ABSTRACT

ANALYTICAL AND SIMULATION MODELS OF WEAVING AREA OPERATIONS UNDER NON-FREEWAY CONDITIONS

by
Muhammad Shahid Iqbal

The Highway Capacity Manual covers adequately the operation of weaving areas on freeways. Weaving on non-freeway facilities, however, has not been addressed as yet. This research effort presents a state-of-the-art procedural analytical approach and simulation models for the analysis of the level of service and operation of non-freeway weaving areas. Weaving under non-freeway conditions is classified into two broad categories; basic weave and ramp weave. The analytical models for these two weaving categories are calibrated and validated based on data obtained from several sites selected in the states of New Jersey and New York. New level of service criteria are developed for these two weaving categories. A FORTRAN program was developed to compute average weaving and nonweaving speeds and determine the level of service. In addition, simulation is used to develop a model for basic weave only. The simulation model is microscopic, enabling the user to study the dynamics of individual vehicles and the overall traffic flow.

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by
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This dissertation is dedicated to
my father

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LIST OF SYMBOLS

α = Minor approach angle, in degrees

c = Commuter traffic adjustment factor

Δ = Horizontal curve deflection angle, in degrees

f_{HV} = Heavy vehicle adjustment factor

f_P = Driver population adjustment factor

L = Length of weaving area, in ft.

LS = Average total lane shift

LS_3 = Average amount of lane shifts performed by the drivers of the weaving vehicles

m = Marked crown adjustment factor (defined for ramp weave configuration)

MR = Minor approach flow to total flow ratio, V_m/V

N = Total number of lanes in the weaving area

PHV = Peak Hour Factor

S_{NW} = Average running speed of non-weaving vehicles in the weaving area, in mph

S_W = Average running speed of weaving vehicles in the weaving area, in mph

V = Total flow rate in the weaving area, in passenger car equivalents, pcph

V_3 = Minor approach weaving volume

V_4 = Minor approach non-weaving volume

V_W = Total weaving flow rate in weaving area, in passenger car equivalents, pcph

V_m = Total flow rate for the minor approach, in passenger car equivalents, pcph

VR = Volume ratio, V_W/V

W = Width of the weaving section, in feet (defined for ramp weave configuration)

GLOSSARY

AAP
Arterial Analysis Package

ASCII Format
Dos Text File Format

BASIC WEAVE
Weaving Configuration Considered (see Figure 1.1)

BPR
Bureau of Public Roads

BRT
Driver's Brake Reaction Time

CARSIM
Car Simulation Model

CPR
Closed Range Photogrammetry

CTSR
Center for Transportation Studies and Research, New Jersey Institute of Technology, Newark, New Jersey

DEC_MAX
Maximum Emergency Deceleration Rate

FREESIM
Freeway Simulation Model for lane closure at work zones

FRESIM
General Freeway Simulation Model

FHWA
Federal Highway Administration

FORTRAN IV
Computer Programming Language for Engineers

GASP IV
Simulation Language

HCM
Highway Capacity Manual

HEADWAY.BAS
Computer program developed on BASIC Interpreter (by NJIT study team) for measuring inter-arrival vehicle headways

HRB
Highway Research Board (Now called TRB)

IMAGE.C
Image Photogrammetry Program Compiled in Microsoft-C Language (by NJIT study team) for microscopic data reduction

INTLC
A SLAM II user-written subroutine called before each simulation run

INTRAS
Integrated Traffic Simulation Package

IVOL_A
Input Volume for Approach A

IVOL_B
Input Volume for Approach B

KERMIT
A utility software used to import and export files from PC to main frame and vice versa

LOTUS 123
An Electronic Worksheet Package

MOE
Measure of Effectiveness

MSTOP
SLAM II variable that causes unconditional termination of program if set in a user-written routine to -1

NCHRP
National Cooperative Highway Research Program

NCRDR & NPRNT
SLAM II variables used to specify devices to read and write files

NED
Nadirshah Edulgi Dinshau, Engineering University in Pakistan

NETSIM
Network Simulation Package

NFREWESIM
Non-Freeway Weaving Simulation Model developed by NJIT

NJDOT
New Jersey Department of Transportation

NJIT
New Jersey Institute of Technology

NNSET
Specifies dimension of SLAM II NSET Array

OTPUT
A SLAM II user-written subroutine called at the end of each simulation run

PC
Personal Computer

QSET & NSET
SLAM II Storage Arrays

RAMP WEAVE
Weaving Configuration Considered (see Figure 1.2)

SAS
A powerful Statistical Package on main frame

SPEED.BAS
Computer program developed on BASIC Interpreter (by NJIT study team) for measuring travel time of vehicles

SIMSCRIPT II.5
A Computer Simulation Language

SLAM II
A Computer Simulation Language

SOAP
Signal Operations Analysis Package

TNOW
Current Simulation Time

TR Circular
Transportation Research Circular

TRANSTAT
A Transportation Statistical Package developed to fit common univariate distribution to traffic data

TRB
Transportation Research Board, Washington, D.C.

TRR
Transportation Research Record

TTFIN
SLAM II variable specifying ending time of simulation

USDOT
United State Department of Transportation

VHS
A Video Signal

WEAVESIM
Freeway Weaving Simulation Model

CHAPTER I

INTRODUCTION

1.1 General Background

Highways may operate under uninterrupted or interrupted flow conditions. Uninterrupted flow facilities have no fixed elements, such as traffic signals, that cause interruptions to traffic flow. Freeways, and their components, represent typical uninterrupted flows. Non-freeway facilities, may or may not, operate under interrupted flow conditions.

The Highway Capacity Manual (HCM) is a state-of-the art document that presents a collection of techniques for estimating highway capacity. The current version of HCM is in its third edition (TRB Special Report 209, 1985), and its development has been guided by the Transportation Research Board's Committee on Highway Capacity and Quality Service. The previous editions of HCM are Special Report 87 published by the then Highway Research Board in 1965, and Special Report 209 published by the then Bureau of Public Roads in 1950.

Capacity analysis provides tools for the analysis and improvement of existing facilities, and for the planning and design of future facilities, and it consists of procedures used to estimate the traffic-carrying ability of facilities over a range of defined operational conditions. Level of service (LOS), as defined by the HCM, is a qualitative measure describing operational conditions within a traffic stream, and how drivers perceive these conditions through such factors as speed, travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety.

Levels of service are given letter designations, from A to F, with LOS A representing the best operating conditions and LOS F the worst. LOS A represents free flow. LOS B through D are in the range of stable flow, with LOS B representing noticeable effects of the presence of other vehicles and LOS D representing high-density flow. LOS E represents operating conditions at or near the capacity level, and LOS F defines forced or breakdown flow.

The 1985 HCM defines weaving as "The crossing of two or more traffic streams travelling in the same general direction along a significant length of highway, without the aid of traffic control devices." Considerable lane-changing activity typically occurs in weaving sections as motorists access lanes appropriate for their destinations. Vehicular conflicts occur as weaving traffic movements are forced to cross one another and merge into non-weaving traffic streams. These intense lane-changing maneuvers often result in operational problems within the weaving area. These problems can be further aggravated by disturbing elements within non-freeway weaving sections such as traffic signals, driveways, exits and entrances to establishments, pedestrians, parked vehicles, etc.

1.2 Problem Statement

The 1985 HCM and its previous editions contain no treatment of weaving on non-freeway facilities. The committee on Highway Capacity and Quality of Service of the Transportation Research Board, rated the "Effect of Arterial Weaving on Arterial Level of Service" of high urgency priority (TR Circular 319, 1987). It indicated that although the 1985 HCM treats weaving areas, rural highways, and urban streets, it does not address the problem created on an arterial by ramps and closely spaced intersections which can result in significant lane changing across the arterial over relatively short distances.

To understand the basic phenomenon of non-freeway weaving area operations, a reliable macroscopic and analytical tool is needed, and a new analysis approach should be established. To accomplish this, first, the vast majority of the non-freeway weaving types has to be classified into distinct categories. An extensive search and site visit effort associated with this project indicated that the vast majority of non-freeway weaving cases can be classified into two broad categories. These two types of weaving are caused by 1) merging and diverging of ramps with an arterial (*basic weave*), and 2) on/off ramps connecting an arterial or highway with a highway (*ramp weave*). Figures 1.1 and 1.2 present typical weaving configurations under basic and ramp weaves, respectively. A new procedural approach is needed for the operational analysis of each weave type, and separate level-of-service criteria have to be established.

Although, analytical models of non-freeway weaving sections provide some basic information regarding the relationship between geometric, traffic, and operational characteristics, many questions remain unanswered. For example, one might be interested in determining the impact of upstream conditions on operational characteristics of weaving sections, determining the level of traffic at which weaving movements between lanes become hazardous, or determining the effect of different weaving lengths or other geometric characteristics on traffic flow.

For a detailed understanding of the weaving behavior under non-freeway conditions, there is a need for developing a realistic and reliable microscopic simulation

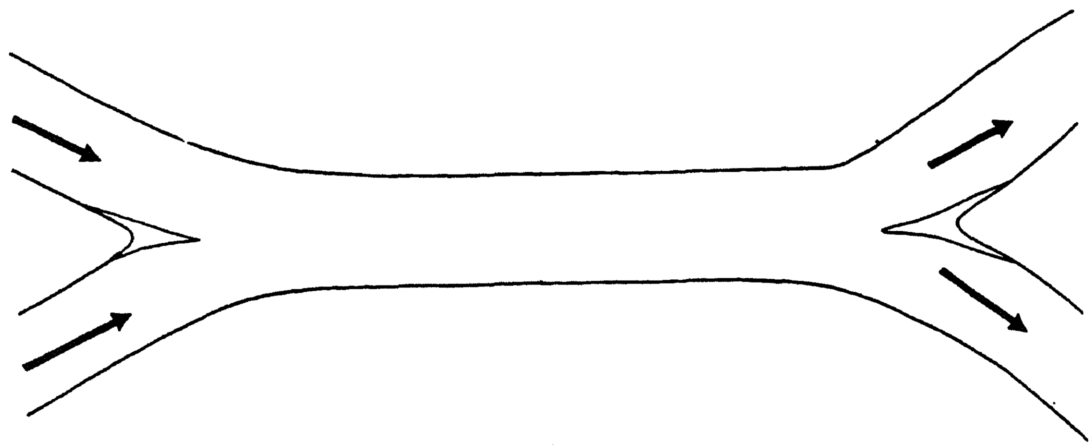


Figure 1.1 Weaving Caused by Merging and Diverging of Ramps With an Arterial (Basic Weave)

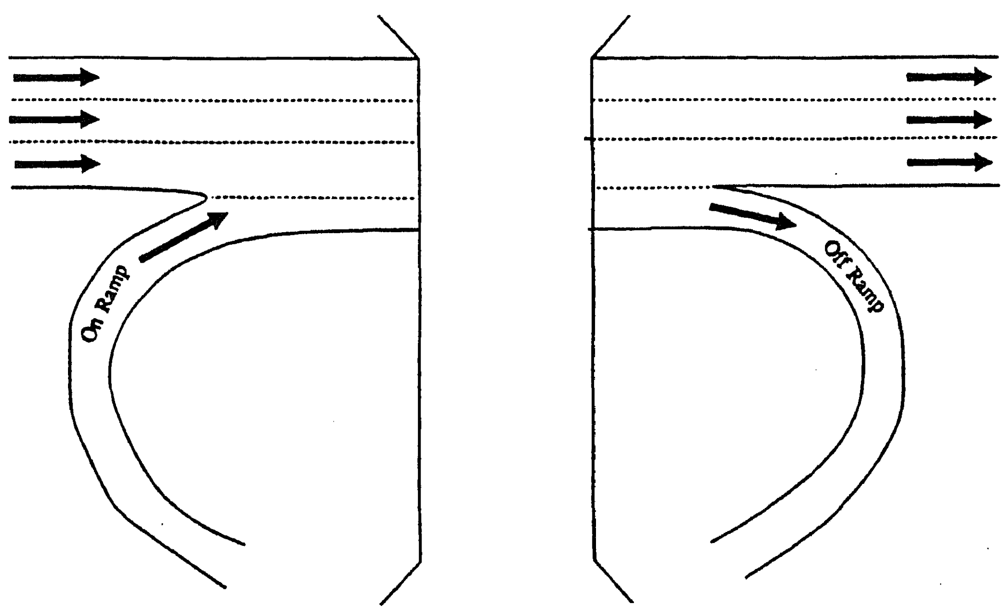


Figure 1.2 On/Off Ramps Connecting an Arterial With a Highway (Ramp Weave)

model to further study the dynamics of traffic flow at weaving sections. Results of various studies on the comparative assessment of performance measure capabilities of existing traffic simulation models have indicated that simulation can reasonably replicate field conditions. Therefore, it can potentially be used to assist in the development of design and analysis procedures by predicting traffic performance under different geometric and traffic conditions.

1.3 Nature of the Reported Research

The intent of this research effort is, first, to establish an analytical approach for design and analysis, and, second, to develop a realistic and reliable microscopic simulation model which provides the means for studying the dynamics of traffic flow and for a detailed understanding of the weaving behavior under non-freeway conditions.

The analytical and simulation models are calibrated and validated based on data collected from a wide range of weaving sites.

The methodology presented for analytical models consists of developing equations predicting the average running speed of weaving and nonweaving vehicles based on known roadway and traffic conditions, defining limiting values of key parameters for each category of weaving, beyond which equations do not apply, and defining level-of-service criteria based on average running speeds of weaving and nonweaving vehicles.

Simulation models are developed using the PC version of the simulation language SLAM II. SLAM II is FORTRAN based, and operates in a windows environment. The models are stochastic and microscopic. Input to the models are simulation run parameters, weaving section parameters, and traffic parameters. The model output is in the form of an echo report, an intermediate report, a summary report, and graphs. The simulation models provide an effective tool for studying the time varying, complex, and stochastic process of traffic flow through weaving sections, and can achieve a high level of detail and accuracy of analysis.

1.4 Output and Expected Usefulness

The results of this research effort fill a void in the analysis and design of non-freeway weaving areas. Models and methodologies have been produced which would result in more efficient, safer operations, and better design of these facilities. Separate level of service criteria are established which can be used for evaluating the operation on non-freeway weaving areas.

Depending on the level of detail needed, the user is provided with the option of using the macroscopic approach (analytical models) or the microscopic approach (simulation models) for operational analysis.

The analytical models predict average weaving and non-weaving speeds based on input volumes and the weaving section geometry. The models could be used for operational analysis and design. A program is written in FORTRAN that automatically computes speeds and LOS for each type of weaving.

The simulation models present distributions of all necessary measures of effectiveness. The output includes mean, standard deviation, minimum, maximum, number of observations, frequency histograms, and cumulative frequencies. Trajectories of individual vehicles could be collected and plotted. The effect of traffic congestion upstream and downstream of the weaving section could be studied.

CHAPTER II

LITERATURE REVIEW

A literature review was conducted using the computerized DIALOG Information Retrieval Service. Three data bases were searched, including HRIS (Highway Research Information Service) produced by the Transportation Research Board, NTIS produced by the National Technical Information Service, and COMPENDEX PLUS produced by Engineering Information. Since there are no existing methods of analyzing weaving areas under non-freeway conditions, the literature search provided citations dealing with freeway weaving topics only.

2.1 Objectives of the Literature Review

The purpose of reviewing the relevant literature on simulation models and the state-of-the-art in weaving area analysis and design is to achieve the following goals:

1. Identifying existing analytical tools for the analysis of weaving areas and their historical development.
2. Getting insight on the nature of systems simulation, simulation models, generic steps involved in the development of simulation models, and the advantages and disadvantages of simulation models.
3. Obtaining specific detailed information on studies, techniques, analyses, and simulation models that are most relevant to traffic operations and weaving.
4. Obtaining general comparative assessments of available traffic simulation models/methods and identifying areas where more work is needed.

2.2 Available Analytical Models

The history of the development of different methods for the design and analysis of freeway weaving sections can be traced back to 1950 when the original HCM was published (BPR, Special Report 209, 1950). The manual provides one of the earliest procedures for the operational analysis and design of freeway weaving sections. These procedures were based on empirical analysis of data collected prior to 1948. In 1953, a major effort was initiated by the U.S. Bureau of Public Roads (BPR) to collect additional data for updating the 1950 procedures. As a result, a new weaving design and analysis procedure was published in the 1965 HCM (HRB Special Report 87, 1965).

Procedures developed for the 1950 HCM, as well as the new methodologies presented in the 1965 HCM exposed some problems areas such as: a) misinterpretation of the instructions, b) occasional unreasonable results, and c) complex procedures.

As part of an ongoing research program sponsored by the National Cooperative Highway Research Program (NCHRP) and Federal Highway Administration (FHWA), Polytechnic Institute of New York analyzed the 1963 data base collected by the then BPR, and additional data collected from 1972 to 1973 (Pignataro et al, 1973). A new analysis methodology was proposed and published in NCHRP Report 159 (Pignataro et al 1976). The key feature of the proposed methodology was that the geometric configuration of lanes in the weaving area was a major determinant of operating quality. However, the methodology presented in the report, consisting primarily of a complex two-part nomograph, was difficult to comprehend and not widely used. As part of the "Freeway Capacity Analysis Procedures" study sponsored by FHWA between 1976 to 1978 (Roess et al, 1978), Polytechnic's weaving procedure was reformatted and revised to provide for easier use and understanding. This revised procedure was published in TRB's Circular 212: Interim Materials on Highway Capacity.

An in-house development by Jack E. Leisch and Associates was first introduced through an article published in the March 1979 issue of the ITE Journal. The individuals involved in its development, felt that they had a significant contribution to make in the design practice for weaving sections based on the analysis of weaving data and their experience in the highway design profession. In February 1974, a report was prepared by Jack E. Leisch entitled "Capacity Analysis Techniques for Design and Operation of Freeway Facilities". Chapter 4 of this report deals with freeway weaving sections. The data used in the development of the model was the 1963 BPR Urban Weaving Area Capacity Study data base and data gathered by Polytechnic in 14 sites for NCHRP Project 3-15. The Leisch procedure was similar in structure to the 1965 HCM method, and used two nomographs for all solutions. Although the procedure was undocumented, it was published in Circular 212 in the hope that users would compare the two methods (Polytechnic and Leisch) and comment on which was more accurate.

By this time, engineers were faced with a dilemma as to which of the two available methods should be used to analyze weaving on freeway, as the weaving procedures yielded substantially different results in many cases.

FHWA later provided support to update and document the Leisch method. As a result, in 1983 J. E. Leisch and J. P. Leisch updated the nomograph previously developed, and expanded and refined the initial statistical analysis to provide full documentation through FHWA-RD-82/54 (Leisch, 1984). The report was prepared in two parts; the first volume covered the development and verification of the procedure;

the second volume provided a user guide to demonstrate the solution of weaving problems.

In response to the outcome of Leisch's work, FHWA sponsored an additional effort from 1983 through 1984 to compare the two procedures, and to make recommendations for a procedure to be included in the 1985 HCM. This study was conducted by JHK & Associates (Reilly et al, 1984). A complete review of both the Polytechnic and Leisch Methods was made and both procedures were applied to a series of 76 example problems.

The JHK study concluded that neither of the two methods in Circular 212 adequately described weaving area operations, as it was found that some of the variables used in both methods generated little or no sensitivity in the output. A series of recommendations were made regarding the material to be included in the new HCM. The study proposed a more simplified method consisting of two equations; one for the prediction of average speed of weaving vehicles, and the other for the prediction of average speed of non-weaving vehicles. This method did not consider any geometric configuration difference or the type of operation (e.g., constrained or unconstrained).

In late 1984, the Highway Capacity and Quality of Service Committee commissioned the NCHRP Project 3-28B team to recalibrate JHK-type equations for the prediction of weaving and non-weaving vehicle speeds in weaving areas for the three basic types of configurations and for constrained and unconstrained operations. This effort resulted in 12 calibrated equations. This revised procedure was presented to and approved by the committee in January 1985 and latter was included in the 1985 HCM (Special Report 209, TRB, 1985).

In 1985, Joe Fazio revised the JHK weaving procedure by enlarging the calibration data and including the variable "lane shift" in determining the speed of weaving and non-weaving vehicles. The lane shift variable represents the average amount of lane shifts performed by the drivers of the vehicles in the weaving traffic streams for a given or proposed weaving section.

In late 1989, a research team at the Institute of Transportation Studies of the University of California at Berkeley reviewed the existing weaving models and proposed three sets of equations for calculating the speed of weaving and non-weaving traffic (Cassidy et al, 1989).

In 1991, Michael J. Cassidy and Adolf D. May developed a new procedure for evaluating weaving performance. This procedure evaluates traffic flow behavior in individual lanes of a weaving section. In this procedure, vehicle flow rates in critical regions within the weaving section are predicted using prevailing traffic flow and geometric conditions. The results are used to assess the capacity sufficiency and level of service of a subject freeway weaving area.

In summary, the available analytical models for the analysis of freeway weaving operations are:

1. Special Report 209, BPR, 1950 (1950 HCM Method)
2. Special Report 87, HRB, 1965 (1965 HCM Method)
3. Report 159, NCHRP, 1976 (Polytechnic Method)
4. TRR 112, TRB, 1978 (Revised Polytechnic Method)
5. FHWA Project RD-82/54, 1983 (Jack E. Leisch Method)
6. Technical Report, FHWA, 1984 (JHK & Associates Method)

7. Special Report 209, TRB, 1985 (1985 HCM Method)

8. Joe Fazio, 1985 (Fazio Method)

9. TRR 1225, TRB, 1989 (University of California at Berkeley Method)

Methods 2, 3, 5, 6, 7, and 8 are described in detail in subsequent subsections.

2.2.1 1965 HCM Method

The 1965 HCM describes a simple weaving section as a length of one-way roadway accommodating weaving, at one end of which two one-way roadways merge and at the other end of which they separate.

Two types of weaving are considered by the method; 1) Single weaving, and 2) Multiple weaving, which are further subdivided into:

a) One-Sided Weaving Section where weaving takes place only on one side of the roadway, and

b) Two-Sided Weaving Section where weaving maneuvers take place on both sides, thus causing weaving to occur across the roadway

The 1965 HCM assesses the operation of a weaving section in terms of "Quality of Flow", which is a function of total weaving traffic and the length of the weaving section. The quality of flow, in the 1965 HCM, ranges form I to V representing a range of excellent to poor flow.

The relationship between geometric features of weaving sections and the traffic volumes and operating speeds attained on them has been represented by means of one basic weaving chart, presented in Figure 2.1, which includes both graphical information and related formulas. Curves on the weaving chart are considered to represent several

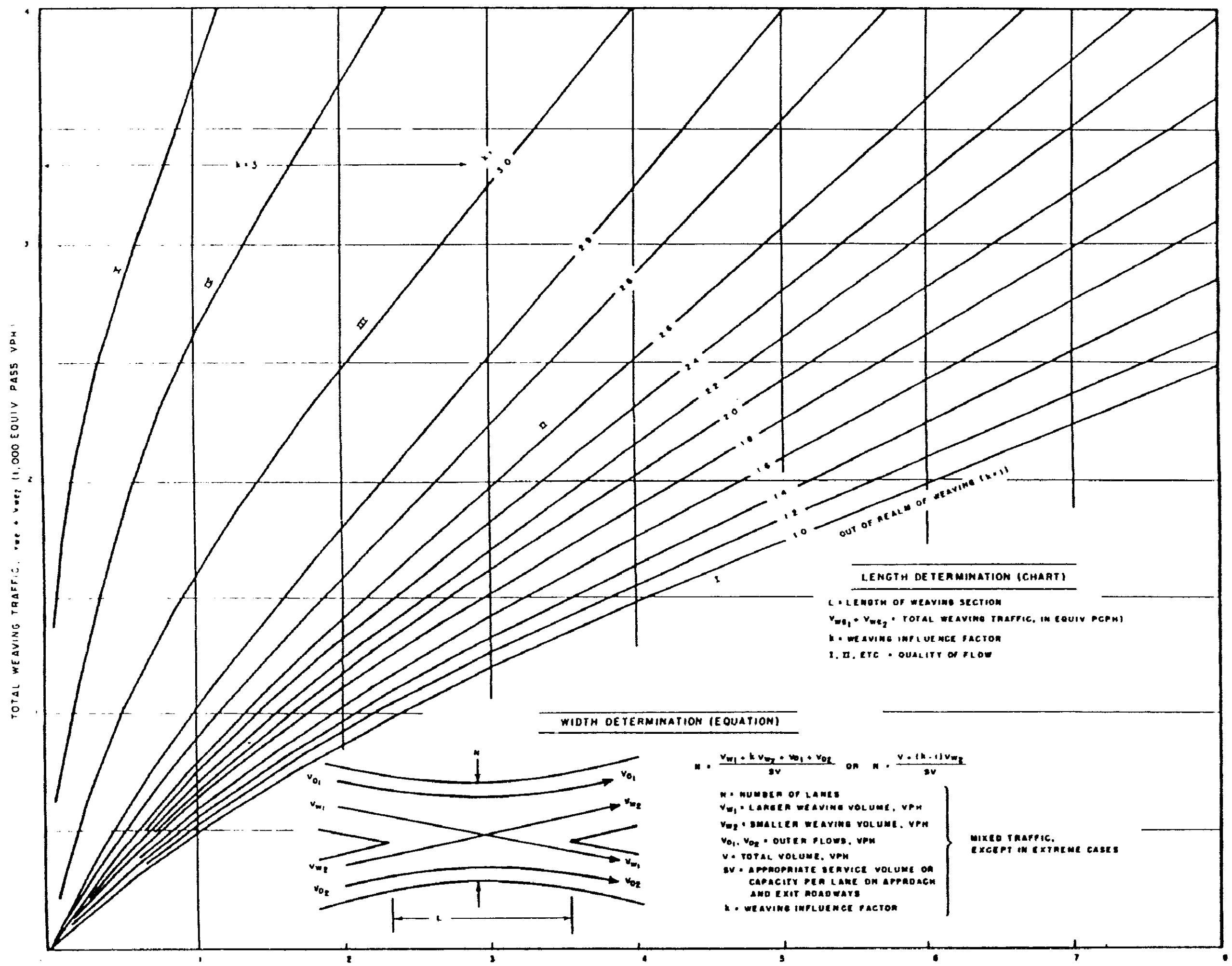


Figure 2.1 Operating Characteristics of Weaving Sections (1965 HCM)

levels of quality of flow, designated by I through V. Table 2.1 serves as a cross-reference relating these quality designations to the equivalent service volumes on the highway. The following are basic considerations related to the development and use of the chart presented in Figure 2.1:

- The fundamental weaving volume determination of this chart incorporates length as the basic variable.
- Values which fall above and to the left of curve I are taken to represent a weaving condition.
- Values between curves I and III are indicative of excellent to good operating conditions in the weaving section, provided an adequate number of lanes is furnished.
- Every vehicle in the weaving stream of traffic must cross the crown line (a real or imaginary line connecting the noses of the entrance and exit forks) somewhere between its extremities.
- As the weaving volumes increase, longer distances are necessary to perform the weaving maneuvers.
- When the number of weaving vehicles exceeds the capacity of a traffic lane, some of the vehicles are involved in two weaving maneuvers, and compound weaving exists.
- Where the weaving traffic approaches a volume equal to double the capacity of a traffic lane, theoretically, the required length is three times that of weaving volume equivalent to a single-lane capacity.

