) = -(V2(SB2)**2)/(2*S1)
    ELSE LET A2(SB2) = -V2(SB2)/C
    ALWAYS
    LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
    IF ACC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
    IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
    'A'
    LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
    LET V2(SB2) = V2(SB2)+A2(SB2)*C
    IF X2(SB2) < X2(P.LANE2)-20
    SCHEDULE A FLTM6 GIVEN SB2 IN C SECONDS
    ELSE IF INT.F(V2) = 0 LET V2(SB2)=0
    ADD 1 TO NSLTS
    SCHEDULE A REM8 GIVEN SB2 IN C SECONDS
    ELSE SCHEDULE A WAIT9 GIVEN SB2 IN C SECONDS
    ALWAYS
RETURN END

EVENT REM8(SB2)
IF X2(F.LANE2) = X2(SB2)
    SCHEDULE A FLTM7 GIVEN SB2 IN 0.75 SECONDS RETURN
ELSE IF X2(P.LANE2) > EXIT2(SB2)+20
    SCHEDULE A FLTM6 GIVEN SB2 IN 0.75 SECONDS RETURN
ELSE IF V2(P.LANE2) > 0
    SCHEDULE A REM8 GIVEN SB2 IN C SECONDS
ELSE IF X2(P.LANE2)-X2(SB2) > 27
    SCHEDULE A FLTM6 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE A REM8 GIVEN SB2 IN C SECONDS
    ALWAYS
RETURN END

EVENT FLTM7(SB2)
DEFINE ACC,DEC AS REAL VARIABLES
LET DEC = A2(SB2)
LET S = EXIT2(SB2)-50-X2(SB2)
LET R2(SB2) = 50
LET VMAX(SB2) = SQRT.F(9.66*R2(SB2))
IF V2(SB2) <= VMAX(SB2)
    LET A2(SB2) = VMAX(SB2)-V2(SB2)
    CALL ACCELERATION(A2,V2) YIELDING ACC
    LET A2(SB2) = ACC
ELSE LET A2(SB2) = (VMAX(SB2)**2-V2(SB2)**2)/(2*S)
    LET A2(SB2) = MAX.F(-MDEC,A2(SB2))
    ALWAYS
IF DEC=-MDEC AND A2(SB2)=-MDEC GO TO A ELSE
A
IF A2(SB2) = -MDEC ADD 1 TO NMDE1 ALWAYS
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
IF X2(SB2) >= EXIT2(SB2)-50
SCHEDULE AN UPDT2 GIVEN SB2 NOW
ELSE SCHEDULE A FLTM7 GIVEN SB2 IN C SECONDS ALWAYS
RETURN END

EVENT MNVR2(SB2)
DEFINE VT,ACC,T AS REAL VARIABLES
REMOVE THIS SB2 FROM LANE2
FILE THIS SB2 IN STWLT
IF V2(SB2) = 0
ADD 1 TO NSLTS
SCHEDULE A REM5 GIVEN SB2 IN 0.75 SECONDS
RETURN
ELSE LET FLG2(SB2) = 1
SCHEDULE A TRVL7 GIVEN SB2 NOW
RETURN END

EVENT TRVL7(SB2)
LET S = EXIT2(SB2)+40
LET VMAX(SB2) = SQRT.F(9.66*R2(SB2))
LET A2(SB2) = VMAX(SB2)-V2(SB2)
CALL ACCELERATION(A2,V2) YIELDING ACC
LET A2(SB2) » ACC
LET X2(SB2) = X2(SB2)+V2(SB2)*C+0.5*A2(SB2)*C**2
LET V2(SB2) = V2(SB2)+A2(SB2)*C
IF X2(SB2) < S
SCHEDULE A TRVL7 GIVEN SB2 IN C SECONDS
ELSE SCHEDULE A REM2 GIVEN SB2 NOW
ALWAYS
RETURN END

EVENT OUT.BM
IF OPTION1 = 1
START NEW PAGE SKIP 3 LINES
PRINT 14 LINES AS FOLLOWS
DEFINITION OF VARIABLES USED IN THE BATCH MEANS PROCEDURE
=====================================================================

1- VARIABLE 1 IS THE STOPPED-DELAY TIME EXPERIENCED BY A THROUGH VEHICLE IN LANE #3

2- VARIABLE 2 IS THE STOPPED-DELAY TIME EXPERIENCED BY A THROUGH VEHICLE IN LANE #2

3- VARIABLE 3 IS THE TIME FROM A LEFT-TURN VEHICLE FROM LANE #3 SLOWED DOWN 250-FT AWAY FROM ITS EXIT UNTIL LEAVING THE SYSTEM
4- VARIABLE 4 IS THE TIME FROM A LEFT-TURN VEHICLE FROM LANE #2
SLOWED DOWN 250-FT AWAY FROM ITS EXIT UNTIL LEAVING THE SYSTEM

SKIP 3 LINES
CALL BM.OUT(1)  CALL BM.OUT(2)
CALL BM.OUT(3)  CALL BM.OUT(4)

ALWAYS
'B'
IF NOUT < N.OUT
   SCHEDULE AN INITIALIZE NOW
ELSE STOP ALWAYS
END

//LKED.SYSLIB DD
// DD DSN=TSAGMC.SIMSCRIT,UNIT=USERDA,DISP=SHR
//GO.SYSIN DD *

FOUR 2
1700 7 7 300 350
2 600 0.5 100
51.5 5.15 550 550 550 550 51.5 5.15
0.5 0.07 0.07 14
1 2 3 4 5
250 350 450 550 650 750 850
250 350 450 550 650 750 850
.00 3 .03 3.5 .124 4 .3 4.5 .53 5 .73 5.5 .86 6 .94 6.5 .97 7
.99 7.5 .996 8 .999 8.5 1.9 *
.00 3 .15 3.5 .32 4 .52 4.5 .69 5 .82 5.5 .9 6 .95 6.5 .97 7
986 7.5 .993 8 .997 8.5 .998 9 .999 9.5 1.10 *
.02 .09 2.5 .18 3 .31 3.5 .49 4 .66 4.5 .81 5 .9 5.5 .96 6
.985 6.5 .995 7 .999 8 1.0 8.5 *
0
/*

//
Appendix C

LISTING OF A SAMPLE OUTPUT
STUDY OF OPERATIONAL CHARACTERISTICS OF TWO-WAY
LEFT-TURN LANE ON FOUR-LANE ARTERIALS USING SIMULATION

MODEL (2): WITHOUT A TWLTL

INPUT DATA

INPUT MEAN SPEED IN NORTH-BOUND = 51.50 FT/SEC
INPUT STD.DEV IN NORTH-BOUND = 5.15 FT/SEC
INPUT MEAN SPEED IN SOUTH-BOUND = 51.50 FT/SEC
INPUT STD.DEV IN SOUTH-BOUND = 5.15 FT/SEC
VOLUME IN LANE 1 = 375 VEH/HR
VOLUME IN LANE 2 = 425 VEH/HR
VOLUME IN LANE 3 = 756 VEH/HR
VOLUME IN LANE 4 = 684 VEH/HR
% OF DRIVERS CHANGE LANES = .50
SCANNING TIME = .50 SECONDS
SIMULATION TIME / SUBRUN = 900.00 SECONDS
% OF LEFT-TURN TRAFFIC FROM NORTH-BOUND = .30
% OF LEFT-TURN TRAFFIC FROM SOUTH-BOUND = .30
MAX DECELERATION = 14.00 FT/SEC/SEC
DISTANCE BETWEEN SECTIONS 1 & 2 = 300 FT
DISTANCE BETWEEN SECTIONS 3 & 4 = 300 FT
LENGTH OF SIMULATED ARTERIAL = 1660.00 FT
NUMBER OF REQUESTED OUTPUTS (SUBRUNS) = 1
WARM UP PERIOD BEFORE COLLECTING DATA = 100.00 SECONDS
RANDOM NUMBER SEED FOR VEHICULAR INTERARRIVAL = 1
RANDOM NUMBER SEED FOR TARGET SPEEDS = 2
RANDOM NUMBER SEED FOR LEFT-TURN PROBABILITY = 3
RANDOM NUMBER SEED FOR LANE-CHANGE PROBABILITY = 4
RANDOM NUMBER SEED FOR LEFT-TURN DESTINATION = 5