Table 2.1 Relationship Between Quality of Flow and Maximum Volumes in Lane Service Volumes in Weaving Sections (1965 HCM)

QUALITY OF FLOW CURVE	MAX. LANE SERVICE VOLUME (PCPH)
I	2,000
II	1,900
III	1,800
IV	1,700
V	1,600

- The effective length of a weaving section is also influenced, at least at the better levels of service, by the distance in advance of the weaving section that drivers on one approach road can see traffic on the other approach road.
- The length of the weaving section should be at least sufficient to provide an operating level compatible with the level of service on the highway facility of which the weaving section is a part.

The width of the weaving section is defined in terms of the number of lanes. The number of lanes required for non-weaving flow (N_{nw} = outer flows) is given by:

$$N_{nw} = (V_{01} + V_{02}) / SV \qquad (2.1)$$

Where; V_{O1} and V_{O2} are the outer non-weaving flows in vhp, and SV is the service volume per lane in vph.

For equivalent volumes more width is required for weaving than for non-weaving flow. The number of lanes required for weaving flow (N_w) is expressed as:

$$N_w = [(V_{W1} + k\ (V_{W2})] / SV \qquad (2.2)$$

Where; V_{W1} and V_{W2} are the two weaving flows in vph, and k is a weaving influence factor, in the range of 1.0 to 3.0. The maximum (k = 3.0) is applicable to the shorter weaving sections represented by curves III, IV, and V.

The total number of lanes required in the weaving section is obtained by the combination of the above two equations.

This method determines the speed of weaving and non-weaving flow poorly since each of the five quality of flow levels simply correspond to a range of speed. Although the 1965 HCM provides several procedures for dealing with weaving sections and served its purpose well, the need for improved methods arose soon.

2.2.2 Polytechnic Method

The key feature of this methodology is that the geometric configuration of lanes in the weaving area is a major determinant of operating quality. This method defines two basic categories of weaving sections with four basic types of weaving configuration, shown in Figure 2.2, which are:

1. Ramp-weaving sections with continuous auxiliary lane
2. Major weave type I (no lane balance at exit gore)
3. Major weave type II (lane balance at exit gore)
4. Major weave type III (with crown line)

For each configuration, the method further introduces the concept of type of operation (constrained and unconstrained) based on the maximum number of lanes which weaving vehicles may occupy, $Nw_{(max)}$. When the weaving volumes are such that they would tend to occupy more than $Nw_{(max)}$ if a natural balance of lane utilization were struck, the section is defined as constrained. In the sections where weaving and nonweaving flows compete for space and strike a natural balance in which Nw is less than $Nw_{(max)}$, the section is considered to be unconstrained.

For each type of weaving configuration, the model consists of three basic equations which determine the maximum value of the number of lanes used by the weaving flow, the relationship between speed of weaving and nonweaving flow, and the portion of total lanes utilized by weaving vehicles.

The application of Polytechnic's method for design involves an iterative process. At first the volumes are converted to passenger car units during the peak period. Next, one of the four configuration types, shown in Figure 2.2, is selected and an arbitrary

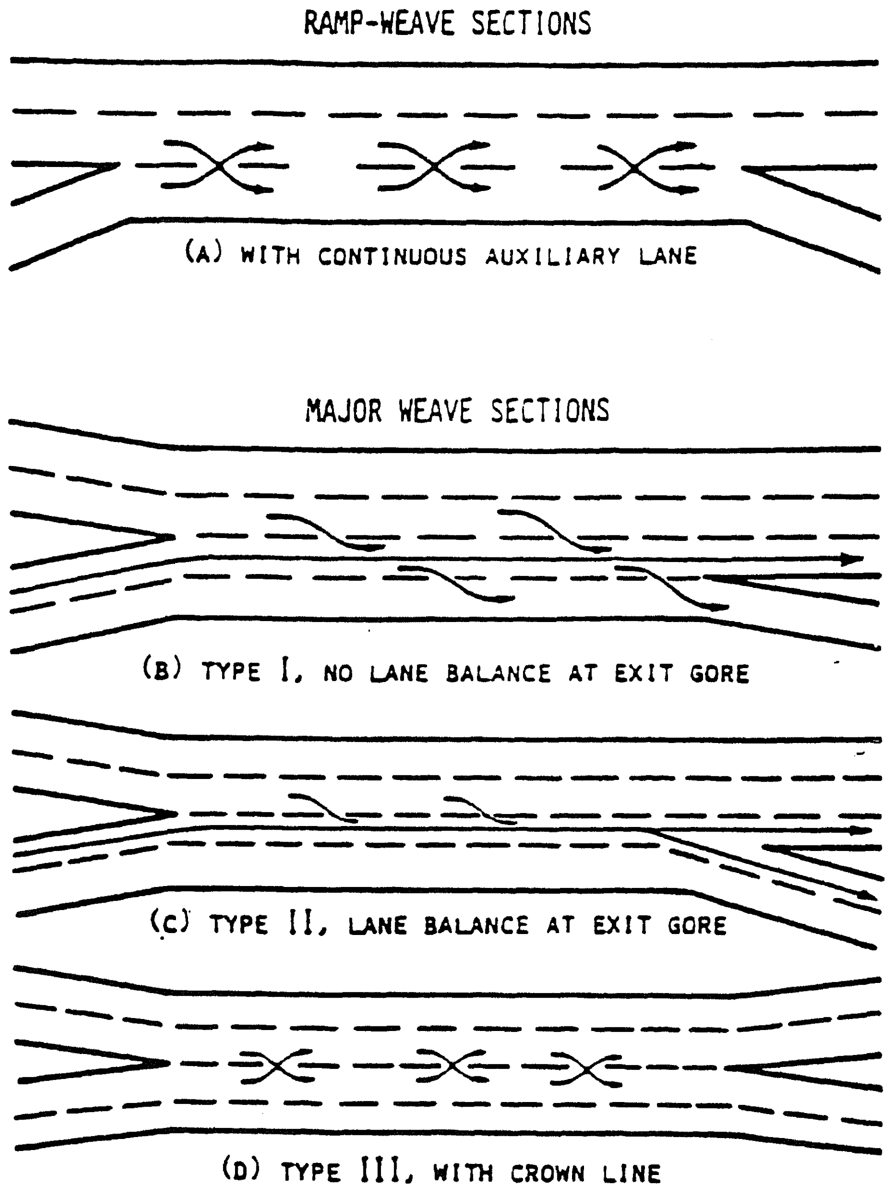


Figure 2.2 Configuration for Weaving Areas (Circular 212)

speed (typically 55 mph) is assumed for nonweaving vehicles. The speed of weaving vehicles is determined and the value of maximum number of lanes $Nw_{(max)}$ for weaving vehicles is read from a set of nomographs. The ratio of $Nw_{(max)}$ over the total number of lanes and average running speed of nonweaving vehicles are then determined graphically from nomographs also. This process is repeated until the assumed and calculated average speeds are the same. Finally, the level of service is determined using Table 2.2.

2.2.3 Jack E. Leisch Method

The Jack Leisch method was developed to update the 1965 HCM weaving procedure. This method classifies weaving sections under the following four categories:

1. Simple Weaving Section, where the weaving segment consists of two joining roadways followed by two separating roadways.
2. Multiple Weaving Section, which is formed by several ramp junctions in sequence (e.g., entrance ramp followed by two exit ramps, or two entrance ramps followed by a single exit ramp). A multiple weaving section may also be of a mixed variety, such as a right-hand ramp followed successively by a left- and a right-hand ramp.
3. One-Sided Weaving Section (a form of simple weaving section), where one right-hand entry is followed by a right-hand exit (some times referred to as ramp weave).
4. Two-Sided Weaving Section, where a right-hand entry is followed by a left-hand exit, or a left-hand entry followed by a right hand exit.

Table 2.2 Level of Service in Weaving Areas (Circular 212)

NON-WEAVING VEHICLES	
LEVEL OF SERVICE	AVG. RUNNING SPEED OF NON-WEAVING VEHICLES MPH (KM/H)
A	$S_{NW} \geq 50$ (80)
B	$S_{NW} \geq 45$ (72)
C	$S_{NW} \geq 40$ (64)
D	$S_{NW} \geq 35$ (56)
E	$S_{NW} \geq 30$ (48)
F	$S_{NW} < 30$ (48)

NON-WEAVING VEHICLES	
LEVEL OF SERVICE FOR WEAVING VEHICLES IS ___ THE LEVEL OF SERVICE FOR NON-WEAVING VEHICLES	IF $\triangle S$ IS MPH (KM/H)
THE SAME AS	$\triangle S \leq 5$ (8)
1 LEVEL POORER THAN	$\triangle S \leq 10$ (16)
2 LEVELS POORER THAN	$\triangle S \leq 15$ (24)
3 LEVELS POORER THAN	$\triangle S \leq 20$ (32)
4 LEVELS POORER THAN	$\triangle S \leq 25$ (40)

In this method, basic forms of one-sided weaving may have three different arrangements; Section A is a case of simple merge (accelerating facility) followed by a normal diverge (decelerating facility) without the use of an auxiliary lane, Section B in which the entrance and exit are connected by an auxiliary lane, and Section C which contains a C-D (collector-distributor) road that separates all weaving from through traffic. Furthermore, this method considers the following two types of operations:

1. Operationally Balanced Section, where weaving traffic operates at or near the LOS of nonweaving traffic.
2. Constrained Section, where the weaving flow intermixes with nonweaving traffic, each tending to operate at different LOS.

The Leisch method incorporated the following considerations in the development of the model:

- Weaving performance is fundamentally dependent upon the length and width of the weaving section, as well as on the amount and makeup of weaving and nonweaving traffic.
- Other geometric and operational features such as design speed, lane widths, gradients, proportion of trucks, and potential speeds of entering and exiting traffic (as affected by ramp geometry and nearby traffic control devices) all have an effect on weaving section performance.
- Internal lane arrangement and lane balance defines further configuration of weaving sections. Lane continuity and lane balance play a primary role in the efficiency and quality of operation. Designs which do not fully provide lane balance, tend to produce two and possibly three times the number of lane shifts

(L.S.) than those required on fully lane-balanced weaving sections. Those sections with the greater number of lane changes, even if the total number of lanes and weaving volumes are the same, would be expected to operate at a lower level of service.

Table 2.3 presents the performance criteria for weaving sections which define level of service in terms of speed and volume measures.

2.2.4 JHK Method

This method recommends two simple equations for calculating average weaving and nonweaving speeds. The JHK method eliminates the concepts of configuration types and types of operation (constrained and unconstrained) as introduced earlier.

Hourly volumes are used which are adjusted to passenger car equivalents by applying a heavy vehicle factor (Q). Table 2.4 presents the equations for predicting weaving and nonweaving speeds. Based on the computed average speeds, levels of service are determined from Table 2.5.

2.2.5 1985 HCM Method

Chapter 4 of the 1985 HCM, entitled "Freeway Weaving", is the result of a modified study conducted by JHK & Associates. The 1985 HCM defines three weaving area configuration types (A, B, and C). These configurations are based on the minimum number of lane changes required by weaving vehicles. Table 2.6 presents weaving section configuration type versus number of required lane changes. The following are the definitions of configuration types:

Table 2.3 Performance Criteria for Weaving Section on Freeway (Leisch Method)

Speed Measures for Level of Service

LEVEL OF SERVICE	AVERAGE RUNNING SPEED - MPH		
	FREEWAY PROPER THRU MOVEMENT APPROACHING AND FOLLOWING RECOVERY LEAVING WEAVING SECTION	ONE SIDED WEAVING SECTION WEAVING TRAFFIC ONLY	TWO SIDED WEAVING SECTION WEAVING AND MOJOR ROUTE TRAFFIC
A	55	50	55
B	50	45	50
C	45	40	45
D	40	35	40
E	30	25 - 30	30

Volume Measure for Levels of Service Applicable to all Traffic-Weaving and Non - Weaving

LEVEL OF SERVICE	SV - MAXIMUM SERVICE VOLUME - PCPH PER LANE FOR NUMBER OF BASIC LANES (N_b) ON MAJOR APPROACH ROADWAY		
	$N_b = 2$	$N_b = 3$	$N_b = 4$
A	750	800	850
B	1000	1100	1200
C	1250	1350	1450
D	1550	1600	1650
E	1900	1900	1900

Table 2.4 JHK Model for Prediction of Average Weaving Speeds

$$S_W = 15 + \frac{50}{1 + 2000(1+V_4/V)^{2.7}(1+V_W/V)^{0.9}(V/Q/N)^{0.6}/L^{1.8}} \quad (3)$$

$$S_{NW} = 15 + \frac{50}{1 + 100(1+V_4/V)^{5.4}(1+V_W/V)^{1.8}(V/Q/N)^{0.9}/L^{1.8}} \quad (4)$$

		LIMITS	
		LOWER	UPPER
S_W	= Predicted weaving speed	> 15	< 65
S_{NW}	= Predicted nonweaving speed	> 15	< 65
V	= One hour volume	> 0	—
Q	= Heavy vehicle factor	> 0	1.0
V/Q	= Total volume, pcph	> 0	—
V_W/Q	= Weaving volume, pcph	0	V/Q
V_W/V	= Volume ratio	0	1.0
N	= Number of lanes in weaving section	1	—
L	= Length of weaving section	> 0	4000
V_4/Q •	= Movement 4 volume, pcph	0	$(V-V_W)/Q$
V_4/V •	= Movement 4 volume over total volume	0	$1-V_W/V$

Caution: Values for volumes must be on an hourly basis

• Added by the author.

Table 2.5 Level of Service Criteria (JHK Method)

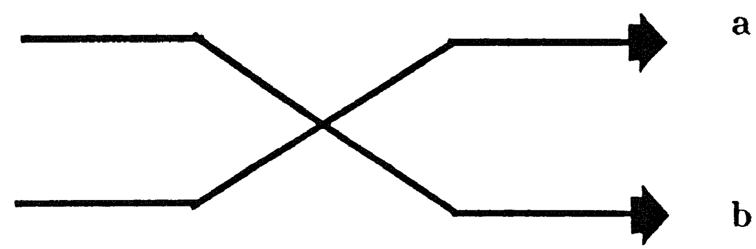
FOR WEAVING VEHICLES

LOS	SPEED (MPH)
A	$\geq$ 50
B	$\geq$ 45
C	$\geq$ 40
D	$\geq$ 35
E	$\geq$ 25
F	< 25

FOR NON-WEAVING VEHICLES

LOS	SPEED (MPH)
A	$\geq$ 55
B	$\geq$ 50
C	$\geq$ 45
D	$\geq$ 40
E	$\geq$ 30
F	< 30

Table 2.6 Configuration Type Versus Number of Required Lane Changes



Number of Req'd Lane Changes for Weaving Mvt b	Number of Required Lane Changes for Weaving Movement a		
	0	1	≥ 2
0	Type B	Type B	Type C
1	Type B	Type A	----
≥ 2	Type C	----	----

Source: 1985 HCM

- Type A configuration requires that each weaving vehicle performs one lane change in order to execute its desired movements. Ramp weave freeway sections are typically of this type.
- Type B weaving area configuration requires vehicles in one weaving traffic stream to execute one lane change, while vehicles in the other weaving traffic stream perform desired movements without changing lanes.
- Type C weaving sections require vehicles in one weaving traffic stream to perform two or more lane changes, while vehicles in the other weaving traffic stream perform their desired maneuvers without changing lanes.

Major aspects of Chapter 4 of the 1985 HCM are the development, illustration, and discussion of the effects of configuration on weaving areas. Configuration is the principal concept affecting the computational procedures for weaving areas. It has a substantial effect on the relative speeds of weaving and nonweaving vehicles by creating a restriction on the use of certain lanes by weaving vehicles.

The methodology discusses and illustrates the development of weaving diagrams and covers basic relationships, level-of-service criteria, and step-by-step procedures for analysis. The procedure also includes illustrative problems and discussion as well as a treatment of multiple weaving sections.

Determining the type of operation (constrained versus unconstrained) in a weaving segment is a key step in applying the 1985 HCM procedures and it is a direct result of configuration type and weaving volumes. An unconstrained operation is defined as one in which both weaving and nonweaving vehicles occupy the proper proportion of lanes within the weaving segment such that their speeds are approximately the same. The configuration often limits weaving vehicles to a smaller proportion of lanes than desired. This leads to a constrained operation with nonweaving vehicles operating at significantly higher speeds than weaving vehicles. Equations based on empirical data are used to determine the type of operation. This is done based on comparison of two variables; N_w and $N_{w(max)}$. Table 2.7 presents the criteria for unconstrained versus constrained operation of weaving areas. Once the type of operation is determined, weaving and nonweaving speeds are calculated from:

$$S_w \text{ or } S_{nw} = 15 + 50 / [1 + a(1 + VR)^b (V/N)^c / L^d] \tag{2.3}$$

where, a, b, c, and d are the calibration constants based on types of operation and configuration. Table 2.8 gives the values of these constants and Table 2.9 presents the parameters effecting the weaving area operation. Finally, levels-of-service for weaving and nonweaving traffic are determined from Table 2.10 based on the computed average weaving and nonweaving speeds.

It is important to note that the methodology used in the 1985 HCM is subject to certain limitations, presented in Table 2.11. The maximum weaving capacity and the maximum flow rate per lane are values beyond which acceptable operations are unlikely. The maximum volume ratio, weaving ratio, and weaving length are limits of the calibrated equations. Values higher than the maxima have not been tested and thus may give inaccurate results.

Table 2.7 Creteria for Unconstrained Versus Constrained Operation of Weaving Areas

TYPE OF CONFIGURATION	NUMBER OF LANES REQUIRED FOR UNCONSTRAINED OPERATION, N_W	MAX. NO. OF WEAVING LANES N_w (max)
TYPE A	$2.19\ N\ VR^{0.571}\ L_H^{0.234} / S_w^{0.438}$	1.4
TYPE B	$N\ (0.085+0.703VR+(2.348/L)-0.018(S_{nw}-S_w))$	3.5
TYPE C	$N\ (0.761-0.011L_H-0.005(S_{nw}-S_w)+0.047VR)$	3.0

All Variables Are Defined in Table 2.11
For 2-Sided Weaving areas, all Freeway Lanes may be used
Note: When $Nw \leq Nw$ (max), Operation is unconstrained
When $Nw \geq Nw$ (max), Operation is constrained
Source: 1985 HCM

Table 2.8 Calibration Constants for Speed Prediction of Weaving and Non-Weaving Flows in Weaving Areas

GENERAL FORM:

$$S_W \text{ or } S_{nW} = 15 + \frac{50}{1 + a\,(1 + VR)^b\,(V/N)^c\,/L^d}$$

TYPE OF CONFIGURATION	CALIBRATION CONSTANTS FOR WEAVING SPEED S_W				CALIBRATION CONSTANTS FOR NON-WEAVING SPEED S_{nW}			
	a	b	c	d	a	b	c	d
TYPE A								
UNCONSTRAINED	0.226	2.2	1.00	0.90	0.020	4.0	1.30	1.00
CONSTRAINED	0.280	2.2	1.00	0.90	0.020	4.0	0.88	0.60
TYPE B								
UNCONSTRAINED	0.100	1.2	0.77	0.50	0.020	2.0	1.42	0.95
CONSTRAINED	0.160	1.2	0.77	0.50	0.015	2.0	1.30	0.90
TYPE C								
UNCONSTRAINED	0.100	1.8	0.80	0.50	0.015	1.8	1.10	0.50
CONSTRAINED	0.100	2.0	0.85	0.50	0.013	1.6	1.00	0.50

Source: 1985 HCM

Table 2.9 Parameters Affecting Weaving Area Operation

SYMBOL	DEFINITION
L	Length of weaving area, ft.
L_H	Length of weaving area, in hundreds of ft.
N	Total number of lanes in the weaving area.
N_w	Number of lanes used by weaving vehicles in the weaving area.
N_{nw}	Number of lanes used by non-weaving vehicles in the weaving area.
V	Total flow rate in the weaving area, in passenger car equivalents, pcph.
V_w	Total weaving flow rate in the weaving area, in passenger car equivalents, pcph.
V_{w1}	Weaving flow rate for the larger of two weaving flows, in passenger car equivalents.
V_{w2}	Weaving flow rate for the smaller of two weaving flows, in passenger car equivalents.
V_{nw}	Total non-weaving flow rate in the weaving area, in passenger car equivalents, pcph.
VR	Volume ratio; V_w/V
R	Weave ratio; V_{w2}/V_w
S_w	Average running speed of weaving vehicles in the weaving area, mph.
S_{nw}	Average running speed of non-weaving vehicles in the weaving area, mph.

Source: 1985 HCM

Table **2.10** Level of Service Criteria for Weaving Section

LEVEL OF SERVICE	MINIMUM WEAVING SPEED Sw	MINIMUM NON-WEAVING SPEED Snw
A	55 mph	60 mph
B	50 mph	54 mph
C	45 mph	48 mph
D	40 mph	42 mph
E	35 mph	35 mph
F	< 35 mph	< 35 mph

Source: 1985 HCM

Table 2.11 Limitations on Weaving Area Operation

TYPE OF CONFIGURATION	WEAVING CAPACITY; MAXIMUM V_w pcph	MAXIMUM V/N pcphpl	MAXIMUM VOL. RATIO VR	MAXIMUM WEAVING RATIO, R	MAXIMUM WEAVING LENGTH, L
TYPE A	1,800	1,900	N VR 2 1.00 3 0.45 4 0.35 5 0.22	0.50	2,000 '
TYPE B	3,000	1,900	0.80	0.50	2,500 '
TYPE C	3,000	1,900	0.50	0.40	2,500 '

Source: 1985 HCM

2.2.6 Fazio Method

In 1985, Joe Fazio refined the JHK & Associates' revised operational analysis and designed procedures by enlarging the calibration data, including lane configuration of the weaving section, and introducing a "lane shift" variable.

The lane shift variable represents the average amount of lane shifts performed by the drivers of the vehicles in the weaving traffic streams for a given or proposed weaving section.

The first step in this procedure is the determination of the lane shift multiplier which is the minimum amount of lane shifts a vehicle must make from a particular lane in order to complete the weaving maneuver. Figure 2.3 presents examples for determining lane shift multipliers for two different types of weaving geometry. All volumes are then converted to the peak flow rate by applying appropriate adjustments. The lane shift variables LS and LS3 are calculated using the equations in Table 2.12. The average weaving and nonweaving speeds are determined using the two equations presented in Table 2.13. Based on the calculated average weaving and nonweaving speeds, levels-of-service are determined from Table 2.14.

2.3 Systems Simulation

Systems simulation is, as defined by Hoover and Perry (1989), the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with models to describe, explain, and predict the behavior of the system.