FUEL CONSUMPTION PARAMETERS
ROLLING RESISTANCE PARAMETER = 0.0362
FUEL FLOW RATE PARAMETER = 0.7460
### LEFT-HAND SIDE DRIVEWAYS

<table>
<thead>
<tr>
<th>DRIVEWAY NUMBER</th>
<th>DISTANCE FROM ORIGIN</th>
</tr>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>460</td>
</tr>
<tr>
<td>3</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>740</td>
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### RIGHT-HAND SIDE DRIVEWAYS

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<tr>
<td>5</td>
<td>810</td>
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<td>LAG SIZE (SEC)</td>
<td>PROBABILITY OF ACCEPTING A LAG</td>
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<td>-------------------------------</td>
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<td>LAG SIZE (SEC)</td>
<td>PROBABILITY OF ACCEPTING A LAG FOR A LANE CHANGE</td>
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</table>
RESULTS OF SUBRUN NO. 1 AT SIMULATION TIME 15.00 MINUTES

==============================================
STATISTICS OF LANE NO. 1

STRAIGHT-THROUGH VEHICLES

NUMBER OF VEHICLES EXISTED IN LANE 1 = 103 VEHICLES
AVERAGE DISTANCE TRAVELLED IN LANE 1 = 1475 FT
AVERAGE TIME SPENT IN LANE 1 = 30.67 SECONDS
AVERAGE RUNNING SPEED IN LANE 1 = 48.10 FT/SEC
VARIANCE OF TIME SPENT IN LANE # 1 = 13.992
AVERAGE FUEL CONSUMPTION RATE = .0590 GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = .0717 GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = .0544 GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = .00001
SUM OF FUEL CONSUMPTION RATE = 6.0786 GALLONS/MILE
NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 1 = 13 VEHICLES
AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = 4
STATISTICS OF LANE NO. 2

STRAIGHT-THROUGH VEHICLES

NUMBER OF VEHICLES EXISTED IN LANE 2 = 36 VEHICLES
AVERAGE DISTANCE TRAVELLED IN LANE 2 = 1475 FT
AVERAGE TIME SPENT IN LANE 2 = 42.92 SECONDS
AVERAGE RUNNING SPEED IN LANE 2 = 34.37 FT/SEC
VARIANCE OF TIME SPENT IN LANE # 2 = 345.711
AVERAGE FUEL CONSUMPTION RATE = .0692 GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = .1040 GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = .0553 GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = .00020
SUM OF FUEL CONSUMPTION RATE = 2.4538 GALLONS/MILE
NUMBER OF STOPS IN LANE 2 = 36
AVERAGE STOPPED-DELAY TIME = 11.41 SECONDS
MAXIMUM STOPPED-DELAY TIME = 36.50 SECONDS
MINIMUM STOPPED-DELAY TIME = .50 SECONDS
VARIANCE STOPPED-DELAY TIME = 118.46
NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 2 = 19 VEHICLES
NO. OF MAX DECELERATION USED BY VEHICLES IN LANE 2 = 22
(INCLUDING LEFT-TURN VEHICLES)
AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = 4
STATISTICS OF LANE NO. 3

STRAIGHT-THROUGH VEHICLES

NUMBER OF VEHICLES EXISTED IN LANE 3 = 84 VEHICLES.
AVERAGE DISTANCE TRAVELLED IN LANE 3 = 1473 FT
AVERAGE TIME SPENT IN LANE 3 = 35.57 SECONDS
AVERAGE RUNNING SPEED IN LANE 3 = 41.42 FT/SEC
VARIANCE OF TIME SPENT IN LANE # 3 = 164.048
AVERAGE FUEL CONSUMPTION RATE = .0627 GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = .0984 GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = .0548 GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = .00009
SUM OF FUEL CONSUMPTION RATE = 5.2695 GALLONS/MILE
NUMBER OF STOPS IN LANE 3 = 50
AVERAGE STOPPED-DELAY TIME = 6.04 SECONDS
MAXIMUM STOPPED-DELAY TIME = 29.50 SECONDS
MINIMUM STOPPED-DELAY TIME = .50 SECONDS
VARIANCE STOPPED-DELAY TIME = 56.21

NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 3 = 30 VEHICLES

NO. OF MAX DECELERATION USED BY VEHICLES IN LANE 3 = 28
(INCLUDING LEFT-TURN VEHICLES)

AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = 7
STATISTICS OF LANE NO. 4

STRAIGHT-THROUGH VEHICLES

NUMBER OF VEHICLES EXISTED IN LANE 4 = 175 VEHICLES
AVERAGE DISTANCE TRAVELLED IN LANE 4 = 1475 FT
AVERAGE TIME SPENT IN LANE 4 = 30.72 SECONDS
AVERAGE RUNNING SPEED IN LANE 4 = 48.01 FT/SEC
VARIANCE OF TIME SPENT IN LANE # 4 = 14.350
AVERAGE FUEL CONSUMPTION RATE = .0591 GALLONS/VEHICLE-MILE
MAXIMUM FUEL CONSUMPTION RATE = .0701 GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION RATE = .0544 GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = .00001
SUM OF FUEL CONSUMPTION RATE = 10.3457 GALLONS/MILE
NUMBER OF VEHICLES CHANGED THEIR LANE FROM LANE 4 = 32 VEHICLES
AVERAGE NUMBER OF VEHICLES OCCUPIED THE SEGMENT = 7
Statistics of Left-Turn Vehicles from Lane 2

Number of Left-Turn Vehicles = 57 Vehicles

Maximum Time Spent in the System = 64.00 Seconds

Minimum Time Spent in the System = 5.50 Seconds

Mean Time Spent in the System = 26.51 Seconds

Variance of Time Spent in System = 187.88

Maximum Fuel Consumption = .27905 Gallons/Vehicle-Mile

Minimum Fuel Consumption = .03620 Gallons/Vehicle-Mile

Average Fuel Consumption = .10956 Gallons/Vehicle-Mile

Variance of Fuel Consumption = .004442

Sum of Fuel Consumption = 6.245 Gallons/Mile

Number of Stops = 48

Histogram of Destinations

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<tr>
<th>Destination (ft)</th>
<th>Frequency (VeHicles)</th>
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<tbody>
<tr>
<td>550 &lt;= Exit &lt; 600</td>
<td>6</td>
</tr>
<tr>
<td>650 &lt;= Exit &lt; 700</td>
<td>10</td>
</tr>
<tr>
<td>800 &lt;= Exit &lt; 850</td>
<td>12</td>
</tr>
<tr>
<td>950 &lt;= Exit &lt;1000</td>
<td>17</td>
</tr>
<tr>
<td>1100 &lt;= Exit &lt;1150</td>
<td>12</td>
</tr>
</tbody>
</table>
STATISTICS OF LEFT-TURN VEHICLES FROM LANE 3

NUMBER OF LEFT-TURN VEHICLES = 113 VEHICLES
MAXIMUM TIME SPENT IN THE SYSTEM = 111.50 SECONDS
MINIMUM TIME SPENT IN THE SYSTEM = 9.00 SECONDS
MEAN TIME SPENT IN THE SYSTEM = 18.14 SECONDS
VARIANCE OF TIME SPENT IN SYSTEM = 146.33
MAXIMUM FUEL CONSUMPTION = .40920 GALLONS/VEHICLE-MILE
MINIMUM FUEL CONSUMPTION = .07172 GALLONS/VEHICLE-MILE
AVERAGE FUEL CONSUMPTION = .10710 GALLONS/VEHICLE-MILE
VARIANCE OF FUEL CONSUMPTION = .001901
SUM OF FUEL CONSUMPTION = 12.103 GALLONS/MILE
NUMBER OF STOPS = 65