Simulation provides a means of dividing the model-building job into smaller component parts that can be formulated more readily and then combining these

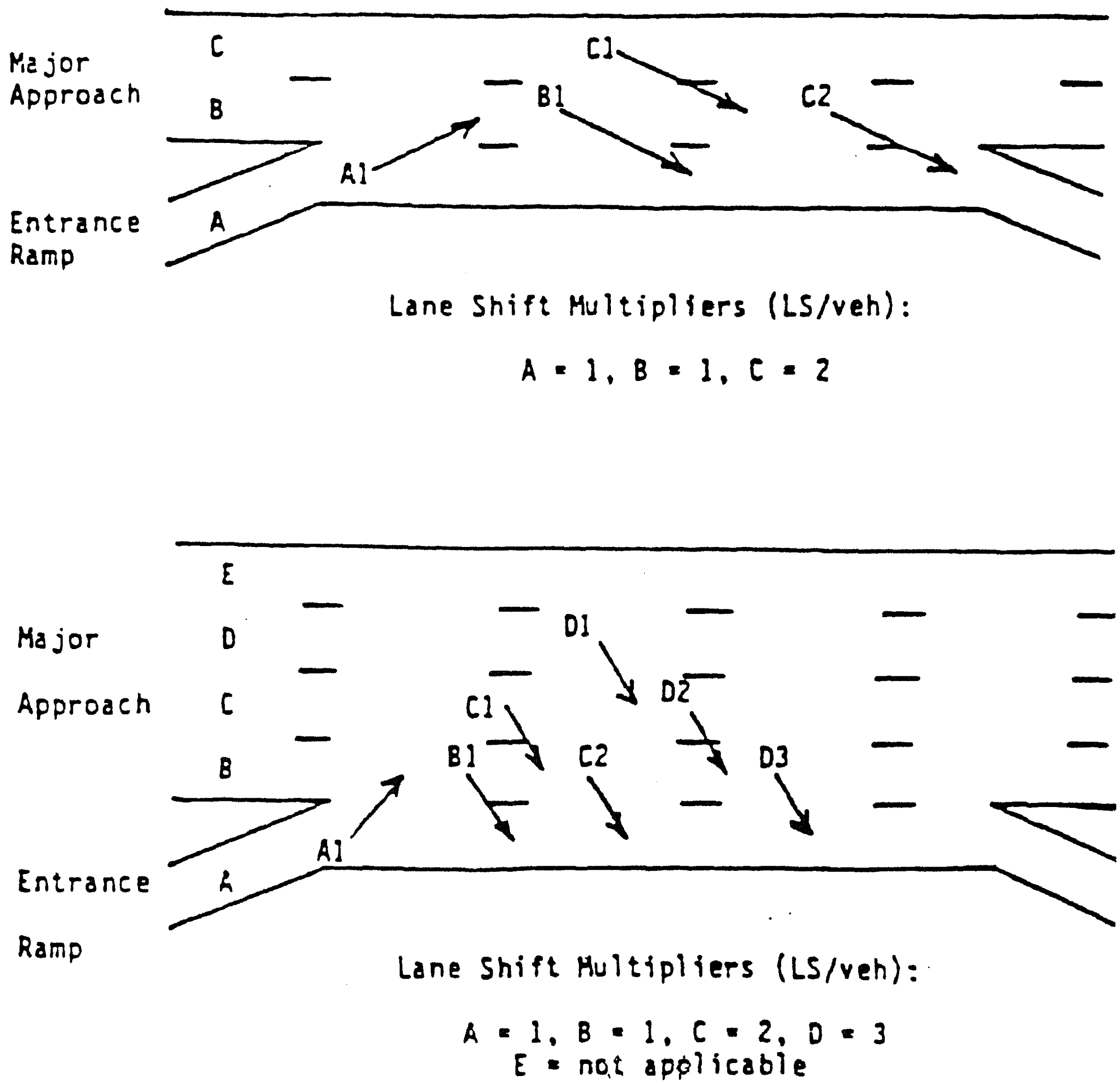


Figure 2.3 Examples on Determining Lane Shift Multipliers (Fazio Method)

Table 2.12 Lane Shift Equations (Fazio Method)

WHEN:	LS_2 EQUALS:	LS_3 EQUALS:
$N_b = 1$	$V_2 B / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$	$V_3 B / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$
$N_b = 2$	$(0.934V_2 B + 0.066V_2 C) / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$	$V_3 B / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$
$N_b \geq 3$	$(0.934V_2 B + 0.066V_2 C + 0.010V_2 D) / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$	$V_3 B / (PHF \cdot f_{HV} \cdot f_W \cdot f_P)$
$LS = LS_2 + LS_3$		

Where:

V_2 = Volume of weaving traffic stream originating form the major approach to the weaving section, vph

V_3 = Volume of weaving traffic stream originating from the minor approach or entrance ramp to the weaving section, vph

N_b = Number of basic lanes on the major approach to the weaving section

A = Lane shift multiplier for entering lane A, lanes shifts per vehicle (LS/veh.)

B = Lane shift multiplier for entering lane B, lanes shifts per vehicle (LS/veh.)

C = Lane shift multiplier for entering lane C, lanes shift per vehicle (LS/veh.)

D = Lane shift multiplier for entering lane D, lanes shift per vehicle (LS/veh.)

LS_2 = Average amount of lane shifts performed by the drivers of movement 2 vehicles, passenger car lane shifts per hour (pcLSph)

LS_3 = Average amount of lane shifts performed by the drivers of movement 3 vehicles, passenger car lane shifts per hour (pcLSph)

LS = Average total amount of lane shifts performed by the drivers of weaving vehicles, (pcLSph)

Table 2.13 Fazio Model for Prediction of Average Weaving Speeds

$$S_W = 15 + \cfrac{50}{1 + \cfrac{[1 + (V_3 + V_4)/V]^{3.045} (V/N)^{0.605} (LS/L)^{0.902}}{75.959\,(1 + LS_3/V)^{3.395}}} \quad (6)$$

$$S_{NW} = 15 + \cfrac{50}{1 + \cfrac{(1 + V_4/V)^{5.080} (1 + V_W/V)^{2.019} (V/N)^{1.523}}{60.995\,(1 + LS_3/LS)^{0.916} (L)^{1.070}}} \quad (7)$$

		LIMITS	
		LOWER	UPPER
S_W	= Predicted weaving speed	> 15	< 65
S_{NW}	= Predicted nonweaving speed	> 15	< 65
V	= One hour volume	> 0	—
V_W	= Total weaving volume	0	V
V_3	= Movement 3 volume, pcph	0	V_W
V_4	= Movement 4 volume, pcph	0	$V-V_W$
N	= Number of lanes in weaving section	1	—
L	= Length of weaving section	> 0	5000
LS	= No. of lane shifts by weaving vehicles	> 0	—
LS_3	= No. of lane shifts by movement 3 vehicles, pcLSph	0	LS

Table 2.14 JHK & Associates Recommended LOS Ranges (Fazio Method)

LOS_W	S_W (mph)
A	$\geq$ 50
B	$\geq$ 45
C	$\geq$ 40
D	$\geq$ 35
E	$\geq$ 25
F	> 25

LOS_{NW}	S_{NW} (mph)
A	$\geq$ 55
B	$\geq$ 50
C	$\geq$ 45
D	$\geq$ 40
E	$\geq$ 30
F	> 30

component parts in their natural order. After constructing the model, we can then activate it by using random numbers to generate simulated events over time according to appropriate probability distributions. The result is a simulation of the actual operation of the system over time, and we can record its aggregate behavior. By repeating this process for the various alternative configurations for the design and operating policies of the system, and by comparing their performances, we can identify the most promising configurations. Because of statistical error, it is impossible to guarantee that the configuration yielding the best simulated performance is indeed the optimal one, but it should be at least near optimal if the simulated experiment was designed properly.

If the computer-based mathematical/symbolic model accurately captures the entities and behavior of the object system, then the performance measures obtained from the simulation should be equivalent to the performance measures that would have been obtained had we experimented directly on the system.

2.4 Traffic Simulation

Simulation of vehicular traffic on highways and on street networks has been a natural application of computer modeling since the early stages of digital computation. The traffic environment is complex and stochastic in nature. Individual vehicles move along specified guideways constrained by the presence of other vehicles and restricted by control devices, while they attempt to satisfy individual objectives. Simulation is a technique which permits the study of a complex traffic system in the laboratory rather than in the field. The great appeal of the simulation approach is, therefore, that this technique offers the user an opportunity to evaluate alternative strategies before implementing them in the field. Thus the optimal strategy may be identified prior to the commitment of substantial funds for implementation of large systems.

Simulation models may be classified as microscopic or macroscopic. Microscopic models are those which simulate the movements of individual vehicles. Each vehicle, under this approach, is represented by a set of variables such as: vehicle type, position, speed, acceleration, etc., and this set of variables is updated at fixed or variable time intervals. A microscopic model generally requires a larger programming and debugging effort, exhibits more stringent storage requirements and consumes more computing time, while providing greater resolution and potentially more accuracy, relative to the other alternative.

Macroscopic models, on the other hand, represent traffic in terms of overall parameters such as: traffic volumes, average speed and density, and handle vehicles in groups. This technique, although being more economical in every respect, may be unable to describe a complex process adequately, yielding inaccurate or misleading results which are usually unacceptable.

Traffic simulation models are computer programs that are designed to represent realistically the behavior of the physical system. Such models are a collection of analytical models that describe such highly variable motorist responses as car following, lane changing, queue formation, discharge, etc. Such models are integrated into a logical structure in the form of computer software.

Inputs to models include known attributes of the system such as the geometric characteristics of the section/network link (e.g., length, width, and number of lanes), area topology, time varying traffic-demand volumes, vehicle classification, vehicle characteristics (acceleration and deceleration properties), and driver characteristics.

Measures of effectiveness (MOE) are collected as output to simulation models. These MOEs are accumulated as statistics in the course of representing the dynamic behavior of traffic. Representative MOEs include speed, stops, delay, density, queue length, spill back, fuel consumption, and vehicle emissions.

Careful examination of the resulting statistical output along with the engineering knowledge of the user, can provide the insight needed to identify the optimal design. The user, therefore, through simulation, has the capability to experiment, evaluate, and design.

To be useful, traffic simulation must satisfy three basic conditions (Davis, G.W. et al, 1974):

1. The results of the simulation must fit the facts.
2. The results of the simulation must be accessible in a format that is meaningful to those using them.
3. The time required to simulate a problem must be reasonable.

Ideally, a traffic simulation model should represent a cooperative effort between a traffic theorist and a computer technologist. A good simulation program should include the following:

- It must provide an easy, inexpensive method of simulation.
- It must be general enough so that any configuration can be simulated using the proper input data.

- The input must be easily understood and capable of execution by non-computer-oriented personnel.
- The output must be easily readable and sufficient.
- It must be written in modular form such that a change in one module does not affect the rest of the program.
- It must be written such that it does not require extensive programming changes to add a new module.
- It must be machine independent, written in one of the higher level languages such as Fortran-77 in such a manner that a novice programmer can modify it.

2.5 Available Traffic Simulation Models

Gibson (1981) and May (1987) each present a comprehensive survey of existing models. Gibson provides a catalog of 104 documented computer models for traffic operation analysis. The models are classified according to the transportation system elements (i.e., intersections, arterials, networks, freeways, and corridors) they simulate. Some of these models, that are considered practical, are included in distinct families by the Federal Highway Administration. For example, SOAP, PASSER, and TRANSYT are included in the Arterial Analysis Package (AAP). NETSIM, TRANSYT-7F, and SIGOP are included in the TRAF family, and PRIFRE, FREQ3CP, INTRAS, and FRESIM are included in the FREQ family.

May provides a comprehensive survey of existing traffic simulation models and applications in freeway corridor analysis, including their historical development and applications. An extensive bibliography of the model descriptions and their application is also given. May argues the need for integration of research, education, and implementation activities as key to the enhancement of the simulation modeling practice.

Hsu and Munjal (1974) identified and reviewed 15 simulation models associated with various aspects of freeway vehicular traffic, and the models are compared against a baseline of eight desirable model features.

In the last few decades, a considerable number of computer models have been developed to aid transportation engineers and planners in evaluating alternative traffic control strategies for transportation facilities. Models able to handle virtually every traffic simulation need are now available. However, the majority of them have some drawbacks and limitations that will be indicated in section 2.6.

The following section presents a brief description of the available arterial and freeway simulation models that are microscopic in nature and are somewhat similar to the one developed here (NFWSIM).

2.5.1 Arterial/Freeway Simulation Models

2.5.1.1 TEXAS Model

The TEXAS model was originally developed in 1977 by T.W Riouc and C.E Lee, Center for Highway Research, University of Texas at Austin (Lee, 1977). It is programmed in FORTRAN IV and evaluates traffic performance at an isolated intersection.

The geometry processor GEOPRO, translates the user input data into the required geometry information . The driver-vehicle processor, DVPRO, randomly generates the individual driver-vehicle units based on a variety of user data and program default values. Stochastic treatment is given to the particular driver characteristics and vehicle generation. SIMPRO, the simulation processor, microscopically processes each driver-vehicle unit through the intersection in a fixed, discrete-time increment, and accumulates data on the vehicle performance and traffic interactions.

2.5.1.2 TRAF-NETSIM Model

TRAF-NETSIM (Rathi, 1990) is an arterial network model, the initial version of which was released in 1971 and was subsequently updated in 1973 and 1978. The model later became a component of the integrated traffic simulation system, TRAF, in the early 1980s (Lieberman, 1981). It is useful for the evaluation of alternative urban arterial network control strategies, with particular emphasis on sophisticated signal control systems.

The earlier, less powerful version of NETSIM was called UTCS-1 which in turn was based on the DYNET and TRANS models. NETSIM treats the street network as a series of interconnected links and nodes, along which vehicles are processed in a time-scan format subject to the imposition of traffic control systems. The NETSIM model has been validated against field data collection in Washington, D.C., Utah, California, and New Jersey. The model has been used successfully in numerous applications throughout the country in the last decade.

2.5.1.3 ARTWORK Model

ARTWORK (Arterial Work Zone Simulation Model) was developed to evaluate traffic control performance at an arterial street lane closure (Sadegh, 1988). The program was written in the SLAM II simulation language. Field studies at two sites were conducted to validate the model. The validation results indicated that the model had adequately described traffic flow through construction zones.

2.5.1.4 VPT (Vehicle Performance in Traffic) Model

The Aerospace Corporation Model VPT (Harju et al, 1972) is an exceptionally detailed, totally microscopic network model. It is a linking of two models known as FREEWAY and VPSST (Vehicle Performance in Surface Street Traffic).

Automobiles, trucks, and buses are generated according to a Poison distribution. The characteristics of the drivers are generated stochastically and include desired speed, desired lane, gap acceptance characteristics, and frustration factor which determines how long a driver will tolerate following a slower driver. Cars follow each other according to a reasonable car following law based on the apparent rate of change of the visual angle subtended by the leading car. This is the only simulation model that includes accidents. When two vehicles merge into the same spot, they are considered disabled and remain parked in that spot throughout the simulation. The validation of this model is poor, and its input requirements are quite extensive.

2.5.1.5 INTRAS Model

The INTRAS model was developed for studying freeway incidents (Wicks, 1980). INTRAS stands for INtegrated TRAffic Simulation and is a vehicle-specific time-stepping simulation designed to realistically represent traffic and traffic control in a freeway and the surrounding surface street environment. The model was originally developed for the FHWA in the late 1970s to assess the effectiveness of freeway control and management strategies. The model is operational on mainframe computers.

INTRAS simulates the movement of each individual vehicle on the freeway and surface street network, based on car-following, lane-changing, and queue-discharge algorithms. The model requires that the network first be coded into links and nodes. Links represent unidirectional traffic streams with homogeneous traffic and geometric characteristics, and nodes indicate the locations where the characteristics change.

Input to the model consists of data on design characteristic of each link, free-flow speeds, vehicle composition, traffic volumes, and percent of trucks for the freeway and ramps. The output includes the travel (vehicle-miles), average and total travel time, volume, density, average speed, number of lane changes, and average and total delay.

Among the existing general-purpose models, INTRAS is the most detailed simulation model of freeway traffic. It has been completely validated and the results of the validation reveal close agreement between simulated and field data.

2.5.1.6 FREECON Model

FREECON was developed by Rouphail as part of his Ph.D dissertation for evaluating traffic control systems at freeway lane closures (Rouphail, 1981). This model was written in the GASP IV simulation language and it consists of a main program and eighteen supporting subprograms and functions.

Vehicle arrivals to the system are generated randomly from one of nine, user specified, probability distribution functions. Upon arrival of vehicles, some tests are performed to satisfy car-following rules at the entry points. The individual vehicle status is described by a set of twenty attributes. The car-following rules apply only to vehicles in a platoon. Some additional segments such as: simulated traffic control devices, simulated human factor elements, simulated traffic control devices blockage, and simulated data collection system were also incorporated in the model.

Validation of the model was performed using data collected at two construction sites in the State of Ohio. Results of the statistical tests reveal that the model accurately predicted drivers' behavior in moderate-to-high volume/density conditions.

2.5.1.7 CARSIM Model

The CAR-following SIMulation model, CARSIM, was developed not only to simulate normal traffic flow but also stop-and-go conditions on freeways (Benekohal, 1988). The model is programmed in the SIMSCRIPT II.5 simulation language.

The features of CARSIM are: 1) marginally safe spacings are taken into account, 2) start-up delays of vehicles are taken into account, 3) reaction times of drivers are randomly generated, 4) shorter reaction times are assigned at higher densities, and 5) differential behavior of traffic in congested and noncongested conditions is taken into consideration in developing the car-following logic.

The validation of CARSIM was performed at microscopic and macroscopic levels. The regression analysis of simulation results versus field data yielded R^2 values of 0.98 and higher, indicating that the results from CARSIM were very close to the values obtained from field data.

2.5.1.8 WEAVESIM Model

WEAVESIM was developed to study the dynamics of traffic flow at freeway weaving sections (Zarean, 1988). Time-laps aerial photography supplied by FHWA was used to develop the calibration data base. The model utilizes the event-scheduling approach of SIMSCRIPT II.5.

WEAVESIM is based on a rational description of the behavior of a driver-vehicle unit. Vehicles are generated randomly at the system entry points and are advanced through the system through a car-following and a lane-changing module.

Validation of the model included the operational testing of the car-following algorithm and the comparison of the simulated observations with field data.

2.5.1.9 FREESIM Model

The objective of FREESIM is to evaluate the potential impact of reduced speed limits at temporary freeway lane closures at work zones at arbitrarily assumed levels of compliance and is written in SIMSCRIPT II.5 (Nemeth and Rathi, 1985).

The model logic is based on a rational description of the behavior of drivers in a lane closure situation. The vehicles are advanced in the system using the classical car-following approach. The model simulates lane changing as well as overtaking. Verification of the simulation model included operational testing of the simulation dynamics algorithms (i.e., car following and lane changing) and a sensitivity analysis of the measure of effectiveness to exogenous (input) variables.

Validation of the simulation model was accomplished by the comparison of simulated time-headway, speed, and merging distributions with four sets of actual observations obtained from three different rural freeway lane closure sites.

2.5.1.10 FRESIM Model

FRESIM is a microscopic, interval scanning, and freeway simulation model that was developed to become a component of the FHWA TRAF system of simulation models (Halati et at, 1991). The FRESIM model is a considerably enhanced and reprogrammed version of its freeway simulation predecessor, the INTRAS model, and is available for both mainframe and 386/486 based microcomputer applications.

In FRESIM the behavior of each vehicle is represented through interactions with the surrounding environment, which is the freeway geometry and other vehicles on the freeway. The status of each vehicle on the freeway is scanned and updated at constant time intervals of fixed duration, which can be varied depending on the desired level of detail required for modeling the traffic behavior on the freeway. Some of the more important elements of the FRESIM model are: 1) input representation, 2) vehicle movement, 3) lane-changing, 4) origin-destination, 5) lane drops and lane additions, 6) incident specification, 7) ramp metering, and 8) freeway surveillance.

FRESIM was calibrated and validated using several sets of comprehensive real-world data and was extensively tested on several complex and diverse scenarios.

2.6 Assessment of Available Traffic Simulation Models

In the past few decades, a considerable number of computer models have been developed to aid transportation engineers and planners in evaluating alternative highway traffic control strategies. Models able to handle virtually every traffic simulation need are now available. However, they have to be further tested, implemented, and enhanced so that they can be more reliable, more efficient, and easier to use. They also have to be efficiently maintained and supported so that the benefits of their application can be maximized.

Considerable human time is spent in input preparation, output interpretation, and bug detection and correction when undetected errors in a program prevent simulation model use. In the past, human time involved in these tasks was substantially increased due to the following factors (indicated by Radelat, 1981):

1. Diversity in Models and Programs

Diversity in models and programs is a source of inefficiency and confusion for users.

2. Documentation

Good documentation is a necessary tool for the understanding of any model. In the development of most early simulation models, less attention was devoted to documentation.

3. Programming Style

Inadequate design, large and complex subroutines that often perform several unrelated functions, and disorganized and poorly annotated code are some of the features of some old models.

4. Maintenance and Support

Most of the traffic simulation models have received inadequate maintenance and support - a deficiency that has resulted in sizeable waste of user time in input preparation, output interpretation, and debugging.

The main problem with the early traffic simulation models was their lack of reliability. Models were not properly validated, and programs were not thoroughly debugged and demonstrated. The importance of testing was not yet evident. The result was a lack of credibility that resulted in the natural lack of use of traffic simulation in the traffic engineering community.

Hsu and Munjal (1974) did a comprehensive comparative assessment of 15 microscopic freeway simulation models against a baseline of eight features and they concluded:

> "A careful examination of the existing models indicates that there was a lack of coordination in the development of models. There were no standards for the models and no application guidelines, which makes it difficult for the user to determine what model to select for his need. Because of the lack of a universally accepted traffic flow theory and varying operational characteristics, each model was developed largely trough intuition. Validation is a very expensive and time-consuming process, and no extensive validation covering a wide range of freeway geometries and traffic patterns has been conducted on any model. Therefore, the realism and utility of the existing traffic simulation models are still doubtful."

The following improvements were recommended in a TRB workshop on "Application of Simulation Models by Different User Groups," held in Williamsburg, Virginia, June, 1981:

> "A simplified method of labeling the various models is needed and documentation should be limited to the latest version. Efforts should also be spent to help establish the credibility of computer modeling among program managers and administrators and to justify adequate budgeting of funds for further development and support. Many models are incompatible and effort should be made to provide a commonality of data input and output formats."

CHAPTER III

DATA COLLECTION AND REDUCTION

3.1 Introduction

The process of data collection requires a full appreciation of the actual data requirements to establish a cost-effective collection program. The three major factors that are important in this area are: 1) Planning, 2) Equipment, and 3) Manpower.

Comprehensive planning is the key to successful data collection. The user must know his needs, recognize what the data are to be used for, how they are to be collected, and how they are to be coded into the model. The data collection, reduction, and manipulation efforts should be carefully planned from the outset so that automation and computer processing could be incorporated in all phases to minimize the time and expense required for the execution of all tasks. With this purpose in mind, a plan was devised for collecting, reducing, and processing data in an efficient manner.

Based on the type of model to be developed (analytical/simulation), the data, equipment, and manpower needs were identified first. Next, a plan was devised for data collection. Finally, procedures were established to reduce and analyze the voluminous data that would be collected.

Data on geometrics was obtained from actual field measurements and engineering drawings and maps. Operational data were collected by primarily videotaping actual traffic flow on site. The NJDOT made available its state-of-the-art, video-equipped vans staffed by its own technical personnel.

The day-of-the week and hours during which videotaping took place included a period of time that led to the peak period to observe changes in operating conditions as traffic volumes increased and reached the maximum. Criteria were also established on the unusual circumstances whose occurrence was a sufficient condition to terminate and abort the data collection efforts for the day (e.g., fire or police department activity, accidents, truck breakdowns, and other incidents that would severely disrupt a typical operation for the segment under observation).

3.2 Data, Equipment, and Manpower Requirements

Data constitute integral components of the calibration and validation processes of model development. The data requirements vary depending on the type of model to be developed. In this case, the analytical models are macroscopic, representing weaving traffic in terms of overall parameters such as volumes and average speeds. On the other hand, simulation models are microscopic, mimicing the movements of individual vehicles. The subsequent subsections identify model type specific data and other requirements.

3.2.1 Analytical Model

3.2.1.1 Data Requirements

Data are needed for calibration and validation of analytical models. As analytical models are macroscopic, the following data are identified for their development:

- Weaving and non-weaving volumes
- Volume classification

- Average weaving and non-weaving speeds
- Geometric characteristics of the facility
- Information on the facility's surroundings

3.2.1.2 Equipment and Manpower Requirements

To collect the data listed above, the following equipment and manpower are needed:

- Two video-installations capable of filming independently
- Two walkie talkies
- Measuring tape
- Two technicians for operating and monitoring the video equipment
- One surveyor for measuring length and width and collecting data on other geometric characteristics of the site and its surroundings.

3.2.2 Simulation Model

3.2.2.1 Data Requirements

The calibration of a simulation model needs a substantial amount of data. Data are needed for the calibration of numerous parameters embedded in the model to represent the dynamics of non-freeway weaving traffic flow. The data needed for the calibration of the microscopic simulation model are listed below:

- Traffic volumes and classification by each movement
- Lane specific (classified) volume distribution
- Vehicle inter-arrival headways
- Vehicle arrival speeds

- Driver's break reaction time
- Gap acceptance distribution
- Lane changing behavior
- Car following behavior
- Vehicular travel times/speeds in the weaving section
- Geometric characteristics of the facility
- Vehicle acceleration profile
- Vehicle deceleration profile

3.2.2.2 Equipment and Manpower Requirements

The equipment and manpower required for the collection of the simulation model data are the same as indicated in section 3.2.1.2 with the addition of complete set of distometer surveying equipment for locating various reference points in the system.

3.3 Data Collection

Operational data were collected by primarily videotaping actual traffic flows on site. Separate data collection setups were planned for the analytical and simulation models. In each case, two video-equipped vans with a platform on top were used for filming weaving sites. Two cameras, one on each van, were mounted on tripods which in turn were placed on the roof of the vans, thereby providing proper vantage positions. The following subsections explain the layout of the data collection setup employed, based on the type of data collected (macroscopic or microscopic).

3.3.1 Data Collection Setup for the Macroscopic Model

The layout employed for macroscopic data collection is presented in Figures 3.1a and 3.1b for basic and ramp weaves, respectively. Cameras 1 and 2 were placed on the site (usually on an island or median) in a way that would not obstruct the sight distances of vehicles. Camera 1 focused on entering vehicles, while camera 2 filmed leaving vehicles. In this case, the two camera setup was used to minimize the error in the data reduction phase that might have been caused by parallax, had only one camera been used.

The video cameras show a digital clock that can measure time up to 1/100th of a second. Both cameras are synchronized and started simultaneously on site. Each site is video-tapped for an average period of three hours capturing low to peak volume conditions.

3.3.2 Data Collection for the Microscopic Model

The data collection and reduction setup used for the development of the analytical models was not sufficient for conducting the studies needed for the simulation models. It was, therefore suggested to introduce some additional innovative technique to enhance the quality of the data and the methods which are used to collect them. This new technique of data collection, developed by NJIT's study team, is an application of image processing, called video-photogrammetry, and is explained in the following section.