HISTOGRAM OF DESTINATIONS

<table>
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<tr>
<th>DESTINATION(FT)</th>
<th>FREQUENCY(VEHICLES)</th>
</tr>
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<tbody>
<tr>
<td>600&lt;=EXIT&lt; 650</td>
<td>29</td>
</tr>
<tr>
<td>750&lt;=EXIT&lt; 800</td>
<td>36</td>
</tr>
<tr>
<td>900&lt;=EXIT&lt; 950</td>
<td>36</td>
</tr>
<tr>
<td>1000&lt;=EXIT&lt;1050</td>
<td>12</td>
</tr>
</tbody>
</table>
DEFINITION OF VARIABLES USED IN THE BATCH MEANS PROCEDURE

1- VARIABLE 1 IS THE STOPPED-DELAY TIME EXPERIENCED BY A THROUGH VEHICLE IN LANE #3
2- VARIABLE 2 IS THE STOPPED-DELAY TIME EXPERIENCED BY A THROUGH VEHICLE IN LANE #2
3- VARIABLE 3 IS THE TIME FROM A LEFT-TURN VEHICLE FROM LANE #3 SLOWED DOWN 250-FT AWAY FROM ITS EXIT UNTIL LEAVING THE SYSTEM
4- VARIABLE 4 IS THE TIME FROM A LEFT-TURN VEHICLE FROM LANE #2 SLOWED DOWN 250-FT AWAY FROM ITS EXIT UNTIL LEAVING THE SYSTEM

<table>
<thead>
<tr>
<th>NO. OF BATCH</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VARIANCE</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1</td>
<td>6.04007E+00</td>
<td>1.14716E+00</td>
<td>.536311</td>
</tr>
</tbody>
</table>

0.95 INTERVAL ESTIMATE

LOWER            UPPER
3.88767E+00      8.19248E+00

TEST OF INDEPENDENCE OF THE 50 BATCH MEANS DID NOT PASS
<table>
<thead>
<tr>
<th>NO. OF BATCHES</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE Variance</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>4</td>
<td>1.14097E-01</td>
<td>8.37970E-01</td>
<td>0.699253</td>
</tr>
</tbody>
</table>

0.95 INTERVAL ESTIMATE
LOWER     UPPER
4.73430E-01 1.80852E-01

TEST OF INDEPENDENCE OF THE 9 BATCH MEANS DID NOT PASS

<table>
<thead>
<tr>
<th>NO. OF BATCHES</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE Variance</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>1.14097E-01</td>
<td>1.73673E-01</td>
<td>0.559208</td>
</tr>
</tbody>
</table>

0.95 INTERVAL ESTIMATE
LOWER     UPPER
-1.83732E-01 2.46568E+01

UNABLE TO DO INDEPENDENCE TEST WITH ONLY 4 BATCHES -- NEED 8 OR MORE
<table>
<thead>
<tr>
<th>NO. OF BATCH</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VARIANCE</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16</td>
<td>1.14097E+01</td>
<td>3.75151E-01</td>
<td>-0.00000</td>
</tr>
</tbody>
</table>

**0.95 INTERVAL ESTIMATE**

<table>
<thead>
<tr>
<th>LOWER</th>
<th>UPPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.78079E+01</td>
<td>8.06274E+01</td>
</tr>
</tbody>
</table>

UNABLE TO DO INDEPENDENCE TEST WITH ONLY 2 BATCHES -- NEED 8 OR MORE

<table>
<thead>
<tr>
<th>NO. OF BATCH</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VARIANCE</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>113</td>
<td>1</td>
<td>1.81372E+01</td>
<td>1.33651E+00</td>
<td>0.176759</td>
</tr>
</tbody>
</table>