3.3.2.1 Video-Photogrammetry, an Innovative Method of Data Collection

A comprehensive technical description of the video-photogrammetry method of data collection can be found in Greenfeld et al, 1993. Figure 3.2 gives an overview of the

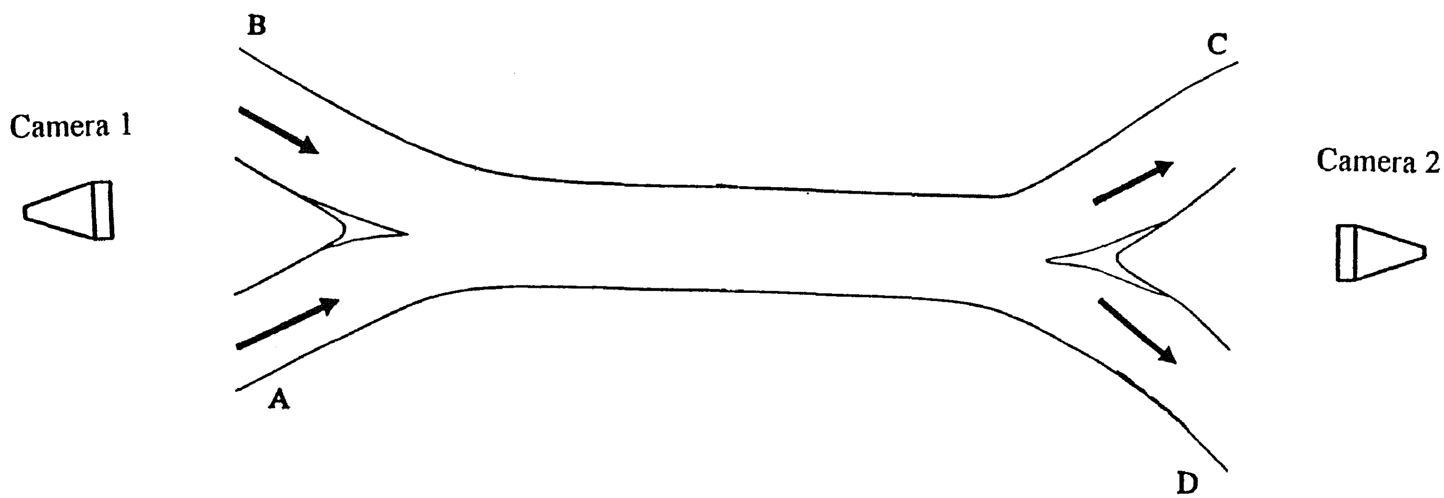


Figure 3.1a Video-Taping Setup for Macroscopic Data Collection (Basic Weave)

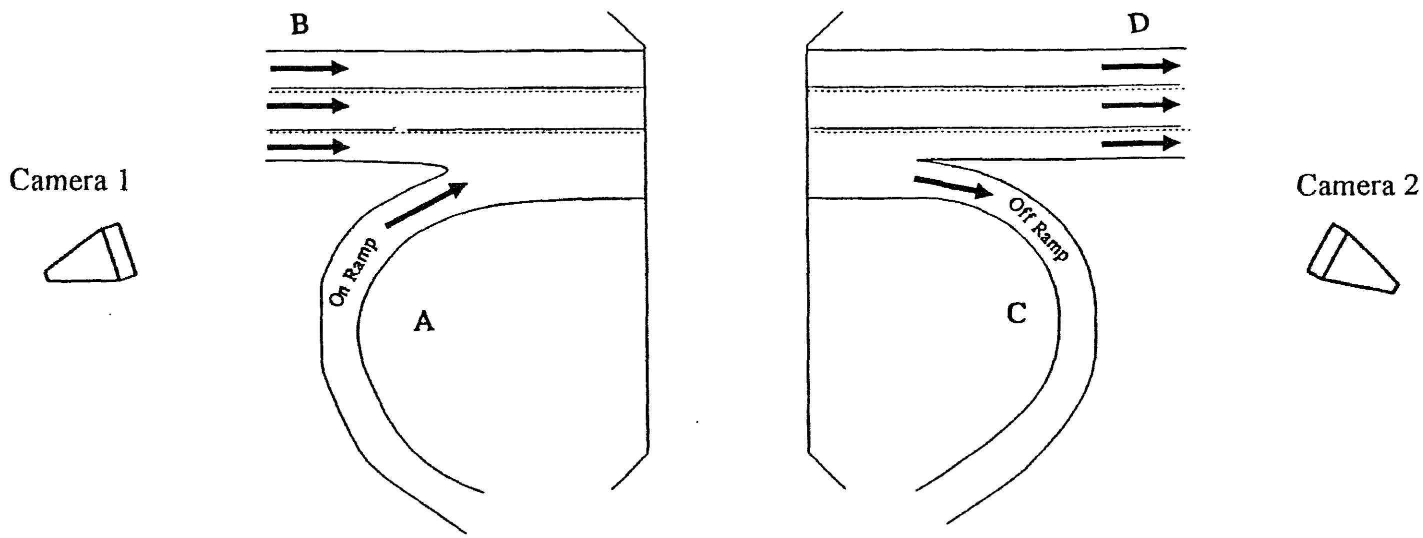


Figure 3.1b Video-Taping Setup for Macroscopic Data Collection (Ramp Weave)

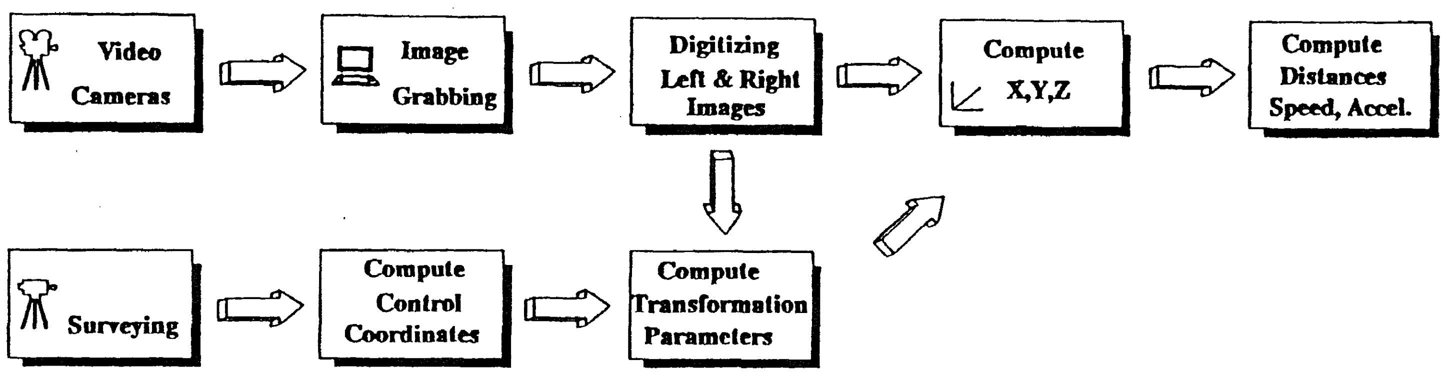


Figure 3.2 Overview of Data Collection and Reduction System

data collection and reduction procedure using the image processing technique. A two camera setup is used to video tape each site, and an image board enables the conversion of VHS video signals into a PC compatible digitized data base.

A C-program was written to grab images from the left and right video cameras. Digitizing left and right images of each vehicle gives X,Y,Z coordinates with respect to time. This information is used to compute vehicle headways, speeds, accelerations, and travel time.

To validate and cross-check the results of the image processing methodology, each data collection session, along with video taping, was accompanied by the identification of control points using a theodolite and distometer.

3.3.2.2 New Data Collection Setup

The two camera setup produces a stereo image of the traffic at any given time. The setup requires that the cameras are mounted (more or less) parallel to each other and that the distance between them is known. The layout of the data collection setup is presented in Figures 3.3a and 3.3b for basic and ramp weaves, respectively. As shown, the two video cameras are so placed that the rear (or front) view of the traffic is exposed to them.

Both cameras are synchronized and started simultaneously on site. The distance between the two cameras is measured. All the pertinent geometric data of the weaving section (length of the section and lane width) are recorded. The location of several

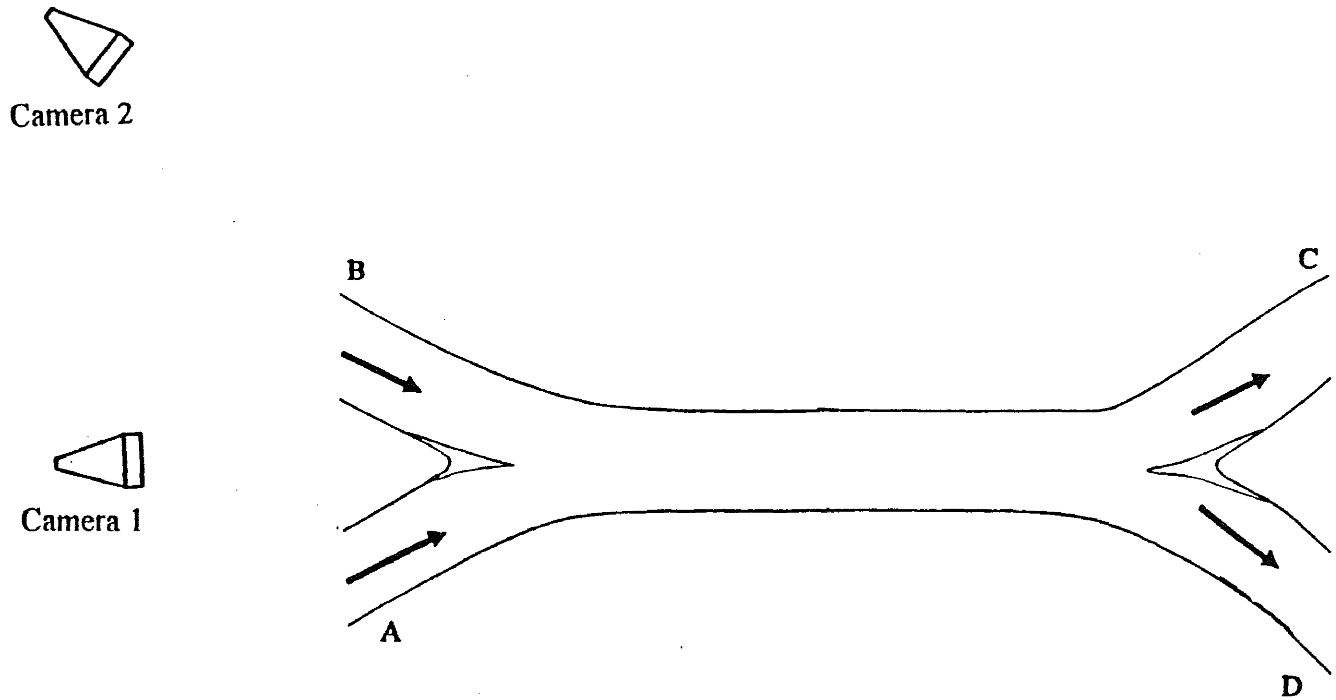


Figure 3.3a Video-Taping Setup for Microscopic Data Collection (Basic Weave)

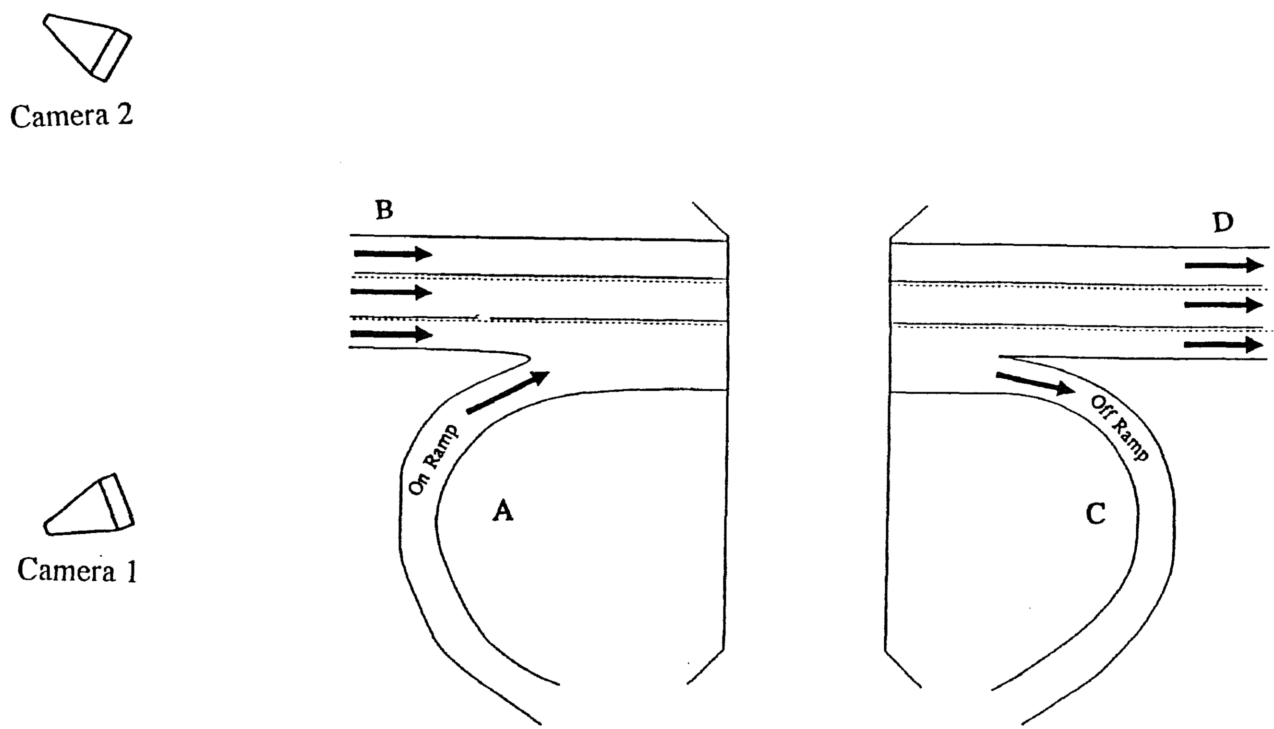


Figure 3.3b Video-Taping Setup for Microscopic Data Collection (Ramp Weave)

permanent objects (e.g., electric pole, top of a sign board, or some self installed mark) are determined. This is done to cross-check the results (X,Y, and Z coordinates) obtained later in the office.

3.4 Data Reduction

A separate data reduction strategy was adopted for the macroscopic and microscopic data needed for the models. The following macroscopic data were obtained from the video tapes:

1. **Traffic Volumes for:**
   - Mainline vehicles on a per lane basis
   - On ramp vehicles
   - Off ramp vehicles
   - Weaving vehicles
   - Non-weaving vehicles
2. **Traffic Classification by the Following Categories:**
   - Passenger cars
   - Single unit trucks and buses
   - Tractor-trailers
3. **Travel Time and Speeds for:**
   - Non-weaving vehicles
   - Weaving vehicles

The volumes and their classification were obtained at real time video speed using a simple self compiled computer program. The total number of cars, single unit trucks, and tractor-trailers were recorded for each lane at 5-minute intervals. A sample count of weaving and non-weaving traffic was taken for each traffic movement. This percentage distribution was applied to the corresponding five minute volumes, thereby obtaining the segregation of weaving and non-weaving traffic.

Vehicle travel times were recorded (on a 5-minute basis) for each traffic lane at real time speed using another user friendly, self-written, computer program. Two reference lines were marked on the TV monitor using thin white tape to indicate the start and end positions (representing weaving section length) for recording the travel times. The program was run twice. First, for the incoming approach A which resulted in the calculation of travel times from A to C (non-weaving) and A to D (weaving), and second, for approach B which gave the travel time from B to D (non-weaving) and B to C (weaving) (see Figures 3.1a and 3.1b).

The recorded travel times were processed further to compute vehicle speeds based on the length of the weaving section and automatically segregating them into weaving and non-weaving speeds.

The microscopic data extracted from the video tapes were:

- Vehicle arrival headways
- Arrival speeds
- Gap acceptance
- Acceleration/deceleration
- Merging points
- Spot speeds
- Delays

The reduction of data was performed using the technique of video-photogrammetry. A software package was written by the NJIT study team in the Microsoft-C language to perform the photogrammetric measurement that produces X, Y, Z coordinates for each vehicle with respect to time. The origin of the coordinate system is arbitrary as long as all the vehicles are related to the same origin. A set of X, Y, Z coordinates for each vehicle and the change in their location (ΔX, ΔY, ΔZ) as a function of time enable the users to compute headways, accelerations, speeds, merging points, accepted gaps etc.

At the current stage of the software's development, the actual measurements of the location of each vehicle are performed using a computer mouse. An operator identifies on the computer's monitor common vehicles from the left and right images, clicking them with the mouse, and the program computes the X, Y, Z coordinates of the vehicle. The images are then advanced one frame, and the same vehicle is traced (visually) and digitized (manually) again in the left and right images. The process is repeated until the vehicle leaves the weaving section. At a later stage this digitizing process can be automated using computer vision and pattern recognition techniques.

3.5 Data Analysis

The output files obtained using various self-written computer programs, were further manipulated using Lotus 123, TRANSTAT, and SAS.

The Lotus 123 worksheet was effectively used for the analysis of macroscopic data (average travel times, average speeds, volumes). Several Macros were developed to automate the process.

The TRANSTAT (Thompson and Young, 1988) software was developed by Monash University, Australia. The program is written in Microsoft's QuickBasic computer programming language and is designed to run on IBM PC-XT/AT microcomputers. Data input is via an ASCII file (output of HEADWAY.BAS), and individual data values are required to be separated by at least one space. There is a data limitation of 2000 observations. TRANSTAT has been developed to fit a common univariate distribution to traffic data, offers two goodness of fit testing methods (Chi-square and Kolmogorov-Smirnov), and was used to fit curves for the microscopic calibration of data.

SAS (Lefkowitz, 1985) is a powerful Statistical Analysis Software on a main frame (VAX TERMINAL). Data files obtained as output of Lotus worksheets were saved on ASCII format and then exported to the main frame using a utility software (KERMIT). The SAS package was used to perform multiple regression analysis for the calibration of analytical models, and other statistical tests for the validation of simulation models.

CHAPTER IV

DEVELOPMENT OF ANALYTICAL MODELS

4.1 Introduction

The combination of facility type, configurations, disturbances, etc., that can exist in non-freeway weaving are practically infinite. This problem can be further aggravated by disturbing elements within the weaving section (such as traffic signals, driveways, exits and entrances to establishments, pedestrians, parking of vehicles, etc.). However, an extensive search and site visit effort, made throughout the State of New Jersey and the metropolitan area of New York City, indicated that the vast majority of non-freeway weaving cases can be classified into two broad categories. These two types of weaving, basic weave and ramp weave, are presented here again (earlier shown in Chapters 1 and 3) in Figures 4.1 and 4.2, which show the designation of each approach as well as all important geometric parameters.

Weaving on non-freeway areas is characterized by comparatively shorter weaving length and lower speeds than those observed on freeways. However, like freeway weaving, there are two weaving flows and there may be two nonweaving flows. In Figures 4.1 and 4.2 flows A-D and B-C are weaving flows, while flows A-C and B-D are nonweaving flows.

Figure 4.1 shows a typical weaving configuration under basic weave. Weaving in this case starts where a ramp is merged into the arterial and stops at the diverge point of another ramp from the arterial. Under this category of weaving various subcategories exist based on factors such as the existence of crown line, lane balance at the diverge

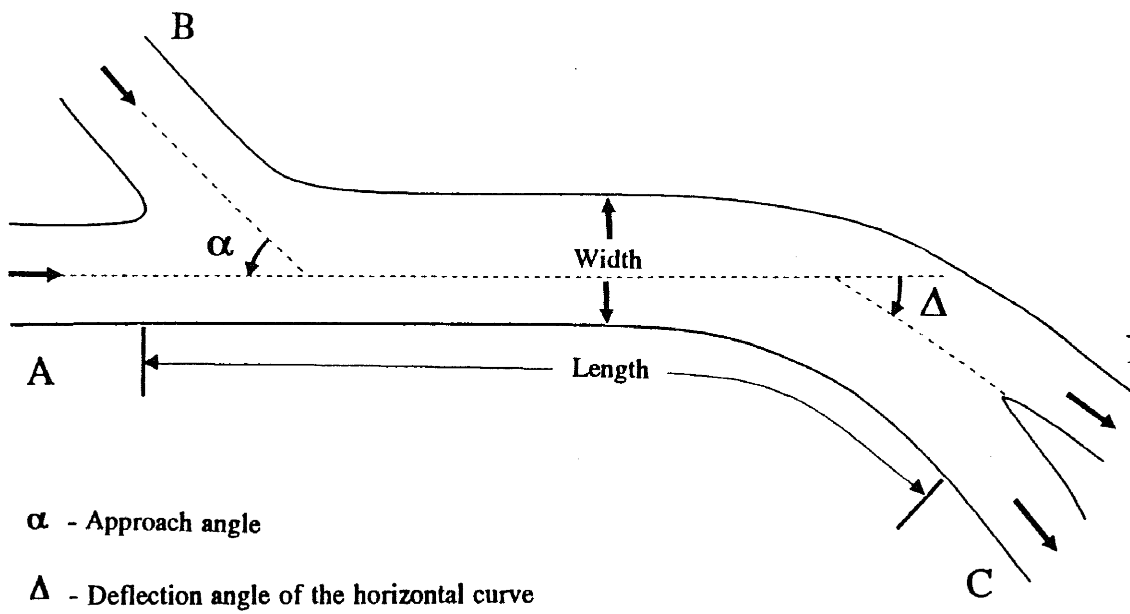


Figure 4.1 Typical Weaving Configuration of Basic Weave

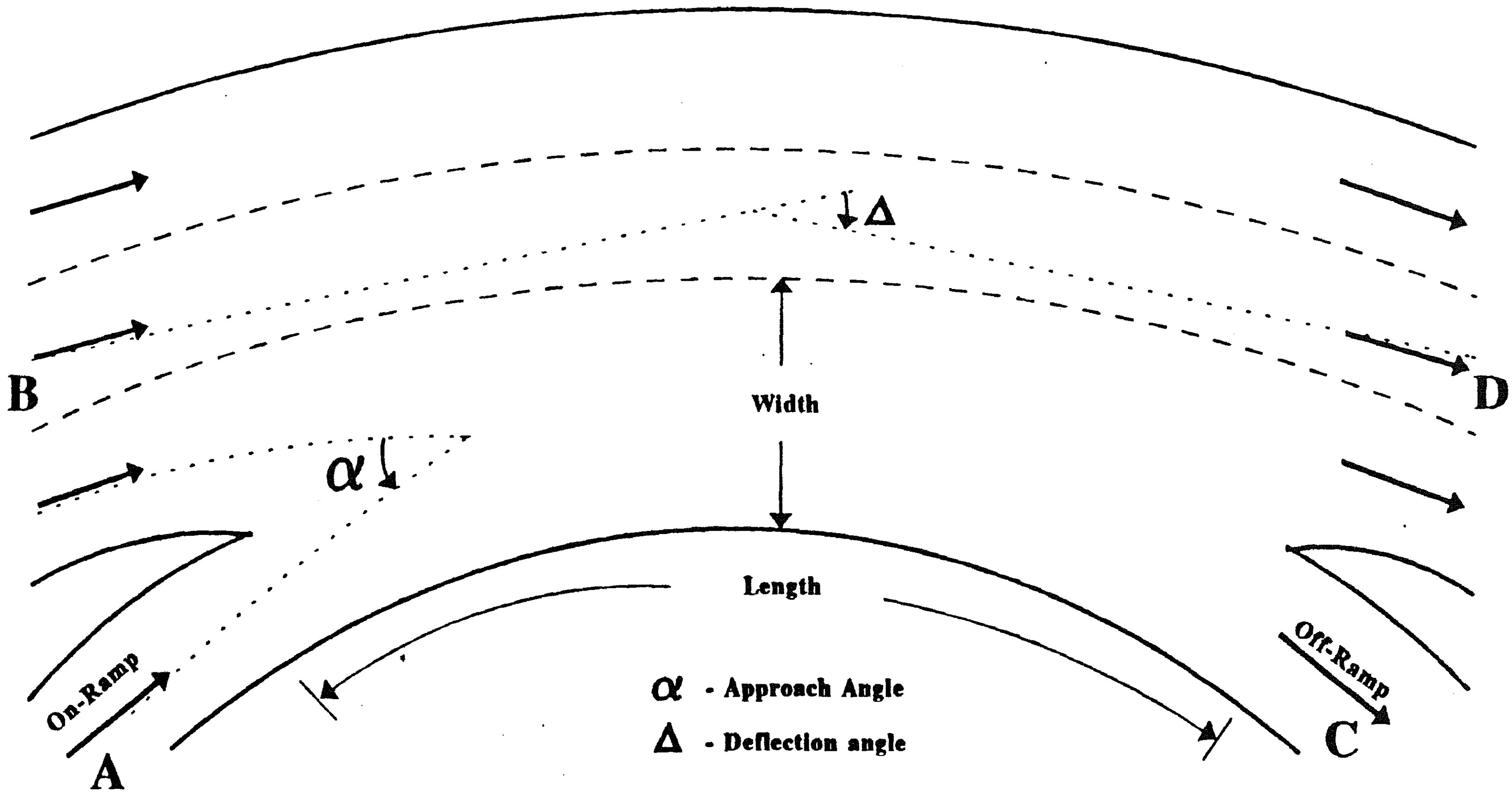


Figure 4.2 Typical Weaving Configuration of Ramp Weave

point, lane configuration, availability of shoulders on each side of the road, speed limits on the arterial and ramps, length of the weaving section, deflection angle and vertical grade (if any) of the weaving section, minor approach angle, and type of traffic (commuter/non-commuter).

A typical configuration for ramp weave is shown in Figure 4.2. As it can be seen, weaving takes place on a segment of highway between an on-ramp followed by an off-ramp connecting an arterial with a highway. The basic weaving maneuver takes place as a result of the on-ramp vehicles crossing the path of the off-ramp vehicles. The trade mark of this category is the short weaving distance between the on and off ramps. A similar category of weaving exists on freeway segments between on and off ramps. The major differences between these are the existence of acceleration and deceleration lanes of the freeway along with a long stretch of an auxiliary lane. Under this category, various subcategories exist based on factors such as number of lanes on the arterial/highway, existence of shoulder and auxiliary lane, availability of sight distance on the on-ramp for merging, speed limits on both the arterial/highway and the ramps, length between the on and off ramp gore areas, deflection angle and vertical grade (if any), minor approach angle, and type of traffic (commuter/non-commuter).

For the successful operation of a weaving area, the speeds of the weaving and nonweaving traffic streams must be nearly equal. Uniformity of operating speeds, in case of non-freeway weaving, can be obtained by properly proportioning the following four controllable (in the planning and designing stages) geometric characteristics:

- Approach angle (degrees)
- Horizontal curve deflection angle (degrees)

- Length of the weaving section (ft)
- Width of the weaving section (ft/number of lanes)

4.1.1 Approach and Deflection Angles

Figure 4.1 shows angle α that is physically subtended by approach B (or minor approach) with respect to approach A (or major approach). The angle of approach affects the speed of entering traffic, the angle of weaving, and the place of weaving.

The deflection angle Δ, as shown in Figure 4.1 is the angle of the horizontal curve of the weaving section (if any), and measures of the deflection of the original direction of weaving and nonweaving vehicles. As the deflection angle increases, it is expected that vehicular speeds would decrease.

4.1.2 Weaving Length

The length of the weaving section constrains the time and space in which the driver must make all required lane changes. Thus, as the length of a weaving area decreases (all other factors being constant), the intensity of lane-changing, and the resulting level of turbulence, increase.

Unlike freeway weaving, the length is simply the distance between the noses of the merge and the diverge gore areas, as shown in Figure 4.1. In case of pavement marking, the length is measured from the merge gore area at a point where the left edge of approach A (for designation see Figures 4.1 and 4.2) and the right edge of approach B merge, to a point at the diverge gore area where the two edges start diverging. The measurement of weaving area length, in such a case, is shown in Figure 4.2. These definitions of length hold for both weaving categories, depending on whether the pavement at the gore areas is marked or not.

4.1.3 Weaving Width

The width of the weaving area is another geometric characteristic with a significant impact on weaving area operations. The width of the weaving section must be sufficient to allow traffic that is going to weave to spread out laterally, thus creating the necessary gaps between vehicles and allowing weaving to take place throughout the length and width of the weaving section. This width must also be sufficient to carry the through traffic at each side with minimum interference for the weaving vehicles. In the case of basic weave, width is measured in terms of number of lanes in the section. For ramp weave width is measured in terms of: a) number of lanes in the section, and b) width of the section measured as the distance from the right edge of the auxiliary lane to the left edge of the right shoulder lane on the highway. Figure 4.2 shows the measurement of width for ramp weave, as explained by definition b) above.

4.2 Calibration and Validation Data Base

The following criteria were established for the purpose of site selection:

- Signal location as far away as possible
- Marked or unmarked pavement between the two gore areas
- A desirable distance of 600 feet or less between the two gore areas located at merge and diverge points (maximum 1000 feet)
- A minimum weaving volume of 800 vehicles per hour

- A minimum nonweaving volume of 800 vehicles per hour
- Any lane combination configuration

4.2.1 Basic Weave

Table 4.1 presents ten potential sites for basic weave that were videotaped and selected for data collection for the calibration and validation of analytical models. In addition to the location of each site, the table includes all pertinent geometric characteristics.

Four sites (JEWEL, LIE91, LIE90, and GCP) are located in New York City, while the remaining six sites are in the state of New Jersey. Site JEWEL, although videotaped, is not included in the calibration data base because of some ongoing construction activity in the weaving area on the survey day and time. Six sites (9&35, 80&20, 80&202, LIE90, GCP, and NIAB) were used for model calibration, whereas three sites (I195, 1,9&7, and LIE91) were used for model validation.

The six calibration sites cover a large variation in the width of the section (26 ft. to 37 ft.), number of lanes (2 to 3), length of the section (210 to 520 ft.), approach angle (15 to 65 degrees), and deflection angle (0 to 35 degrees). Only in one site (80&20) the crown line is marked. In addition, one site (NIAB) represents a typical non-commuter non-freeway weaving operation in the vicinity of an airport.

A total of 147 data points were obtained for the calibration of the weaving speed model, whereas 102 data points were available for the nonweaving speed model. This difference in the weaving and nonweaving speed calibration data points is attributed to the fact that in sites 80&20 and GCP no nonweaving maneuvers occur. Sixty (60) data

Table 4.1 Basic Weave Data Collection Sites for Analytical Models

SN	Site Location: Name	Site Location: City, County, & State	Acronym	Survey Date, Day, & Time	Width (ft)	Length (ft)	Lane Configuration (# of Lanes in Section): Before A[1]	Before B[1]	Within	After C[1]	After D[1]	Approach Angle (degrees)	Deflection Angle (degrees)	Commuter Traffic	Marked Crown
1	[3]Broad Street and I−195	Hamilton Burlington New Jersey	I195	10/5/89 Thursday 3:00−5:00 pm	26	478	1	1	2	1	1	20	40	Yes	No
2	[2]Route 9 and Route 35	South Amboy Middlesex New Jersey	9&35	12/19/89 Tuesday 7:10−9:15 am	37	520	2	1	3	1	2	65	15	Yes	No
3	[2]Market Street, I−80 and I−20	Paterson Bergen New Jersey	80&20	2/1/90 Thursday 6:55−9:00 am	31	210	1	1	2	1	1	15	35	Yes	Yes
4	[2]Route 202 and I−80 East	Parsipanny Morris New Jersey	80&202	4/26/90 Thursday 7:15−9:00 am	26	385	1	1	2	1	1	50	0	Yes	No
5	[2]Exit 30 N on Long Island Expressway (1990)	New York Queens New York	LIE90	7/16/90 Monday 3:00−6:30 pm	30	302	1	1	2	1	1	20	0	Yes	No
6	[3]Jersey City, Route 1 & 9 and Route 7	Jersey City Hudson New Jersey	1,9&7	8/1/90 Wednesday 3:50−6:15 pm	46	250	2	1	3	1	2	65	25	Yes	No
7	Jewel Ave and Grand Central Parkway	New York Queens New York	JEWEL	8/2/90 Wednesday 3:30−6:15 pm	28	520	2	1	3	2	1	35	0	Yes	No
8	[3]Exit 30 N on Long Island Expressway (1991)	New York Queens New York	LIE91	12/11/91 Wednesday 1:15−5:15 pm	30	302	1	1	2	1	1	20	0	Yes	No
9	[2]Exit 10 on Grand Central Parkway North	New York Queens New York	GCP	5/28/92 Thursday 6:45−9:30 am	34	436	1	1	2	1	1	30	0	Yes	No
10	[2]Newark International Airport (Basic)	Newark Essex New Jersey	NIAB	9/15/92 Thursday 4:00−7:00 pm	28	310	1	1	2	1	1	20	0	No	No

[1]For A, B, C, and D designation see Figure 4.1

[2]Data used for model calibration

[3]Data used for model validation

points were used for the validation of the weaving and nonweaving speed models.

4.2.2 Ramp Weave

Table 4.2 presents ten potential sites for ramp weave that were videotaped and selected for data collection for the calibration and validation of analytical models.

Only one site (NCV) is located in New York, but unfortunately, this site is not included in the calibration data base because of unusually low volumes and high speeds. The rest of the nine sites are located in New Jersey. Five sites (1&MS, 4E&17, 4W&17, 17S&4, and NIAR) were used for model calibration, whereas four sites (17N&4, 73NAM, 73NPM, and 73S) were used for model validation.

The five calibration sites cover a large variation in width of the weaving section (22 to 32 ft.), number of lanes (3 to 4), length of the section (216 to 310 ft.), approach angle of the section (20 to 45 degrees), and deflection angle of the horizontal curve of the section (0 to 35 degrees). All sites have an auxiliary lane and one site (4W&17) has a lane addition from the on-ramp. In addition, one site (NIAR) represents a typical non-commuter non-freeway weaving operation in the vicinity of an airport.

A total of 107 data points were obtained for the calibration of both weaving and nonweaving speed models. Seventy (70) data points were used for the validation of the weaving and nonweaving speed models.

4.3 Evaluation of Existing Analytical Models

All available analytical models for the analysis of freeway weaving operation use speed within the freeway weaving area as a measure of effectiveness to determine the level of

Table 4.2 Ramp Weave Data Collection Sites for Analytical Models

SN	Site Location: Name	Site Location: City, County, & State	Acronym	Survey Date, Day, & Time	Width (ft)	Length (ft)	Lane Configuration (# of Lanes in Section): Before A[1]	Before B[1]	Within	After C[1]	After D[1]	Approach Angle (degrees)	Deflection Angle (degrees)	Commuter Traffic	Auxiliary Lane
1	[2]Route 1 and Market Street	Trenton Mercer New Jersey	1&MS	7/27/89 Thursday 2:00–5:30 pm	32	216	1	2	3	1	2	45	35	Yes	Yes
2	[2]Route 4 East and Route 17	Rochelle Park Bergen New Jersey	4E&17	1/23/90 Tuesday 7:30–9:00 am	23	300	1	3	4	1	3	30	0	Yes	Yes
3	[2]Route 4 West and Route 17	Rochelle Park Bergen New Jersey	4W&17	3/14/90 Wednesday 2:30–5:30 pm	23	259	1	2	3	1	3	35	0	Yes	Lane Add. From On–Ramp
4	[2]Route 17 South and Route 4	Rochelle Park Bergen New Jersey	17S&4	10/8/91 Tuesday 2:30–4:30 pm	22	246	1	2	3	1	2	40	0	Yes	Yes
5	[3]Route 73 North and I–295 (AM)	Mt. Laurel Burlington New Jersey	73NAM	9/20/90 Thursday 6:45–9:00am	24	280	1	2	3	1	2	40	0	Yes	Yes
6	[3]Route 73 South and I–295	Mt. Laurel Burlington New Jersey	73S	9/25/90 Tuesday 3:30–6:20 pm	24	284	1	2	3	1	2	35	0	Yes	Yes
7	[3]Route 73 North and I–295 (PM)	Mt. Laurel Burlington New Jersey	73NPM	10/2/90 Tuesday 3:30–6:30 pm	24	280	1	2	3	1	2	40	0	Yes	Yes
8	[3]Route 17 North and Route 4	Rochelle Park Bergen New Jersey	17N&4	1/3/92 Thursday 3:00–6:00 pm	24	260	1	2	3	1	2	30	0	Yes	Yes
9	North Conduit Av. and Van Wyck Expressway	New York Queens New York	NCV	2/27/92 Thursday 3:00–6:00 pm	22	400	1	3	4	1	3	30	0	Yes	Yes
10	[2]Newark International Airport (Ramp)	Newark Essex New Jersey	NIAR	9/15/92 Tuesday 4:00–7:00 pm	28	310	1	3	4	1	3	20	0	No	Yes

[1]For A, B, C, and D designation see Figure 4.2

[2]Data used for model calibration

[3]Data used for model validation

service. After reviewing all existing procedures, and comparing the results of the mean differences between the predicted speed of each model and the observed data, the JHK, 1985 HCM, and Fazio models were chosen for further evaluation. These models were evaluated in three different forms as indicated in the following sections.

4.3.1 Existing Models

The original format of the three existing models was used with all non-freeway weaving calibration data points and the speeds of weaving and non-weaving traffic were predicted. The predicted speeds were then compared with the observed speeds to determine the validity of the models. Based on the analysis of the number of lane change maneuvers, types of operation, and limitations set by the 1985 HCM, a Type A/Type B weaving area configuration was used. A check was also made to determine whether the operation was constrained or unconstrained.

4.3.2 Recalibrated Models

The existing models were recalibrated using the non-freeway weaving data points with the hope of representing better non-freeway conditions. The existing non-linear models were transformed into linear formats and the Multiple Linear Regression Procedure of SAS was used to recalibrate them. The Least Square Method was used to fit the general linear models to the non-freeway data. The new calibrated linear models were once more transformed back into their original non-linear formats which resulted in the same structure as before with new coefficients and exponents.

4.3.3 Modified Models

The JHK, 1985 HCM, and Fazio models in their original forms use upper and lower speed limits of 65 mph and 15 mph which were observed in freeway weaving areas. Since for non-freeway weaving the range of speeds that were observed in all the sites were different, an attempt was made to modify the original models by using the actual observed upper weaving and nonweaving speed limits of 45 mph for basic weave, and in the case of ramp weave, 40 mph for weaving and 55 mph for nonweaving speed. Once again, the original structure of each model was not altered, and the SAS program was used to recalibrate the existing models using the reduced speed range with the collected non-freeway weaving data.

4.3.4 Fazio Model

Table 4.3 presents the original structure of the Fazio model along with a comparison of the speed range, coefficients, and exponents of the original, the recalibrated, and the modified speed prediction models. Table 4.3 indicates that regression analysis performed using non-freeway weaving calibration data resulted in a few negative exponents for the recalibrated and modified models of both weaving categories. The negative exponent values are shown shaded and indicate an unrealistic structure (as compared to the original proposed structure) for the model. This, some times, although unacceptable, might result in a higher R^2 value.

Table 4.3 Various Forms of Fazio Model

$$S_w = 15 + \frac{f_1}{\dfrac{1+f_2[(1+(V_3+V_4)/V]^{f3}\,(V/N)^{f4}\,(LS/L)^{f5}}{(1+LS_3/V)^{f6}}}$$

$$S_{nw} = 15 + \frac{f_7}{\dfrac{1+f_8[(1+V_4/V)^{f9}\,(1+V_w/V)^{f10}\,(V/N)^{f11}}{(1+LS_3/LS)^{f12}(L)^{f13}}}$$

MODEL	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}
Original	50	0.013	3.045	0.605	0.902	3.395	50	0.016	5.080	2.019	1.523	0.916	1.070
Recalibrated (Basic Weave)	50	1.88	0.32	−0.09	0.19	0.22	50	33.12	0.014	0.15	0.21	−0.24	0.83
Modified (Basic Weave)	30	0.72	0.55	−0.14	0.35	0.67	30	6953	6.72	7.78	−0.22	−6.49	2.75
Recalibrated (Ramp Weave)	50	4.19×10^{4}	−4.19	−1.58	2.10	55.86	50	1.34×10^{-10}	49.85	6.66	1.95	27.37	−1.49
Modified (Ramp Weave)	25	5.47×10^{4}	−5.73	−1.76	2.48	62.92	40	9.90×10^{-14}	79.83	7.74	2.72	30.69	−1.67

Note: Shaded values indicate unrealistic sign of the exponent

4.3.5 HCM 85 Model

The original structure of the HCM 85 model along with a comparison of the speed range, coefficients, and exponents of its original, recalibrated, and modified models are presented in Table 4.4. The recalibrated and modified versions of the HCM model for the basic weave category were found to be inappropriate due to the negative values of the resulting exponents. The recalibrated and modified models for the ramp weave category were acceptable.

4.3.6 JHK Model

Finally, Table 4.5 presents the original structure of the JHK weaving and nonweaving speed prediction models along with a comparison of the speed ranges, coefficients, and exponents of its original, recalibrated, and modified versions. The recalibrated and modified versions of the JHK model for the basic weave category were found to be inappropriate due to the negative values of the resulting exponents, while the recalibrated and modified models for the ramp weave category were acceptable.

4.3.7 New Speed Models (NJIT Models)

The observed weaving and nonweaving speeds for both weaving categories were plotted against every available independent variable in the calibration data set. The results identified reasonable variables which influence speed in the weaving area.

Many multiple regression models were developed for predicting the speed of weaving and nonweaving flow in non-freeway weaving areas using different combinations of independent variables. The best equations that were selected were chosen on the basis

Table 4.4 Various Forms of HCM 85 Model

$$S_w = 15 + \frac{h_1}{1+h_2(1+VR)^{h3}\,(V/N)^{h4}/L^{h5}}$$

$$S_{nw} = 15 + \frac{h_6}{1+h_7(1+VR)^{h8}\,(V/N)^{h9}/L^{h10}}$$

MODEL	h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9	h_{10}
HCM Type A	50	0.226	2.20	1.00	0.90	50	0.02	4.00	1.30	1.00
HCM Type B	50	0.10	1.20	0.77	0.50	50	0.02	2.00	1.42	0.95
Recalibrated (Basic Weave)	50	5.83	-1.07	0.21	0.37	50	34.12	0.01	0.23	0.83
Modified (Basic Weave)	30	5.55	-2.16	0.41	0.68	30	$1.90\text{x}10^{5}$	4.85	-0.02	2.79
Recalibrated (Ramp Weave)	50	$3.59\text{x}10^{6}$	6.46	0.62	3.63	50	$5.34\text{x}10^{-5}$	8.19	1.79	0.85
Modified (Ramp Weave)	25	$1.89\text{x}10^{7}$	7.37	0.87	4.43	40	$2.95\text{x}10^{-7}$	9.28	2.37	0.88

Note: Shaded values indicate unrealistic sign of the exponent

Table 4.5 Various Forms of JHK Model

$$S_w = 15 + \frac{j_1}{1 + j_2(1+V_4/V)^{j3}\,(1+VR)^{j4}\,(V/N)^{j5}/L^{j6}}$$

$$S_{nw} = 15 + \frac{j_7}{1 + j_8(1+V_4/V)^{j9}\,(1+VR)^{j10}\,(V/N)^{j11}/L^{j12}}$$

MODEL	j_1	j_2	j_3	j_4	j_5	j_6	j_7	j_8	j_9	j_{10}	j_{11}	j_{12}
Original	50	2000	2.70	0.90	0.60	1.80	50	100	5.40	1.80	0.90	1.80
Recalibrated (Basic Weave)	50	18.14	−1.26	−1.53	0.18	0.47	50	36.53	−0.17	0.03	0.22	0.83
Modified (Basic Weave)	30	42.84	−0.27	−2.98	0.37	0.87	30	$9.39\text{x}10^{4}$	1.77	4.67	0.07	2.78
Recalibrated (Ramp Weave)	50	$2.38\text{x}10^{6}$	21.95	6.63	0.73	3.70	50	$1.56\text{x}10^{-5}$	65.91	8.71	2.05	1.06
Modified (Ramp Weave)	25	$1.26\text{x}10^{7}$	21.75	7.53	0.97	4.50	40	$4.70\text{x}10^{-8}$	97.84	10.05	2.83	1.19

Note: Shaded values indicate unrealistic sign of the exponent

of the following criteria:

a) Reasonable independent variables,

b) Higher values of R^2 than all existing models,

c) All the alpha levels of the independent variables derived from the t-test of the null hypothesis are significant at a level of 0.05 or less, and the results of the F-test are significant with Probability > F ranging from 0.0001 to 0.015.

For the basic weave category, the weaving and nonweaving speeds observed in the calibration database ranged from 15 mph to 45 mph. These values were used as upper and lower speed limits in developing the new speed prediction models for basic weave.

For the ramp weave category, the weaving speeds observed in the calibration database ranged from 15 mph to 40 mph, while the observed nonweaving speeds ranged from 15 mph to 55 mph. These values were used as upper and lower speed limits in developing the new speed prediction models for ramp weave.

Table 4.6 presents equations for the prediction of the average weaving and nonweaving speeds by the NJIT model for the basic weave configuration along with the definition of new variables introduced in the models. The R^2 value for the weaving speed model is 0.36, and 0.55 for the nonweaving speed model. Several new variables were introduced in the new speed prediction models, such as minor approach angle (α), deflection angle (Δ), and commuter factor (C). Approach and deflection angles are measured in degrees and were explained earlier in sections 4.1.1 and 4.1.2, respectively. C is a commuter factor which has a value of 1 if the site is used by regular commuters. If the weaving site is located in the vicinity of an airport that is not used by regular

Table 4.6 **Equations for Prediction of Average Weaving and Non-weaving Speeds-** NJIT Models for Basic Weave

($R^2 = 0.36$)

$$S_w = 15 + \frac{30}{1 + 6.02\left[\frac{(V/N)^{0.79}(V_w/L)^{0.25}}{(L\cos\alpha)^{1.49}}\right](C)}$$

($R^2 = 0.55$)

$$S_{nw} = 15 + \frac{30}{1 + 5.35\left[\frac{(V_w/L)^{0.37}}{(N\cos\Delta)^{4.99}}\right](C)}$$

Where C = Commuter factor = 1 for regular commuter

= 1.68 otherwise (like airport site)

α = Minor Approach angle (degrees)

Δ = Deflection angle for horizontal curve (degrees) commuters, then a C value of 1.68 should be used. The statistical analysis results of the calibration data set for this category of weaving indicated no significant effect of total volume on nonweaving speed. This variable (total volume, V), therefore, did not appear in the new nonweaving speed prediction model.

Table 4.7 presents equations for the prediction of the average weaving and nonweaving speeds by the NJIT model for the ramp weave configuration along with the definition of new variables introduced in the models. The R^2 value for the weaving speed model is 0.86, and 0.78 for the nonweaving speed model. Two additional new variables, lane addition factor (La) and width (W), were introduced in the new speed prediction models. In the case of a normal ramp weave site with an on-off ramp combination, auxiliary lane and main line through lanes, the La factor is 1, while if a lane is added from the on ramp, La is 0.69. The width for this category of weaving is measured in feet, is explained in section 4.1.4, and is shown in Figure 4.2. The commuter factor, C, is 8.22 for a site located in the vicinity of an airport that is not used by regular commuters. For a regular commuter weaving site, C is 1. Approach and deflection angles are the same as defined for the basic weave. The statistical analysis results of the calibration data set for this category of weaving indicated no significant effect of weaving volume (V_w) and Length (L) on nonweaving speed, and they did not appear in the new nonweaving speed prediction model.

4.3.8 Evaluation of the Models

Table 4.8 presents R^2 results of the basic weave regression model along with an indication of the models' acceptability. The R^2 values for the original and acceptable

Table 4.7 Equations for Prediction of Average Weaving and Non-weaving Speeds- NJIT Models for Ramp Weave

($R^2 = 0.86$)

$$S_w = 15 + \frac{25}{1 + 5.3 \times 10^9 \left[\frac{(V/N)^{0.41} (V_w/L)^{0.17}}{\left[W(\ Cos\alpha)(Cos\Delta)\right]^{8.5}} \right] (C)(La)}$$

($R^2 = 0.78$)

$$S_{nw} = 15 + \frac{40}{1 + 9.2 \times 10^3 \left[\frac{(V/N)^{1.75}}{(WCos\alpha)^{7.28}} \right] (C)(La)}$$

Where	C = Commuter factor	= 1 for regular commuter = 8.22 otherwise (like airport site)
	La= Lane addition factor	= 0.69 for lane addition from on-ramp = 1 otherwise
	α = Approach angle (degrees) Δ = Deflection angle (degrees)	

Table 4.8 R^2 Results of Regression Models (Basic Weave)

MODEL		WEAVING SPEED (Sw)		NONWEAVING SPEED (Snw)	
		R^2	Model Defect[4]	R^2	Model Defect[4]
JHK	[1]Original	0.22	None	0.46	None
	[2]Recalibrated	0.37	Negative exponent for $1+VR$ Negative exponent for $1+V_4/V$	0.67	Negative exponent for $1+V_4/V$
	[3]Modified	0.34	Negative exponent for $1+VR$ Negative exponent for $1+V_4/V$	0.52	None
HCM	[1]Original	0.26	None	0.44	None
	[2]Recalibrated	0.30	Negative exponent for $1+VR$	0.46	None
	[3]Modified	0.28	Negative exponent for $1+VR$	0.52	Negative exponent for V/N
FAZIO	[1]Original	0.10	None	0.42	None
	[2]Recalibrated	0.08	Negative exponent for V/N	0.67	Negative exponent for $1+LS_3/LS$
	[3]Modified	0.06	Negative exponent for V/N	0.57	Negative exponent for V/N Negative exponent for $1+LS_3/LS$
NJIT	New	0.36	None	0.55	None

[1]Original Freeway Model

[2]Freeway Model Recalibrated using Non–Freeway Weaving Speed Data

[3]Freeway Model Modified by Changing Maximum Speed Limit to 45 mph and recalibrating using Non–Freeway Weaving Speed Data

[4]Refer to the original form of the model in Table 4.5 for JHK, Table 4.4 for HCS, & Table 4.3 for Fazio models

recalibrated and modified JHK, HCM, and Fazio models for the weaving speed range from 0.10 to 0.26, while R^2 for the proposed NJIT weaving speed model is 0.36. The R^2 values for the original and acceptable recalibrated and modified JHK, HCM, and Fazio models for nonweaving speeds range from 0.42 to 0.52, while R^2 for the proposed NJIT weaving speed model is 0.55.

Table 4.9 presents R^2 results of the regression models for ramp weave along with an indication of the models' acceptability. The R^2 values for the original and acceptable recalibrated and modified JHK, HCM, and Fazio models for the weaving speeds range from 0.18 to 0.64, while R^2 for the proposed NJIT weaving speed model is 0.86. The R^2 values for the original and acceptable recalibrated and modified JHK, HCM, and Fazio models for nonweaving speeds range from 0.32 to 0.53, while R^2 for the proposed NJIT weaving speed model is 0.78.

In order to determine how well each model predicts average speeds, 147 data points were used to recalibrate and modify existing models and to develop the new models. Table 4.10 presents a comparison between the observed and predicted weaving speeds for all basic weave models. As the statistical measures indicate, the NJIT model predicted an average weaving speed of 36.07 mph as compared to an average observed weaving speed of 35.64 mph. The observed weaving speed ranged from 26.73 mph to 41.69 mph. The range of weaving speed predicted by NJIT model was 31.29 mph to 39.90 mph.