**0.95 INTERVAL ESTIMATE**

<table>
<thead>
<tr>
<th>LOWER</th>
<th>UPPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.58723E+01</td>
<td>2.04020E+01</td>
</tr>
</tbody>
</table>

TEST OF INDEPENDENCE OF THE 113 BATCH MEANS DID NOT PASS

<table>
<thead>
<tr>
<th>NO. OF BATCH</th>
<th>SAMPLE SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VARIANCE</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>2</td>
<td>1.81372E+01</td>
<td>1.42404E+00</td>
<td>0.371133</td>
</tr>
</tbody>
</table>

**0.95 INTERVAL ESTIMATE**

CRITICAL VALUE: 0.153379, 0.215896
<table>
<thead>
<tr>
<th>No. of Batches</th>
<th>Sample Size</th>
<th>Sample Mean</th>
<th>Sample Var.</th>
<th>Critical Value</th>
<th>Lower Estimate</th>
<th>Upper Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>4</td>
<td>1.81372E+01</td>
<td>2.10617E+00</td>
<td>.34312</td>
<td>1.51594E+01</td>
<td>2.11150E+01</td>
</tr>
</tbody>
</table>

**Test of Independence of the 56 Batch Means Did Not Pass**

**Batch Means Estimate for Variable 3**

**0.95 Confidence Interval Estimation**

<table>
<thead>
<tr>
<th>No. of Batches</th>
<th>Sample Size</th>
<th>Sample Mean</th>
<th>Sample Var.</th>
<th>Critical Value</th>
<th>Lower Estimate</th>
<th>Upper Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>8</td>
<td>1.81372E+01</td>
<td>3.01930E+00</td>
<td>.526832</td>
<td>1.43832E+01</td>
<td>2.18911E+01</td>
</tr>
</tbody>
</table>

**Test of Independence of the 28 Batch Means Did Not Pass**

**Batch Means Estimate for Variable 3**

**0.95 Confidence Interval Estimation**

<table>
<thead>
<tr>
<th>No. of Batches</th>
<th>Sample Size</th>
<th>Sample Mean</th>
<th>Sample Var.</th>
<th>Critical Value</th>
<th>Lower Estimate</th>
<th>Upper Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>8</td>
<td>1.81372E+01</td>
<td>3.01930E+00</td>
<td>.526832</td>
<td>1.43832E+01</td>
<td>2.18911E+01</td>
</tr>
</tbody>
</table>
### BATCH MEANS ESTIMATE FOR VARIABLE 3

<table>
<thead>
<tr>
<th>NO. OF BATCHES</th>
<th>SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VAR.</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>16</td>
<td>1.81372E+01</td>
<td>4.06024E+00</td>
<td>.281166</td>
</tr>
</tbody>
</table>

**0.95 INTERVAL ESTIMATE**

<table>
<thead>
<tr>
<th>LOWER</th>
<th>UPPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.32067E+01</td>
<td>2.30676E+01</td>
</tr>
</tbody>
</table>

**UNABLE TO DO INDEPENDENCE TEST WITH ONLY 7 BATCHES — NEED 8 OR MORE**

### BATCH MEANS ESTIMATE FOR VARIABLE 4

<table>
<thead>
<tr>
<th>NO. OF BATCHES</th>
<th>SIZE</th>
<th>SAMPLE MEAN</th>
<th>SAMPLE VAR.</th>
<th>CRITICAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>1</td>
<td>2.65132E+01</td>
<td>3.35493E+00</td>
<td>.052897</td>
</tr>
</tbody>
</table>

**0.95 INTERVAL ESTIMATE**

<table>
<thead>
<tr>
<th>LOWER</th>
<th>UPPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.28439E+01</td>
<td>3.01824E+01</td>
</tr>
</tbody>
</table>

**TEST OF INDEPENDENCE OF THE 57 BATCH MEANS PASSED**