A set of 102 data points were used for the original, recalibrated, and modified existing nonweaving speed models and the new model proposed by NJIT for basic weave. This difference in the calibration data points of weaving and nonweaving speeds

Table 4.9 R^2 Results of Regression Models (Ramp Weave)

MODEL		WEAVING SPEED (Sw)		NONWEAVING SPEED (Snw)	
		R^2	Model Defect[4]	R^2	Model Defect[4]
JHK	[1]Original	0.59	None	0.32	None
	[2]Recalibrated	0.62	None	0.49	None
	[3]Modified	0.64	None	0.53	None
HCM	[1]Original	0.48	None	0.37	None
	[2]Recalibrated	0.61	None	0.46	None
	[3]Modified	0.64	None	0.49	None
FAZIO	[1]Original	0.18	None	0.37	None
	[2]Recalibrated	0.69	Negative exponent for 1+MR Negative exponent for V/N	0.53	Negative exponent for L
	[3]Modified	0.71	Negative exponent for 1+MR Negative exponent for V/N	0.56	Negative exponent for L
NJIT	New	0.86	None	0.78	None

[1]Original Freeway Model

[2]Freeway Model Recalibrated using Non-Freeway Weaving Speed Data

[3]Freeway Model Modified by Changing Max. Speed Limit to 55 mph for Snw,& 40 mph for Sw & recalibrating using Non-Freeway Weaving Speed Data

[4]Refer to the original form of the model in Table 4.5 for JHK, Table 4.4 for HCS, & Table 4.3 for Fazio models

Table 4.10 Comparision Among the Observed and Predicted Weaving Speeds, mph (Basic Weave)

Model	Mean	Standard Deviation	Minimum Value	Maximum Value	No. of Data Points (n)
Observed	35.64	2.66	26.73	41.69	147
Original HCM 85	32.77	3.84	27.67	44.50	147
Recalibrated HCM 85	35.69	1.51	32.45	38.31	147
Modified HCM 85	35.88	1.49	32.40	38.38	147
Original JHK	23.18	4.18	17.56	34.09	147
Recalibrated JHK	35.69	1.65	31.98	37.99	147
Modified JHK	34.84	1.96	30.32	37.88	147
Original Fazio	31.48	6.93	23.48	52.27	147
Recalibrated Fazio	36.06	0.83	34.46	38.44	147
Modified Fazio	35.89	0.84	34.38	38.18	147
NJIT	36.07	1.62	31.29	39.90	147

(147 vs. 102) for this weaving category is due to the fact that two of the calibration sites had no nonweaving flow. The comparison of the average nonweaving speeds predicted by all models is presented in Table 4.11. The new NJIT model predicted an average nonweaving speed of 37.69 mph as compared to an average observed weaving speed of 38.84 mph. The observed weaving speed ranged from 28.78 mph to 44.99 mph. The range of weaving speed predicted by NJIT model was 30.11 mph to 44.19 mph.

A set of 107 data points were used to evaluate the original, recalibrated, and modified existing weaving and nonweaving speed models and the new NJIT models for the ramp weave category. Table 4.12 presents a comparison between the observed and predicted weaving speeds for all ramp weave models. As the statistical measures indicate, the NJIT model predicted an average weaving speed of 25.37 mph as compared to an average observed weaving speed of 27.18 mph. The observed weaving speed ranged from 16.86 mph to 37.65 mph. The range of weaving flow speed predicted by the NJIT model was 18.80 mph to 36.35 mph.

The comparison of the average nonweaving speeds predicted by all ramp weave models is presented in Table 4.13. The new NJIT model predicted an average nonweaving speed of 36.73 mph as compared to an average observed weaving speed of 37.36 mph. The observed weaving speed ranged from 16.69 mph to 52.35 mph. The range of weaving flow speed predicted by the NJIT model was 23.20 mph to 49.28 mph.

The absolute differences between the average observed and predicted weaving and nonweaving speeds for all models were compared and analyzed. The statistical measures of these comparisons are listed in Table 4.14 for the basic weave and in Table 4.15 for the ramp weave categories. The results indicate that among all acceptable models, the

Table 4.11 Comparision Among the Observed and Predicted Non–Weaving Speeds, mph (Basic Weave)

Model	Mean	Standard Deviation	Minimum Value	Maximum Value	No. of Data Points (n)
Observed	36.80	4.05	28.78	44.99	102
Original HCM 85	28.43	6.66	20.75	47.46	102
Recalibrated HCM 85	36.87	3.36	31.82	43.94	102
Modified HCM 85	37.59	4.55	27.58	44.16	102
Original JHK	24.77	6.96	17.72	41.83	102
Recalibrated JHK	37.18	3.08	31.78	43.86	102
Modified JHK	37.59	4.45	28.55	44.16	102
Original Fazio	29.46	7.98	20.28	51.28	102
Recalibrated Fazio	36.85	3.37	31.66	43.57	102
Modified Fazio	37.18	4.72	25.92	44.68	102
NJIT	37.69	4.21	30.11	44.19	102

Table 4.12 Comparision Among the Observed and Predicted Weaving Speeds, mph (Ramp Weave)

Model	Mean	Standard Deviation	Minimum Value	Maximum Value	No. of Data Points (n)
Observed	27.18	5.08	16.86	37.65	107
Original HCM 85	31.22	2.99	27.61	39.14	107
Recalibrated HCM 85	27.20	4.67	18.92	39.07	107
Modified HCM 85	24.98	3.69	18.14	33.20	107
Original JHK	20.70	1.87	18.60	25.32	107
Recalibrated JHK	26.80	4.57	18.64	39.25	107
Modified JHK	25.10	3.71	18.11	33.50	107
Original Fazio	21.78	2.41	18.66	28.96	107
Recalibrated Fazio	26.84	4.71	18.49	44.06	107
Modified Fazio	24.78	3.74	17.78	35.57	107
NJIT	25.37	4.28	18.80	36.35	107

Table 4.13 Comparision Among the Observed and Predicted Non–Weaving Speeds, mph (Ramp Weave)

Model	Mean	Standard Deviation	Minimum Value	Maximum Value	No. of Data Points (n)
Observed	37.36	9.17	16.69	52.35	107
Original HCM 85	24.77	4.38	20.49	37.13	107
Recalibrated HCM 85	33.00	6.73	20.32	50.13	107
Modified HCM 85	37.44	6.61	22.46	50.92	107
Original JHK	24.45	3.40	20.71	33.47	107
Recalibrated JHK	36.87	7.00	21.70	54.97	107
Modified JHK	37.37	6.85	21.59	52.20	107
Original Fazio	26.18	5.12	21.10	40.69	107
Recalibrated Fazio	36.45	7.09	20.60	57.67	107
Modified Fazio	36.79	6.98	20.32	53.06	107
NJIT	36.73	8.42	23.20	49.28	107

Table 4.15 Statistical Measures of Absolute Differences of Observed and Predicted Speeds for Ramp Weave

Model	Weaving Speeds (mph)		Non–Weaving Speeds (mph)	
	Mean	Standard Deviation	Mean	Standard Deviation
Original HCM 85	4.53	3.06	12.77	7.09
Recalibrated HCM 85	2.26	2.17	6.32	4.73
Modified HCM 85	2.81	2.47	5.07	3.77
Original JHK	6.62	3.58	13.09	7.47
Recalibrated JHK	2.16	2.25	5.04	3.82
Modified JHK	2.73	2.45	4.82	3.92
Original Fazio	5.77	4.18	11.46	6.90
Recalibrated Fazio	2.08	1.97	4.79	3.63
Modified Fazio	2.90	1.99	4.51	3.59
NJIT	2.13	1.53	3.25	2.44

Note: Shaded rows indicate results of unacceptable models

Table 4.14 Statistical Measures of Absolute Differences of Observed and Predicted Speeds for Basic Weave

Model	Weaving Speeds (mph)		Non-Weaving Speeds (mph)	
	Mean	Standard Deviation	Mean	Standard Deviation
Original HCM 85	4.31	2.72	8.92	3.48
Recalibrated HCM 85	1.78	1.35	1.92	1.23
Modified HCM 85	1.80	1.33	2.62	2.11
Original JHK	12.46	4.21	12.11	4.44
Recalibrated JHK	1.67	1.31	1.92	1.22
Modified JHK	1.86	1.53	2.61	2.03
Original Fazio	7.00	4.28	8.59	3.77
Recalibrated Fazio	2.13	1.52	1.90	1.22
Modified Fazio	2.20	1.49	2.64	2.32
NJIT	1.66	1.36	2.16	1.86

Note: Shaded rows indicate results of unacceptable models

NJIT model has the smallest absolute differences between the observed and predicted speeds and the smallest standard deviation.

4.4 Limits on Weaving Area Operations for NJIT Models

The speed prediction equations presented in Tables 4.6 and 4.7 are calibrated based on the data obtained from non-freeway weaving sites. This database does not cover all possible variations in the parameters affecting weaving area operations. It is, therefore, important to indicate the range of these parameters beyond which the prediction of weaving and nonweaving speeds under non-freeway conditions becomes approximate. Limiting values of key variables related to non-freeway weaving conditions are given in Table 4.16. Weaving capacity is defined as the maximum total weaving flow rates that can be accommodated in weaving areas. Graphs of speeds versus weaving volume (V_w) were plotted, and the capacity for basic weave was established as 1,950 pcph, and for ramp weave as 2,300 pcph. An important finding which is worth mentioning is that the capacities of both non-freeway weaving categories exceed the limiting capacity value of 1,800 pcph for type A weaving configuration under freeway conditions, as given in Table 4-5 of the 1985 HCM. This is attributed to the fact that none of the sites included in the database (including ramp weave sites) had a marked crown, and in each case there was merging at the entrance gore and lane balance at the exit gore. Such type of weaving section geometry falls under a type B weaving configuration, as defined in the 1985 HCM. The limiting capacity for a type B configuration is 3,000 pcph under freeway conditions, which is well above the capacities established for the two weaving categories under non-freeway conditions. Capacities of this type of weaving configuration for

Table 4.16 Limitations on Weaving Area Equations

Type of Weave	Weaving Capacity (Maximum V_w)	Maximum V/N	Maximum V_w/L	Width Range	Maximum Approach Angle	Maximum Deflection Angle	Maximum Length, L
Basic Weave	1,950 pcph	1,300	6.5 pcphpf	N = 2 – 3 W = 26 – 37 ft.	65°	35°	520 ft.
Ramp Weave	2,300 pcph	1,700	8.5 pcphpf	N = 3 – 4 [1]W = 22 – 32 ft. (width of shoulder & auxiliary lanes only)	45°	35°	310 ft.

[1]For definition of the width of ramp weave configuration, see Figure 4.2

freeway weaving sections are higher because of larger weaving lengths. This type of weaving configuration is most efficient and must be encouraged in non-freeway weaving design, as it can handle much higher weaving volumes, V_w.

Based on the observations of the calibration data base, the maximum total flow rate per lane, V/N, in a non-freeway weaving section was established as 1,300 pcphpl for the basic weave, and as 1,700 pcphpl for the ramp weave. Similarly, the limits on V_w/L are those that were found in the calibration data base. Furthermore, Length (L), width (W), approach angle (α), and deflection angle (Δ), limitations represent the range of these parameters in the calibration data base. Higher or lower values of these parameter may occur but will produce approximate results.

4.5 Level of Service Criteria

Level of service criteria for non-freeway weaving were established based on average running speeds of weaving and nonweaving vehicles as observed in the calibration data base.

The level of service definition used is the same as that given in the 1985 Highway Capacity Manual. Levels of service A through D correspond to a range of stable flow, with level of service A representing the most desirable free flow speeds. Level of service E corresponds to speeds at capacity, and level of service F represents unstable flow.

Owing to the fact that considerable differences exist in their operation, separate level of service criteria were established for the two categories under non-freeway conditions. Level of service criteria for the basic weave case are presented in Table 4.17 and for the ramp weave case in Table 4.18.

Minor differences between weaving and nonweaving speeds were observed for the basic weave configuration. Weaving vehicles, under this weaving category, occasionally travel faster than nonweaving vehicles. This occurs under congested conditions, where nonweaving vehicles often segregate to the outer area to avoid weaving turbulence. Some times, this segregation results in slower speeds in the outer area than in the actual weaving area. When this occurs, the level of service for weaving vehicles may be better than the level of service for nonweaving vehicles. However, as a general rule, for a given level of service, weaving vehicles are expected to travel somewhat slower than nonweaving vehicles because of the relative difficulty of the weaving maneuver. This difference in speeds tends to get smaller as the speeds are reduced.

In the case of the ramp-weave configuration, considerable speed differences occur. This is due to the fact that weaving vehicles are more or less restricted to the auxiliary lane and the shoulder lane regardless of the number of lanes provided. Additional lanes in ramp-weave sections will be used primarily by nonweaving vehicles. Where total width is excessive, weaving vehicles may operate at low speeds in two lanes, while outer flows travel at considerably higher speeds. This fact is reflected by the equations for predicting weaving and nonweaving speeds, and by the level of service criteria established for ramp-weave configurations under non-freeway conditions.

TABLE 4.17 Level of Service Criteria for Basic Weave

Level of Service	S_w (mph)	S_{nw} (mph)
A	42	45
B	38	40
C	33	35
D	30	30
E	25	25
F	< 25	< 25

TABLE 4.18 Level of Service Criteria for Ramp Weave

Level of Service	S_w (mph)	S_{nw} (mph)
A	> 38	> 50
B	33	45
C	30	40
D	25	35
E	20	25
F	< 20	< 25

4.6 Procedures for Application

The procedural steps for the analysis of weaving sections are presented here from an operational point of view. The operational analysis evaluates the speed for the weaving and nonweaving vehicles for a known or projected situation and, as a result, the level of service at which the section is or will be operating is determined.

The computational steps needed for the operational analysis are explained and illustrated for each of the two non-freeway weaving categories in the following sections.

4.6.1 Calculation 1 - Analysis of a Basic Weave Section

<u>**Description:**</u>

The non-freeway weaving area shown in Figure 4.1 serves the following traffic volumes:

A-C = 148 vph; A-D = 433 vph; B-C = 445 vph; B-D = 820 vph.

Traffic volumes include 4 percent trucks, and the peak hour factor is 0.96. The section is located in level terrain. The width of the weaving section is 26 ft (N = 2), the minor approach angle is 45 degrees, the deflection angle is 25 degrees, and the length is 480 ft. The weaving area is used by regular commuters. At what LOS will the section operate?

Step 1 - Establish Roadway and Traffic Conditions

All existing or projected roadway conditions are specified. Roadway conditions include the length, width, and number of lanes of the weaving area under study.

Traffic conditions include the distribution of vehicle types in the traffic stream and the peak hour factor. The analysis is performed on the basis of peak flow rates for a

Table 4.19 Passenger Car Equivalents

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T for Trucks	1.7	4.0	8.0
E_B for Buses	1.5	3.0	5.0
E_R for RV's	1.6	3.0	4.0

Source: Table 3-3 of the 1985 HCM

In the given example:

PHF = 0.96 (Given)

E_T = 1.7 (Table 5)

P_T = 0.04 (Given)

f_{HV} = 0.97 (Computed as 1 / [1 + 0.04(1.7 -1)];

Then:

A-C = 148 / (0.96 x 0.97) = 159 pcph

A-D = 433 / (0.96 x 0.97) = 464 pcph

B-C = 445 / (0.96 x 0.97) = 478 pcph

B-D = 820 / (0.96 x 0.97) = 881 pcph

Critical volumes may also be computed and other parameters may be listed for use in the analysis:

15-min. interval within the hour of interest. In the given example:

A-C = 148 vph; A-D = 433 vph; B-C = 445 vph; B-D = 820 vph.

α = 45°

Δ = 25°

C = 1

L = 480 ft.

PHF = 0.96

Step 2 - Convert all Traffic Volumes to Peak Flow Rates Under Ideal Conditions

$$\nu = \frac{V}{PHF \times f_{HV}}$$

where:

ν = flow rate for peak 15 min., in pcph, under ideal conditions;

V = hourly volumes, in vph, under prevailing conditions;

f_{HV} = heavy vehicle adjustment factor, given by:

$$f_{HV} = \frac{1}{[1 + P_T(E_T - 1) + P_R(E_R - 1) + P_B(E_B - 1)]}$$

where:

E_T, E_R, E_B = the passenger car equivalents for trucks, recreational vehicles, and buses respectively (refer to Table 4.19), and

P_T, P_R, P_B = the proportion of trucks, recreational vehicles, and buses respectively in the traffic stream.

$\nu_W = 464 + 478 = 942$ pcph

$\nu = 159 + 464 + 478 + 881 = 1982$ pcph

Step 3 - Compute Weaving and Nonweaving Speeds

Using the equations for the basic weave case from Table 4.6, compute the predicted weaving vehicle speed, S_w, and nonweaving vehicle speed, S_{nw}.

$S_w = 38.4$ mph, say 38 mph

$S_{nw} = 37.2$ mph, say 37 mph

Step 4 - Check Weaving Area Limitations

Consult Table 4.16 to ensure that none of the limitations specified for speed predictions are exceeded. The prediction of the speeds become approximate where one or more of these limits are exceeded. In the given example, all values are within the established limits.

Step 5 - Determine the Level of Service

The prevailing level of service is determined by comparing the estimated values of S_w and S_{nw} to the LOS criteria in Table 4.17.

Comparing the predicted S_w and S_{nw} to the criteria of Table 4.17 shows that the level of service for the weaving vehicles is B and for the nonweaving vehicles is C.

4.6.2 Calculation 2 - Analysis of a Ramp Weave Section

<u>Description</u> - The non-freeway weaving section shown in Figure 4.2 serves the traffic flows (in terms of peak flow rates) indicated below. At what LOS will the section operate?

Step 1 - Establish Roadway and Traffic Conditions

B-D = 2380 pcph

A-D = 1042 pcph

B-C = 528 pcph

W = 23 ft

α = 30°

Δ = 0°

L = 300 ft

C = 1

N = 4

La = 1

Step 2 - Convert all Traffic Volumes to Peak Flow Rates Under Ideal Conditions

In the above example, peak flow rates under ideal conditions are already given.

$$\nu_w = 1042 + 528 = 1570 \text{ pcph}$$

$$\nu = 2380 + 1042 + 528 = 3950 \text{ pcph}$$

Step 3 - Compute Weaving and Nonweaving Speeds

Using the equations for the ramp weave from Table 4.7, compute the predicted values of the average running speeds for weaving vehicles, S_w, and nonweaving vehicles, S_{nw}.

S_w = 27.02 mph, say 27 mph

S_{nw} = 40.53 mph, say 41 mph

Step 4 - Check Weaving Area Limitations

By consulting Table 4.16, it can be seen that all the values given in this example for computation are within the established limits. Therefore, the operation is expected to be as computed in step 3.

Step 5 - Determine the Level of Service

Comparing the predicted weaving and nonweaving speeds to the LOS criteria established in Table 4.18, indicates that the LOS for the weaving operation is D and for the nonweaving operation it is C.

CHAPTER V

DEVELOPMENT OF NFWSIM SIMULATION MODEL

5.1 Introduction

NFWSIM is an acronym for Non-Freeway Weaving SImulation Model. This chapter discusses the selection of the suitable simulation programming language and the methodology that is adopted for the development of NFWSIM.

The selection of a suitable simulation programming language depends on various factors that are presented in section 5.2. An extensive discussion is made on the modeling capabilities and technical aspects of the selected language.

The remaining portion of the chapter focusses on the modeling process of NFWSIM. An investigation of some of the studies that have direct bearing on the modeling process is also presented. Descriptions of the main program and the individual modules of the model are further augmented by flow charts which portray the flow of activities through the model. The required input elements are listed and a detailed discussion on their sources and reduction method is presented. The functional structure of the model is explained, including the description of the main program and the function of individual subroutines.

5.2 Simulation Language

It is possible to write simulation models in programming languages such as FORTRAN, BASIC, or PASCAL, or even languages like C, PROLOG, or LISP. To construct and use a simulation model written in one of these languages, however, requires extensive programming skills. Simulation languages permit modelers to focus attention on the description of the system components and their inter-relationships, and relieve them completely from knowing the technical details of programming languages.

Kiviat (1969) defines the static structure of a simulation language to have three parts: identification of object characteristics, relationships between objects, and generation of objects. He defines the dynamic structure of the language in terms of the method for advancing simulated time.

The choice of a suitable simulation language is influenced by the following factors as mentioned by Graybead and Pooch (1980).

1. The complexity of the model to be simulated.
2. The need for a comprehensive analysis and display of the results of the simulation run.
3. The programmer's familiarity with the language.
4. The ease with which the language is learned and used, if the programmer is not already familiar with it.
5. The language supported at the installation where simulation is to be done.

Table 5.1 provides a comparison of several simulation languages based on the work of Banks and Carson (1984).

Based on an evaluation of the factors influencing the choice of a simulation language, SLAM II was chosen as the most suitable language to program the NFWSIM model. A detailed discussion on the modeling capabilities and technical aspects of the SLAM II simulation language is presented in the following sub-sections.

TABLE 5.1 Comparison of Several Simulation Languages

CRITERIA	LANGUAGES				
	FORTRAN	GASP	SIMSCRIPT II.5	GPSS V	SLAM
Ease of Learning	Good	Good	Good	Excellent	Excellent
Ease of Conceptualzing	Poor	Fair	Good	Excellent	Excellent
System Oriented Toward	None	All	All	Queuing	All
Modeling Approach:					
o Event–Scheduling	No	Yes	Yes	No	Yes
o Process–Interaction	No	No	Yes	Yes	Yes
o Continous	No	Yes	Yes	No	Yes
Support:					
o Random Sampling Built in	No	Yes	Yes	No	Yes
o Statistical–Gathering Capability	Poor	Excellent	Excellent	Good	Excellent
o List–Processing Capability	Poor	Good	Excellent	Fair	Good
o Ease of Gathering Standard Report	Poor	Excellent	Fair	Excellent	Excellent
o Ease of Designing Special Report	Fair	Good	Excellent	Poor	Good
o Debugging Aids	Fair	Good	Excellent	Fair	Good
Computer Runtime	Excellent	Good	Good	Poor	Good
Documentation for Learning Language	Very Good	Very Good	Fair	Very Good	Very Good
Self–Focumenting Code	Poor	Good	Good	Excellent	Good
Cost	Low	Low	High	Low(GPSS H, High)	Medium

Source: Banks and Carson, 1984

5.2.1 SLAM II Simulation Language

SLAM II is an advanced FORTRAN based simulation language developed by A. Alan B. Pritsker (1986). This language was specifically selected for the following reasons:

1. It is FORTRAN based, thus does not require a separate compiling system.
2. The SLAM II processor completely relieves the user of the responsibility for chronologically ordering the events on an event calendar. The scheduling of events in the system is handled automatically in the SLAM subroutines.
3. SLAM II provides the user with a set of subroutines for performing all file manipulations which are commonly encountered in discrete event simulation.
4. Statistic collection of the variables of interest is readily available in SLAM subprograms. Both statistics based on observation and statistics on time persistent variables are easily provided by SLAM.
5. SLAMSYSTEM provides a graphical builder to construct the facility and to stylize symbols to represent system elements, and thereby, animating the process.

SLAM II allows models to be built based on three different world views: 1) It provides network symbols for building graphical models that are easily translated into input statements for direct computer processing; 2) It contains subprograms that support both discrete event and continuous model development; and 3) It combines network, discrete event, and continuous modeling capabilities. As NFWSIM is a discrete event model, only the technical aspects of the discrete event modeling procedures of SLAM II will be presented here.

5.2.2 Discrete Event Framework of SLAM II

SLAM II provides a set of FORTRAN subprograms for performing all commonly encountered functions such as event scheduling, statistics collection, and random sample generation. The advancing of simulated time (TNOW) and the order in which the event routines are processed are controlled by the SLAM II executive program.

Each event subroutine is assigned a positive integer numeric code called the event code. The event code is mapped onto a call to the appropriate event subroutine by subroutine EVENT (I) where the argument I is the event code. This subroutine is written by the user and consists of a computed GO TO statement indexed on I, causing a transfer to the appropriate event subroutine call followed by a return.

The executive control for a discrete event simulation is provided by subroutine SLAM which is called from a user-written main program. This allows the user to dimension the SLAM II storage arrays NSET and QSET in the main program without the need to recompile the SLAM II executive control program. The array QSET is in unlabeled COMMON and is equivalenced to the array NSET which is prescribed to have the same dimension. This allows for both integer and real values to be stored within a single contiguous array storage area. These arrays are employed by SLAM II for storing both events with their associated attributes and entities in files with their associated attributes.

The main program is also used to specify values of the SLAM II variables NNSET, NCRDR, NNRUN, and NPRNT which are in the labeled COMMON block SCOM1, and are defined in Table 5.2.

Table 5.2 Labled COMMON Block SCOM1 Variables

Variable	Definition
ATRIB(I)	Buffer for the Ith attribute value of an entry to be inserted or removed from the file storage area.
DD(J)	Value of the derivative of state variable J at TNOW - DTNOW.
DTNOW	Length of the current time step used in integration of state variables.
II	An integer global variable.
MFA	Location of the first available space in file storage.
MSTOP	Set by the user to -1 to stop a simulation run prematurely.
NCLNR	The file number of the event file.
NCRDR	The unit number from which SLAM II input is read, normally 5.
NPRNT	The unit number to which SLAM II output is to be written, normally 6.
NNRUN	The number of the current simulation run.
NNSET	The dimension of NSET/QSET.
SS(I)	Value of state variable I at time TNOW.
SSL(I)	Value of state varialble I at TNOW - DTNOW.
TNEXT	The time of the next scheduled event.
TNOW	The vlue of current simulated time.
XX(I)	The Ith global variable.
Source:	Alan, A. Pritsker, B., 1986

Subroutine INTLC and OTPUT are two additional user-written subroutines commonly employed. Subroutine INTLC is called by subroutine SLAM before each simulation run and is used to set initial conditions and to schedule initial events.

Subroutine OTPUT is called at the end of each simulation and is used for end-of-simulation processing such as printing problem specific results from the simulations.

The organization of the SLAM II program for discrete event modeling is illustrated in Figure 5.1.

5.2.3 SLAM II Next Event Logic

The SLAM II next-event logic for simulating discrete event models is depicted in Figure 5.2. The SLAM II processor begins by reading the SLAM II statements, if any, and initializing the SLAM II variables. A call is then made to subroutine INTLC which specifies additional initial conditions for the simulation. The processor then begins execution of the simulation by removing the first event from the event calendar. Events are ordered on the calendar based on low values of event times. The variable I is set equal to the event code and TNOW is advanced to the event time for the next event. Subroutine SLAM then calls the user-written subroutine EVENT (I) which in turn calls the appropriate event routine. Following execution of the user-written EVENT routine, a test is made to determine if the simulation run is complete. A discrete event simulation is ended if any of the following conditions are satisfied:

1. TNOW is greater than or equal to TTFIN, the ending time of the simulation;
2. No event remains on the event calendar for processing; or
3. The SLAM II variable MSTOP has been set in a user-written routine to -1.

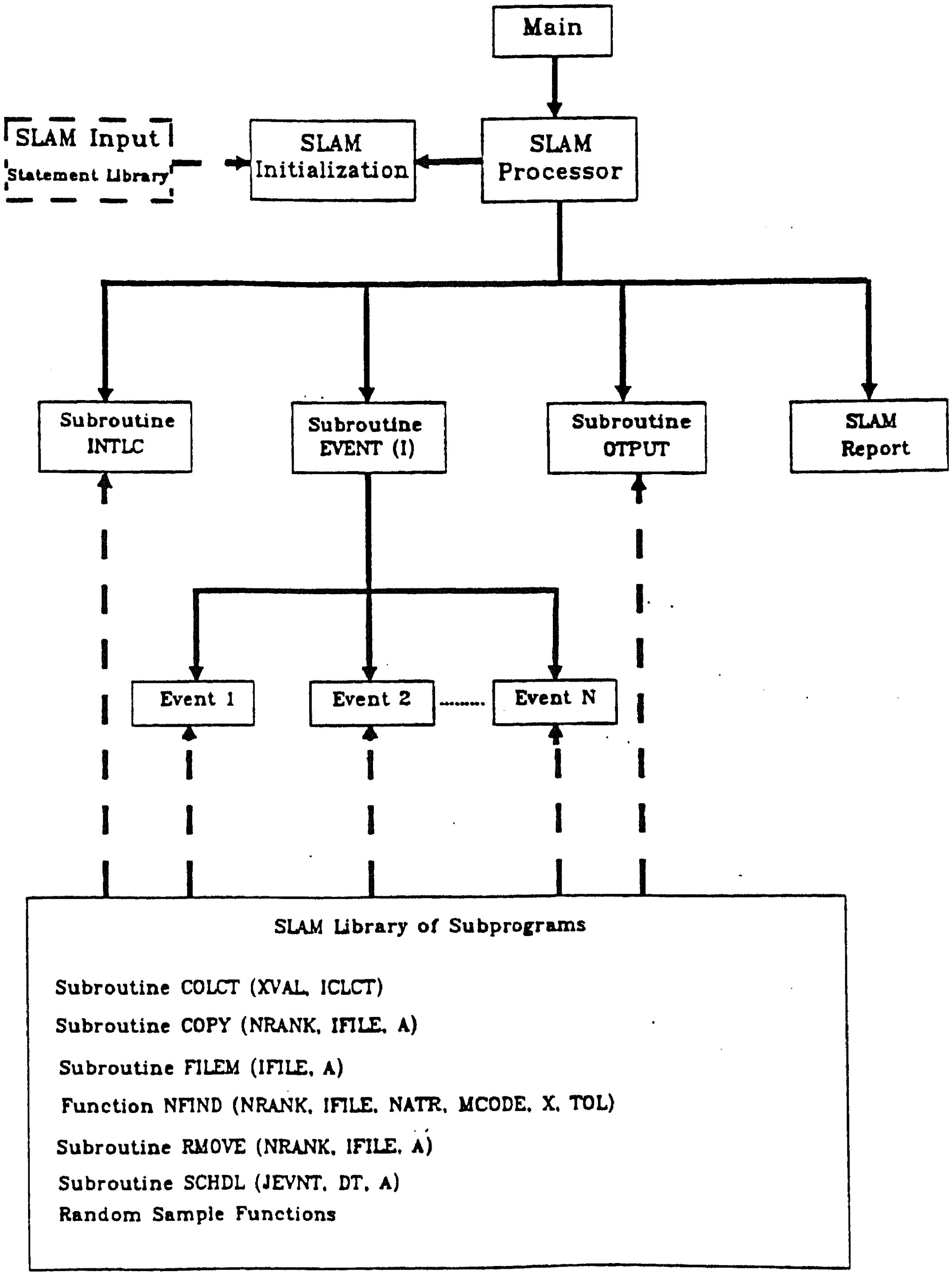


Figure 5.1 SLAM II organization for discrete event modeling
(Source: A. Alan, B. Pritsker, 1986)

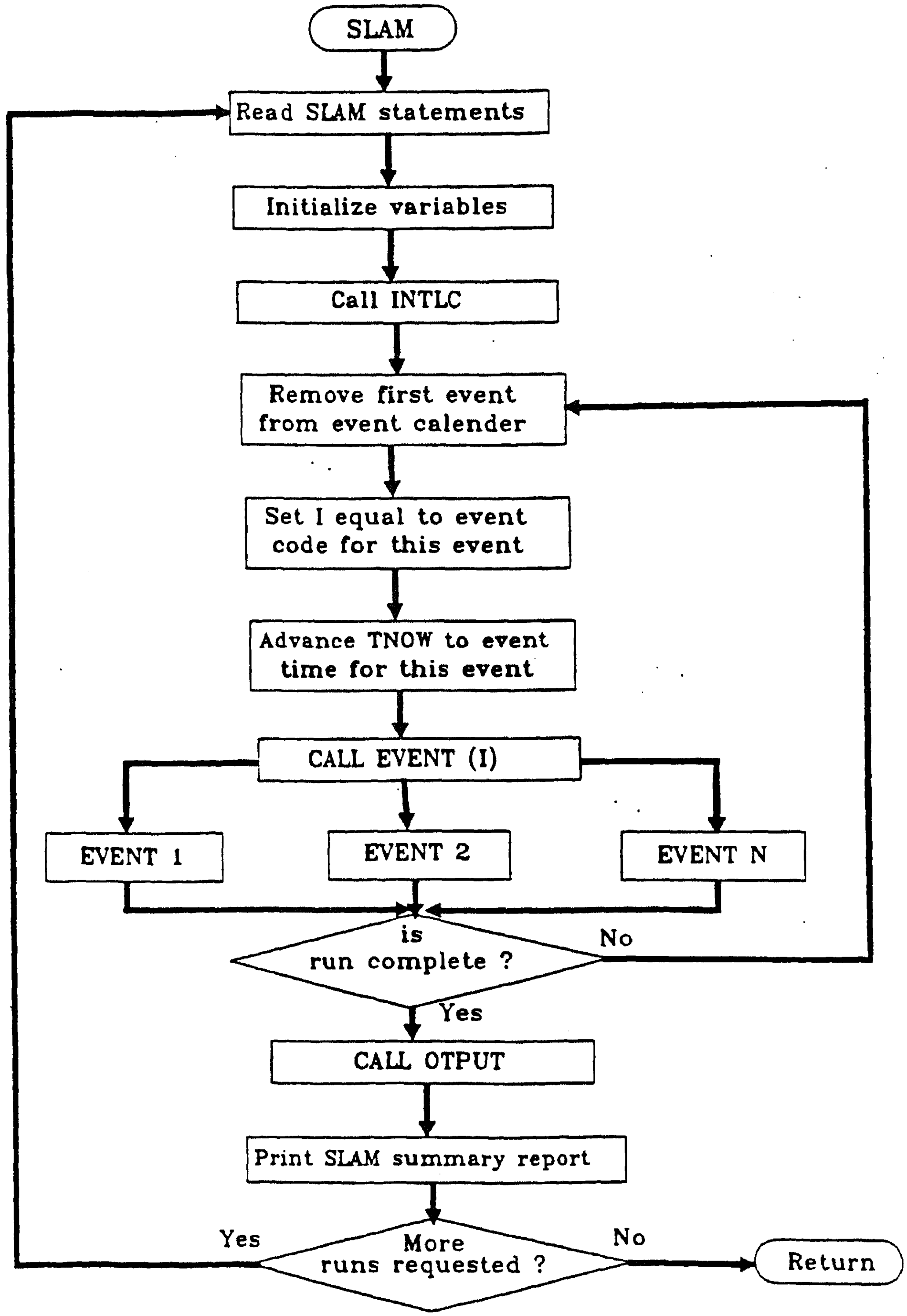


Figure 5.2 SLAM II Next Event Logic for Simulating Discrete Event Models
(Source: A. Alan, B. Pritsker, 1986)

If the run is not complete, the new first event is removed from the event calendar and processing continues. Otherwise a call is made to subroutine OTPUT. After the return from OTPUT, the SLAM II Summary Report is printed. A test is then made on more runs remaining. If more runs remain, control returns to initialization and the next simulation run is executed. Otherwise, a return is made form the SLAM II processor back to the user written main program.

A detailed description and illustration of the basic and advance concepts and procedures employed in constructing discrete event simulation models using SLAM II can be found in Chapters 11 and 12 of (Alan, A. Pritsker, B., 1986).

5.3 Formulation of NFWSIM

The modeling process of NFWSIM involves the selection and calibration of input elements and the development of the logic which controls the generation and movement of vehicles through the weaving area. The following is a list of the parameters that provide the required input to the model:

Input Parameters

1. Vehicle Generation

- Vehicle Arrival Headway Distribution
- Vehicle Arrival Speed Distribution
- Lane-Specific Volume Distribution
- Lane-Specific Vehicle Type Distribution

2. Driver Characteristics

- Break Reaction Time Distribution

- Gap Acceptance Distribution
- Lane and Vehicle-Specific Desired Speed Distributions

3. Vehicle Type Specific Parameters

- Limiting Vehicle Speeds
- Vehicle Acceleration Profile
- Vehicle Deceleration Profile

4. Car-Following Model

5. Lane Changing Algorithm

6. Level of Service Criteria

In the following sub-sections, a detailed description of each of these input elements is presented and their sources and calibration means are indicated.

5.3.1 Vehicle Generation

The two key elements associated with the generation of the incoming vehicles to the system are: A) vehicle arrival headways and B) vehicle arrival speeds. A set of attributes are assigned to each generated vehicle. Section 5.5 presents a discussion on the type of attributes allocated to the generated vehicles and their drivers.

A. Vehicle Arrival Headway

The time interval between the fronts of successive vehicles is referred to as headway. Vehicle inter-arrival time headways are directly related to the input volume.

Vehicle arrival headways were reduced using HEADWAY.BAS, a small self written BASIC program. The observer views the video tape and hits the "Enter" key as soon as arriving vehicles touch a reference line marked on the TV screen. The program records the inter-arrival vehicle time. The simplicity of the program's operation enables the observer to get a 100% sample. More than 70,000 headway points were reduced from the videotapes. The data are reduced on a 5 minute basis. The five-minute sample size is multiplied by 12 to obtain hourly volume of arriving vehicles. Weaving sites shown in Table 4.1 were used to reduce the arrival headways. For every five-minute interval an average sample size of 100 headways was obtained. Therefore, the average sample volume was 1200 vph (100 x 12).

Data for each five-minute interval were stored in a separate file. These files served as an input for the TRANSTAT statistical analysis software. TRANSTAT is used to perform curve fitting and obtain a theoretical distribution that best represents the arrival headways. The available distribution options of TRANSTAT are Earlang, Logistic, Exponential, Normal, Shifted Exponential, and Log-normal. Kolmogrov-Smirnov (KS) and chi-square tests were used to determine the goodness of fit. In the majority of cases, a lognormal distribution was found to be best. The lognormal distribution is an appropriate model for processes where the value of an observed variable is a random proportion of the previously observed value. Equation 5.0 gives the density function for the lognormal distribution.

$$f(x) = [1/(\sigma\sqrt{(2\pi)})] \exp \{-\tfrac{1}{2}[(\ln(x) - \mu)/\sigma]^2\} \qquad (5.0)$$

The arrival headway summary statistics of the data files reduced for approach A of the Long Island Expressway site is presented in Table 5.3. The results of the chi-square and Kolmogrov-Smirnov goodness of fit tests for the log-normal distribution are presented in Tables 5.4 and 5.5 and Figures 5.3 and 5.4.

Table 5.3 Summary of Arrival Headway File Statistics for LIEAM Site (Approach A)

File Name	Volume	5 Min. Sample Size (7:00 - 9:00)	Minimum	Maximum	Mean	Mode	Median	Standard Deviation	Coeff. of Variation	Percentile 50th	Percentile 85th
HEAD1.DAT	1332	111	0.77	10.44	2.58	1.26	1.98	1.81	0.70	2.03	4.28
HEAD2.DAT	1440	120	0.66	11.37	2.48	1.59	1.97	1.75	0.71	1.97	4.34
HEAD3.DAT	1476	123	0.82	8.79	2.45	1.43	1.92	1.55	0.63	1.92	4.00
HEAD4.DAT	1068	89	0.93	12.36	3.43	1.26	2.80	2.46	0.72	2.91	6.42
HEAD5.DAT	1440	120	0.72	12.64	2.48	1.26	1.97	1.83	0.74	1.98	3.57
HEAD6.DAT	1488	124	0.60	8.07	2.30	1.10	1.87	1.34	0.58	1.98	3.46
HEAD7.DAT	1212	101	0.76	12.19	3.03	2.91	2.20	2.43	0.80	2.25	5.27
HEAD8.DAT	1332	111	0.88	12.47	2.64	1.16	1.98	1.85	0.70	2.03	4.72
HEAD9.DAT	1488	124	0.66	10.10	2.44	1.26	1.70	1.93	0.79	1.81	4.00
HEAD10.DAT	1464	122	0.77	9.61	2.43	1.32	2.03	1.51	0.62	2.04	3.79
HEAD11.DAT	1308	109	0.71	10.43	2.77	1.04	2.03	1.83	0.66	2.14	4.94
HEAD12.DAT	1164	97	0.99	11.65	3.09	1.10	2.14	2.21	0.72	2.30	6.15
HEAD13.DAT	1212	101	0.88	10.54	2.94	1.10	1.98	2.30	0.78	2.03	5.76
HEAD14.DAT	1320	110	0.66	10.71	2.71	0.77	2.00	1.87	0.69	2.08	4.99
HEAD15.DAT	1344	112	0.82	11.26	2.66	1.32	1.92	1.97	0.74	1.92	4.61
HEAD16.DAT	1344	112	0.88	11.53	2.68	1.10	1.98	1.99	0.74	2.08	4.66
HEAD17.DAT	1404	117	0.77	11.43	2.39	1.15	1.70	1.75	0.73	1.76	4.12
HEAD18.DAT	1452	121	0.87	11.70	2.47	1.15	1.87	1.67	0.67	1.92	4.12
HEAD19.DAT	1488	124	0.87	11.70	2.50	1.15	1.87	1.75	0.73	1.76	4.12
HEAD20.DAT	1344	112	0.82	11.54	2.56	1.16	1.84	1.67	0.68	1.92	4.12
HEAD21.DAT	1392	116	0.60	9.04	2.38	0.88	1.76	1.99	0.83	1.81	3.73
HEAD22.DAT	1248	104	0.72	11.86	2.87	1.48	1.93	2.36	0.82	1.98	5.31
HEAD23.DAT	1008	84	0.66	14.00	3.31	1.81	2.23	2.66	0.80	2.48	6.21
HEAD24.DAT	960	80	0.60	12.85	2.98	0.88	1.68	2.78	0.93	1.92	5.82

Table 5.4 Results of Chi-Square Goodness of Fit Test for LIEPM Site

Chi-Square Summary Information

For Log-Normal Model

Chi-Square Goodness of Fit Statistics = 0.34 (6 DF)

Alpha	Critical Value
0.01	16.80
0.05	12.54
0.10	10.61

"Based on above information, there is little evidence that distributions differ therefore, the fit is good one"

Table 5.5 Results of Kolmogrov-Smirnov Goodness of Fit Test for LIEPM Site

KS Test Results

For Log-Normal Model

D^+	=	0.0512	at	2.6904
D^-	=	-.0348	at	2.0430

"Value of Test Statistics (D) = 0.0512"

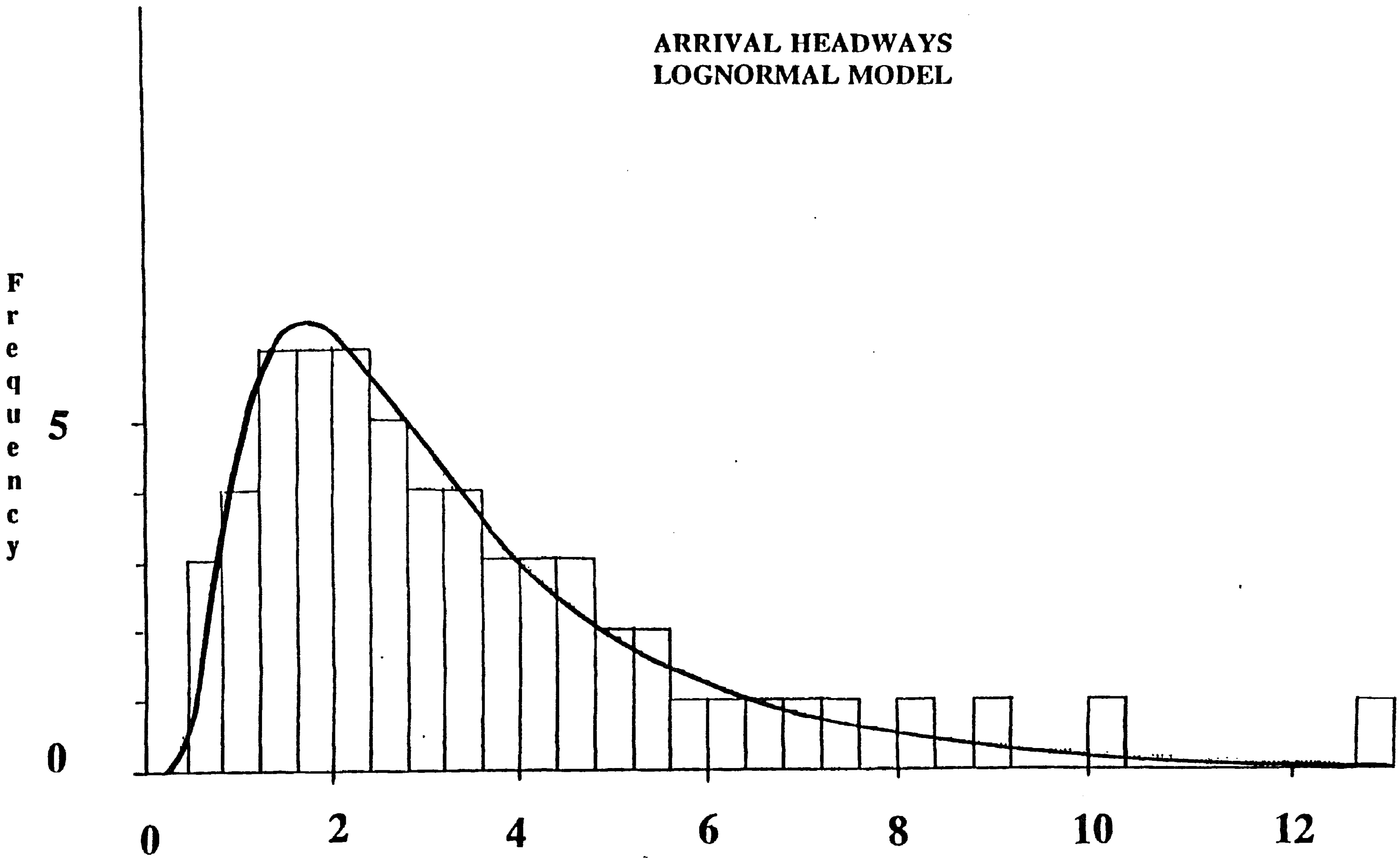


Figure 5.3 Plot of Theoretical and Observed Frequency Curves for the Log-Normal Model (Chi-Square Test)

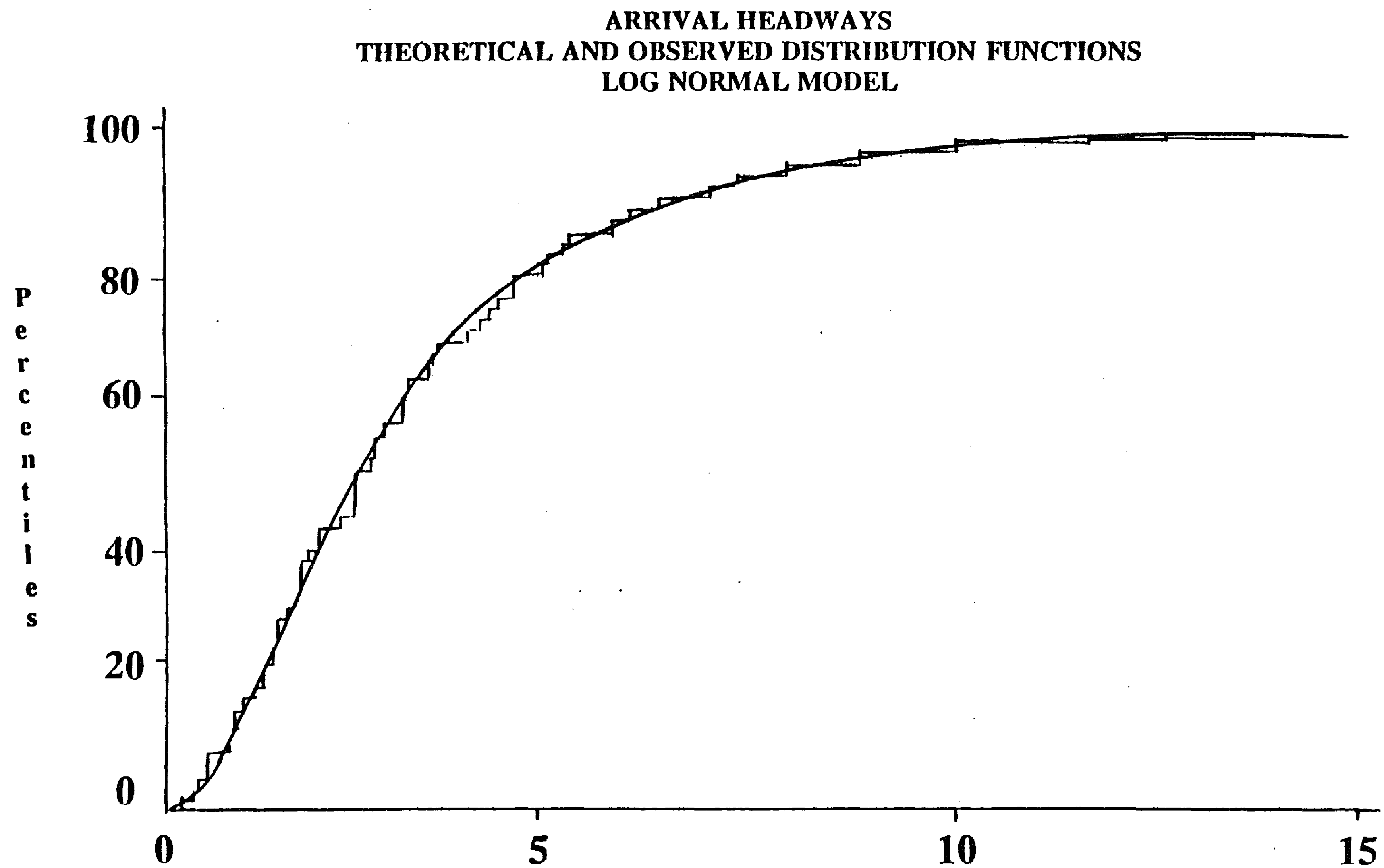


Figure 5.4 Plot of Theoretical and Observed Distribution Functions for the Log-Normal Model (Kolmogrov-Smirnov Test)

Calibrating Mean and Standard Deviation of Arrival Headways in Terms of Volumes

In NFWSIM the arrival headways are generated from a log-normal distribution with a minimum value of 0.6 and a maximum of 12 seconds. For a more realistic representation of vehicle arrivals, the mean (μ) and standard deviation (σ) were calibrated as a function of the input volume. The data that showed close resemblance to the log-normal model were chosen for further analysis. Volume was selected as the independent variable, the mean of the arrival headway as the dependant variable and the following equations were calibrated through a simple linear regression.

1. Basic Weave

$$\mu = 6.175 - V/308.925 \qquad (R^2 = 0.93) \tag{5.1}$$

$$\sigma = 4.883 - V/450.204 \qquad (R^2 = 0.78) \tag{5.2}$$

2. Ramp Weave

$$\mu = 275/V + 0.7 \qquad (R^2 = 0.95) \tag{5.3}$$

$$\sigma = 175/V + 0.8 \qquad (R^2 = 0.88) \tag{5.4}$$

The required distribution is generated in SLAM II as a function of mean, standard deviation, and random number seed (J) using the following FUNCTION:

RLOGN (μ, σ, J)

B. Vehicle Arrival Speed

Vehicle arrival speed is one of the primary attributes that is assigned to the generated vehicles. The distribution of arrival speeds is influenced by various factors such as traffic volume, traffic density, roadway and vehicle conditions, environmental conditions, and speed regulations and constraints.

A truncated normal distribution was found to best represent speeds of arriving vehicles. The truncation is provided at a minimum of 15 mph and a maximum of 50 mph.

Calibration of Arrival Speeds

The program HEADWAY.BAS was slightly modified for the reduction of vehicle arrival speeds. Two lines were marked on the TV screen at the arrival approach of interest before the actual weaving section starts. The distance between the lines represented the length of the roadway which was already measured at the site (usually ranging from 100 to 200 ft.). When an arriving vehicle touches the first reference line, the observer hits the "Enter" key. The observer then traces that vehicle, and when it touches the second reference line, "Enter" is hit again. The program records travel time. The vehicle's arrival speed is then computed using the relation:

$$\text{speed (mph)} = \text{distance (ft)} \ / \ 1.47 \times \text{time (sec.)}$$

While applying the above relation, a constant vehicle travelling speed was assumed within the marked roadway section. If the observer found that the vehicle's deceleration (due to congestion ahead) or acceleration is noticeably large, he would not select that vehicle.

Table 5.6 shows the arrival speed files and their statistical summary that were reduced for one approach of the Long Island Expressway site. In majority of the cases, the observed data were found to obey normal distribution. Figure 5.5 present a plot of chi-square goodness of fit test for normal distribution model.

Table 5.6 Summary of Arrival Speed File Statistics for LIEAM Site (Approach B)

File Name	Volume	5 Min. Sample Size (7:00 - 9:00)	Minimum	Maximum	Mean	Mode	Median	Standard Deviation	Coeff. of Variation	Percentile 50th	Percentile 85th
SPED1.DAT	1332	34	14.97	40.64	28.11	25.86	28.44	5.05	0.18	28.71	35.07
SPED2.DAT	1440	33	20.32	38.16	28.64	27.21	27.41	4.97	0.17	28.45	35.97
SPED3.DAT	1476	29	13.91	44.07	28.60	33.64	28.44	6.98	0.24	30.09	35.56
SPED4.DAT	1068	35	15.80	38.16	25.70	31.61	25.86	5.60	0.22	25.86	33.28
SPED5.DAT	1440	34	17.29	43.46	27.44	31.61	27.21	5.91	0.22	28.45	33.64
SPED6.DAT	1488	38	18.07	43.44	30.03	29.80	30.08	5.69	0.19	30.09	35.56
SPED7.DAT	1212	48	14.55	52.14	29.85	33.65	29.95	6.41	0.21	31.60	35.56
SPED8.DAT	1332	48	17.08	57.94	33.75	40.63	33.64	8.02	0.24	35.55	44.06
SPED9.DAT	1488	58	15.41	38.17	27.36	35.56	27.10	5.92	0.22	27.21	35.56
SPED10.DAT	1464	48	17.88	52.16	28.34	31.61	28.44	6.22	0.22	28.45	35.55
SPED11.DAT	1308	54	13.26	43.59	28.37	35.55	27.83	7.94	0.28	28.45	37.71
SPED12.DAT	1164	59	14.81	38.17	28.06	30.09	27.21	5.02	0.18	28.44	33.65
SPED13.DAT	1212	61	15.41	37.69	28.45	30.09	28.45	4.41	0.16	28.46	33.64
SPED14.DAT	1320	54	15.41	47.43	29.10	28.44	28.58	6.79	0.23	29.81	37.70
SPED15.DAT	1344	58	13.26	40.63	28.37	28.44	29.13	6.30	0.22	29.81	35.54
SPED16.DAT	1344	63	19.68	49.07	28.33	27.21	22.51	4.50	0.16	28.46	33.30
SPED17.DAT	1404	54	17.19	47.43	29.99	31.60	30.08	6.66	0.22	31.60	38.17
SPED18.DAT	1452	67	12.37	51.31	28.54	25.86	28.44	7.21	0.25	28.46	35.98
SPED19.DAT	1488	54	10.75	44.07	29.50	35.54	29.94	6.85	0.23	31.60	37.70
SPED20.DAT	1344	48	17.30	47.40	31.68	31.60	31.61	5.80	0.18	31.62	38.17
SPED21.DAT	1392	45	16.73	46.16	29.81	27.44	28.44	5.66	0.19	29.81	40.64
SPED22.DAT	1248	40	18.96	40.63	30.42	33.66	30.09	4.77	0.16	31.60	35.58
SPED23.DAT	1008	40	18.44	40.64	29.90	30.09	30.09	5.55	0.19	31.60	37.70
SPED24.DAT	960	34	13.55	40.66	30.19	30.09	31.60	5.98	0.20	31.62	35.96

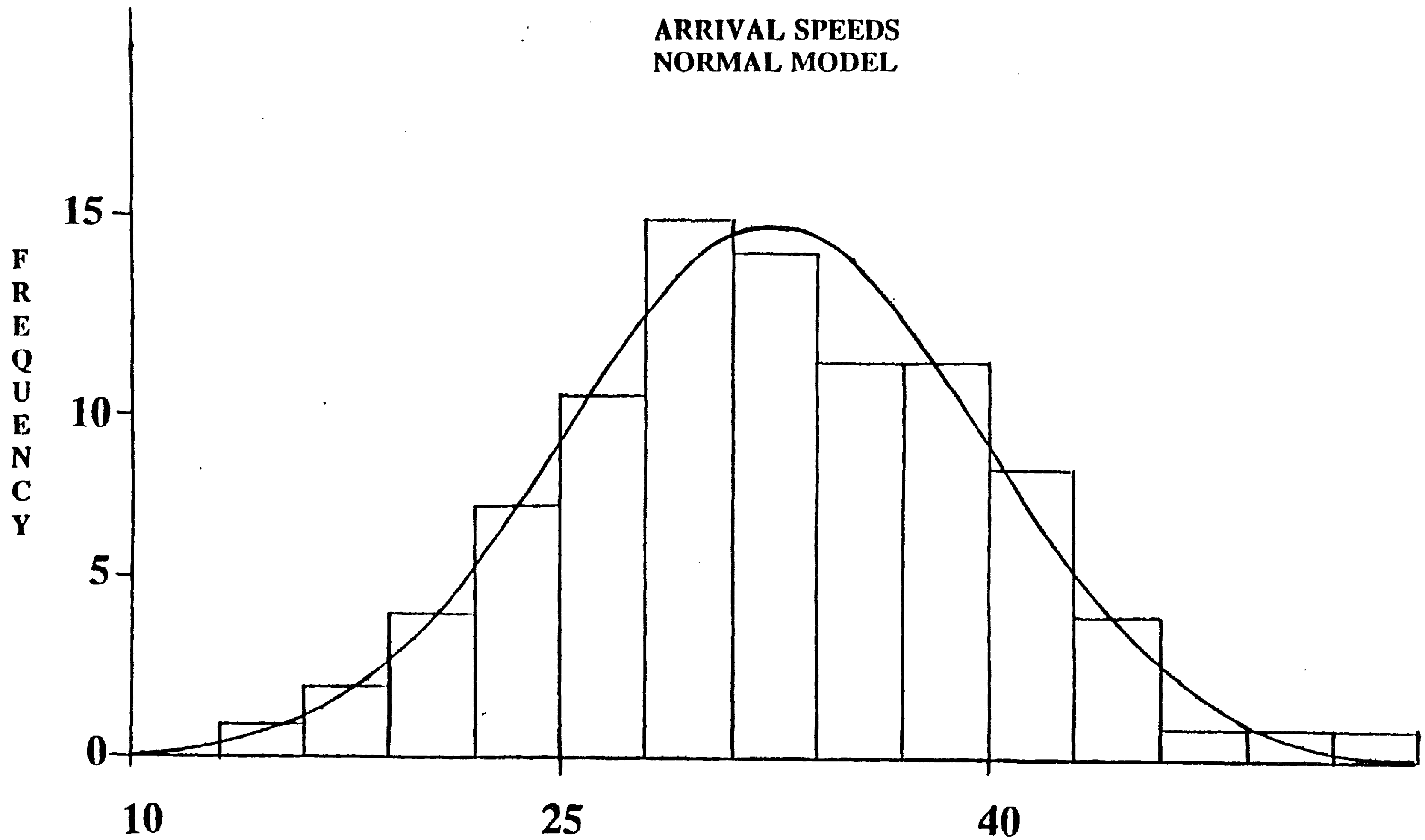


Figure 5.5 Plot of Theoretical and Observed Frequency Curves for Normal Model (Chi-Square Test)

5.3.2. Driver Characteristics

A. Break Reaction Time

Human performance, capabilities, and behavioral characteristics are vital inputs to many traffic engineering analysis. The term "reaction time" is used to described the period between the occurrence or appearance of a visual stimulus and the driver's physical reaction to it.

Different drivers will have different reaction times, because reaction time is affected by a wide range of individual characteristics such as experience, skill, degree of alertness, motivation, risk-taking behavior, and blood alcohol level.

Studies performed by Hulbert and McCormic (1983) have shown that in many situations the average driver reaction to stimuli is typically in the range of 1.5 sec. to 2.5 sec., but the variance of the distribution of reaction time is very high. Ogden (1990) mentioned several ways by which the average reaction time and variance can be reduced effectively. Forbes (1972) reported several tests that were performed in a laboratory to measure driver response times for task of differing complexity. The response time averaged about 0.5 sec. for simple tasks to 0.75 sec. or more for complex tasks. Johannson and Rumar (1971) tested a group of 321 drivers under alert conditions in 1971, and the results of the reaction times obtained are shown in Table 5.7. The median reaction time is 0.66 sec., and the values range from 0.3 sec. to 2.0 sec.

The results of Johannson and Rumar were used by the author to fit a Gamma distribution with a mean (μ) of 0.745 and variance (σ^2) 0.073 sec. which has a good fit for a 95% confidence. To prevent generation of unreasonable brake reaction times, the generated values are truncated below 0.25 and above 1.5 seconds.

Table 5.7 Driver Reaction Time (sec.)

Frequency	Time
3	0.3
12	0.4
48	0.5
92	0.6
52	0.7
25	0.8
28	0.9
22	1.0
8	1.1
11	1.2
5	1.3
8	1.4
3	1.5
1	1.6
2	2.0

321

μ = 0.75 sec.

σ^2 = 0.50 sec.

(Source: Johansson, Gunnar and Rumar, Kare, 1971)

B. Gap Acceptance distributions

Inherent in the traffic interaction associated with weaving maneuvers is the concept of gap acceptance. A "gap" is defined as a major stream headway that is scanned by a minor stream driver waiting to complete a certain maneuver. A "lag" is the time interval between the arrival of a minor stream vehicle and the arrival of a major stream vehicle at a reference point(s) where the two streams either cross or merge. Golias and Kanellaidis (1990) defined "critical gap" (acceptance threshold) as the minimum size of an acceptable headway in the main stream traffic which is considered to be sufficiently large to allow a driver in the minor stream of traffic to merge or cross.

In general, the merging process is influenced by headways, gaps, lags, speed of the major stream vehicles, speed of the merging vehicles, relative speed, major-stream flow, and minor stream flow. In addition, gap acceptance is influenced by the critical gap, percent of ramp vehicles delayed, mean length of queue, and total waiting time on the ramp.

The image processing technique that was employed to reduce microscopic data for model calibration, currently is at its developmental stage and it is not possible to reduce and calibrate gaps that are accepted by weaving vehicles. Critical gaps were, therefore, generated using an already calibrated equation and applied by several predecessor simulation models (Halati, 1990; Sadegh, 1988; Zarean, 1988). The equation for the generation of random critical gaps is given below:

$$\text{Critical Gap} = \{11.325 + \text{Anti-Log}[R/(1-R)]\}/0.1188 \tag{5.5}$$

Where, R is a uniformly distributed random number in the domain of (0,1).

5.3.3 Vehicle Type Specific Parameters

A. Limiting Vehicle Speeds

The limiting speeds of vehicles are influenced by longitudinal grade as well as vehicle type. Table 5.8 presents the vehicle type specific limiting speeds used in NFWSIM for various grades.

B. Vehicle Acceleration

The acceleration of a vehicle is influenced by speed (current speed and target speed), grade, and vehicle type. Information on both, maximum acceleration rate and vehicle specific acceleration-speed profile are needed for modeling the movement of the vehicles through the system.

Table 5.9 presents the maximum acceleration rates with respect to change in speed for specific grades and vehicle types used in NFWSIM. These values are derived form Tables 2.4, 2.5, 2.6, and 2.7 of the Transportation and Traffic Engineering Handbook (1976) which in turn are based on the data that were observed for vehicles used in the operating cost research study conducted for NCHRP Project 25A.

C. Vehicle Deceleration

Deceleration of motor vehicles occurs automatically when the acceleration pedal is released because of the retarding effect of various resistance forces. However, maximum deceleration rates come into play when brakes are applied to restrain the vehicle's motion. Normal deceleration rates for passenger cars, trucks, and trailers of -1 mph/s, -2 mph/s, and -2.5 mph/s, respectively, were employed in the model.

The maximum deceleration rate for all vehicles is -13.2 mph/sec. and from the fact that:

Table 5.8 Grade Specific Speeds of Representative Vehicles

VEHICLE TYPE	GRADE			
	0%	2%	4%	6%
1. Passenger Car	—	—	—	—
2. Single Unit Truck	—	—	47	39
3. Trailer Truck	—	34	22	16

Source: Transportation & Traffic Engineering Handbook, 1976

Table 5.9 Maximum Acceleration Rate of Representative Vehicles Operating on Various Grades

VEHICLE TYPE	SPEED CHANGE (MPH)																	
	0 – 15			0 – 30			15–30			30–40			40–50			50–60		
	GRADE			GRADE			GRADE			GRADE			GRADE			GRADE		
	0%	2%	6%	0%	2%	6%	0%	2%	6%	0%	2%	6%	0%	2%	6%	0%	2%	6%
1. Passenger Car	4.7	4.6	4.2	4.5	4.2	4	4.2	4.0	3.7	3.8	3.5	3.4	2.8	2.7	2.5	1.9	1.7	1.5
2. Truck	2.0	1.6	0.7	1.0	0.8	0.5	1.0	0.6	0.0	0.6	0.6	0.0	0.2	0.2	0.0	0.0	0.0	0.0
3. Trailer Truck	2.0	1.6	0.7	1.0	0.8	0.5	0.8	0.6	0.0	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Transportation and Traffic Engineering Handbook, 1976

$$S = \frac{V^2}{30\,(f \pm g)} \tag{5.6}$$

and

$$S = \frac{(1.47\ V)^2}{2d} \tag{5.7}$$

Where, S = Braking distance (ft)

V = Speed (mph)

f = coefficient of friction between pavement and tire surface

g = gradient

d = Maximum deceleration rate (ft./sec/sec)

The value of d is obtained by setting the right hand sides of equations 5.6 and 5.7 equal to each other, and assuming a mean value of 0.6 for the friction factor and a zero gradient (level terrain).

5.3.4 Car-Following Model

The car-following procedure applies to pairs of vehicles, moving under the close influence of each other, in a single-lane of traffic with no overtaking. Two vehicles are considered at a time, one of which is the leader and the other is the follower. Car-following models are defined in the form of a stimulus-response equation in which the response is the reaction of the driver in the following vehicle to the motion of the immediately preceding vehicle. This response is generally the acceleration or deceleration of the following vehicle in proportion to the magnitude of the stimulus at time (t) and begins after a time lag (T).

$$\text{Response } (t + T) = \text{Sensitivity x Stimulus } (t)$$

The car-following model embodied in NFWSIM is based on the fail-safe approach of PITT model developed for INTRAS (Wicks, D. A. and Lieberman, E. B., 1980). The two basic concepts of the modeling approach are:

1. The following vehicle will always seek a desired headway which is a function of vehicle speed, relative speed, highway capacity, and driver and vehicle type.

2. An overriding collision prevention model which is based on the following vehicle being able to avoid collision when the leader undergoes its most extreme deceleration pattern.

Primary Car-Following Relationship:

Following are the symbols used in the model:

T = Time scanning interval (sec)

L^l = Length of the leading vehicle (ft)

D_{max} = Maximum emergency deceleration rate (fps^2)

Bt^f = Break reaction time of follower (sec)

Sd = Safety distance (ft)

P^l_t = Position of leader at time t (ft)

P^l_{t+T} = Position of leader at time t + T (ft)

V^l_t = Velocity of leader at time t (fps)

V^l_{t+T} = Velocity of leader at time t + T (fps)

A^l_t = Acceleration of leader at time t (fps^2)

A^l_{t+T} = Acceleration of leader at time t + T (fps^2)

P^f_t = Position of follower at time t (ft)

P^f_{t+T} = Position of follower at time t + T (ft)

V^f_t = Velocity of follower at time t (fps)

V^f_{t+T} = Velocity of follower at time t + T (fps)

A^f_t = Acceleration of follower at time t (fps^2)

A^f_{t+T} = Acceleration of follower at time t + T (fps^2)

Three possible conditions can occur in the car-following model:

Condition 1: The leader vehicle comes to a complete stop. The follower should also come to a stop while maintaining a space headway of at least equal to the length of the leader plus a safety distance (Sd).

Mathematical Relationship

According to condition 1

$$P^l_{t+T} - P^f_{t+T} \geq L^l + Sd \tag{5.8}$$

But the updated position of the follower is given by:

$$P^f_{t+T} = P^f_t + V^{f\,2}_t / 2\,(A^f_{t+T}) \tag{5.9}$$

Substituting P^f_{t+T} from equation (5.9) in equation (5.8)

$$P^l_{t+T} - [P^f_t + V^{f\,2}_t / 2\,(A^f_{t+T})] \geq L^l + Sd \tag{5.10}$$

Solving for the acceleration of the follower

$$A^f_{t+T} \leq - V^{f\,2}_t / 2\,(P^l_{t+T} - P^f_t - L^l - Sd) \tag{5.11}$$

Condition 2: The updated speed of the leader is greater than zero but less than the current speed of the follower. The follower should, therefore, decelerate to avoid collision.

Mathematical Relationship

According to this condition, the space headway relationship is given by:

$$P^l_{t+T} - P^f_{t+T} \geq L^l + Sd + Bt^f \times V^f_{t+T} +$$

$$(V^{f\,2}_{t+T} - V^{l\,2}_{t+T})/2D_{max} \qquad (5.12)$$

This headway relationship satisfies the non-collision constraint. The basic concept here is that the follower should be able to maintain a space headway equal to the length of the leader plus a safety distance, when the leader uses its maximum emergency deceleration rate.

The updated position of the follower is:

$$P^f_{t+T} = P^f_t + V^f_t \times T + A^f_{t+T} \times T^2 / 2 \qquad (5.13)$$

And the updated speed of the follower is given by:

$$V^f_{t+T} = V^f_t + A^f_{t+T} \times T \qquad (5.14)$$

Substituting equations (5.13) and (5.14) in equation (5.12) and simplifying, the resulting equation is:

$$(A^f_{t+T})^2 + B \times A^f_{t+T} + C \leq 0 \qquad (5.15)$$

Where

$$B = (2V^f_t + D_{max} \times T + 2Bt^f \times D_{max}) / T \qquad (5.16)$$

$$C = -2D_{max} / T^2 \, (P^l_{t+T} - P^f_t + V^f_t \times T - L^l - Sd$$

$$- Bt^f \times V^f_t - (V^{f\,2}_t - V^{l\,2}_{t+T})/2D_{max} \qquad (5.17)$$

Solving equation (5.15) for A^f_{t+T}

$$A^f_{t+T} \leq [-B + (B^2 - 4C)^{0.5}] / 2 \qquad (5.18)$$

To compute the maximum allowable acceleration only the positive value has been used. In particular, $B^2 - 4C$ is always positive and thus the acceleration given by expression 5.18 has a real value.

Condition 3: The updated speed of the leader is greater than the current speed of the follower.

Mathematical Relationship

According to this condition the space headway is expressed as:

$$P^{l}_{t+T} - P^{f}_{t+T} \geq L^{l} + Sd + Bt^{f} \times V^{l}_{t+T} \tag{5.19}$$

Substituting equations (5.13) and(5.14) in equation (5.19) and simplifying, A^{f}_{t+T} is given by:

$$A^{f}_{t+T} \leq 2[P^{l}_{t+T}-P^{f}_{t}-L^{l}-Sd-V^{l}_{t+T}(T+Bt^{f})]/(2Bt^{f}xT+T^{2}) \tag{5.20}$$

After computing the appropriate acceleration of the following vehicle the updated position and speed are determined using the following relationships:

$$V^{f}_{t+T} = V^{f}_{t} + A^{f}_{t+T} \times T \tag{5.21}$$

$$P^{f}_{t+T} = P^{f}_{t} + V^{f}_{t} \times T + (A^{f}_{t+T} \times T^{2}) / 2 \tag{5.22}$$

The combination of the two algorithms of conditions 2 and 3, allows vehicles to temporarily maintain headways that are smaller to their desired headways. Thus, the simulation can reproduce very short headways and headway oscillations that are typically observed in congested flows. The logic also allows for realistic modeling of off-ramp back-ups onto the highway or arterial.

The PITT model is simple, flexible and easily adopted to modular form. It easily accommodates variable scanning periods and different driver and vehicle types. The model shows a realistic oscillatory following behavior and reasonable consistency over a range of scanning intervals. The model updates the status of the follower according to the behavior of the leader.

5.3.5 Lane-Changing Logic

Weaving areas entail intense lane-changing maneuvers as drivers must access lanes appropriate to their desired exit point. Thus, traffic in a non-freeway weaving area is subject to turbulence in excess of that normally present on basic highway sections.

The lateral movement of vehicles, in NFWSIM, is controlled by a lane-changing algorithm. It is essential that the lane changing component be carefully integrated with the car-following component. This is accomplished by confirming that the lane changing vehicle satisfies the safe headway conditions for both the leader and the follower of the gap that it is moving into. During the time of lane change, temporarily unsafe positions are allowed in NFWSIM. The mechanism replicates forced lane changing as it allows changing vehicles to crowd into otherwise nonexistent gaps in congested conditions. If a non-weaving vehicle travelling at its desired speed encounters a slower vehicle ahead, it will attempt to change lane. If unsuccessful, the vehicle will decelerate.

The lane changing logic of NFWSIM is rather simple. Since no significant number of random lane-change (lane change without any apparent reason) and discretionary lane-change (performed to bypass slow moving leader) were observed in non-freeway weaving, the lane changing logic incorporates only mandatory lane-changes. A mandatory lane-change is performed only by weaving vehicles. In the model, the lane changing probability for weaving vehicles remains constant and is determined prior to their entrance to the weaving section.

Upon arrival to the system each vehicle is assigned an origin and a destination. This is done randomly based on the percentage of weaving vehicles, which is an input to the model. In order to reach their destination, weaving vehicles need to change lane while non-weaving vehicle do not require any lane-change.

The lane-changing logic in NFWSIM consists of the following checks:

1. Check if the vehicle is weaving or nonweaving. This is done by checking the status of the vehicle.

2. If the vehicle is weaving, has it reached its destination? If not, call the lane changing subroutine.

3. Find a desired new lane for the vehicle flagged for lane-changing. This is done by comparing the current lane with the adjacent lane.

4. Perform a check to establish whether or not the change of lane is currently possible (emergency constraint conditions satisfied or not?).

The emergency constraint established in the car-following model, is also applied to the lane changing vehicles where the vehicles in the adjacent lane may not be in a safe relative position. In this case the lane changing is not initiated due to the following reasons:

1. The emergency constraint set provides a real acceleration but it is $< D_{max}$ and thus the lane change is not initiated.

2. The discriminant (B^2 - 4C) is negative. In this case the lane change is automatically not initiated, since the two vehicles must be in an unsafe relative position for occupying the same lane.

When the vehicle has successfully passed the above checks it will be moved to its new lane and its current lane will be updated accordingly. In case of violation of the above checks, the lane changing attempt is aborted for the current time scan. However, a lane changing attempt will be initiated at each successive time interval until a successive merge is performed.

5.3.5.1 Calibration of Lane Changing Logic

The lane changing logic of NFWSIM was calibrated to insure that all weaving vehicles perform the required lane changing maneuver to reach their destination. Initially, the lane changing algorithm was satisfying a lead gap (10 ft.), lag gap (15 ft.), and critical gap (assigned stochastically to each arriving vehicle) based on the car-following model's logic. However, the results of few simulation runs indicated that most of the weaving vehicles were not able to get the required gaps, and therefore, went without weaving.

The weaving vehicles merging point data obtained from the field were carefully reviewed. The data indicated that under non-freeway weaving conditions, weaving vehicles strive for lane changing as soon as they enter the weaving section. For instance, for the Long Island Expressway site, the length of weaving section is 302 ft. and in few cases the minimum merging point observed is less than 5 ft. In more than 30% cases the minimum merging point is less than 30 ft. The mean merging point is about 125 ft. (approximately 40% of the weaving section length), the standard deviation is about 55 ft., and the average maximum merging point is approximately 245 ft. (about 80% of the total weaving length).

Based on the above mentioned facts, adjustment were made to the speed of the lane changing vehicle and the lane changer's critical gap.

5.3.5.1.1. Adjustment in Changer's Speed

To determine safe lead and lag gaps for the changer, collision avoidance equations are satisfied rather than the car-following equations. This facilitates finer tolerances and lane-changing in heavy flow conditions.

As soon as a weaving vehicle enters the weaving section, a search is made for safe lead and lag gaps in the adjacent lane. If safe lead and lag headways are not available, the lane changer tries to adjust his speed to improve the possibility of lane changing in future scans.

To improve the lead gap in future scans, the updated position of the changer is computed using as comfortable deceleration rate for the current scan. If the updated lead gap is less than the current gap (downward speed adjustment worsens the situation) and the lead headway of the leader is at least 70 ft., then the changer is flagged for upward speed adjustment. Otherwise the changer is flagged for downward speed adjustment. This adjustment is incorporated in the next scan while computing the vehicle's new acceleration.

To improve the lag gap in future scans, the updated position of the changer is computed using the maximum acceleration rate. If the updated lag gap is greater than the current gap (upward speed adjustment improves the possibility of lane-changing) and the speed of the changer is greater than the speed of the follower, then the changing vehicle is flagged for upward speed adjustment. Otherwise, a downward speed adjustment is flagged.

5.3.5.1.2 Adjustment in Changer's Critical Gap

In the lane changing algorithm, a lane changing factor (LCF) is introduced to incorporate forced lane changing as the vehicle approaches the end of the weaving section. A similar concept was used in the WEAVSIM model (Zarean, 1987). The LCF varies between 1 at the entrance gore and about 1.35 at exit gore depending on volumes. The initially assigned critical gap of the changer is divided by the LCF and the result is compared with the available gap. If the new critical gap is less than the available gap, it is considered safe to change lanes. In this exercise a check is made to see if the new critical gap is less than the minimum required (safe lead gap + length of changer + safe lag gap). If it is then the maximum of the two is assigned as the new critical gap. Figure 5.6 presents a typical lane changing maneuver with lead, lag, and available gaps shown.

The LCF is assumed to have an exponential form of:

$$LCF = A + e^{B*X} \tag{5.23}$$

Where, X = the distance travelled by the changer form the entrance gore

A and B = constants

i) $LCF = 1.0$ when $X = 0.0$

ii) $LCF = 1 +$ (Lane weaving volume/Total weaving volume) when $X = L$

Where L = Length of weaving section (ft)

Substituting condition (i) in equation (5.23) and solving,

$$A = 0.0 \tag{5.24}$$

Substituting condition (ii) in (5.23) and solving,

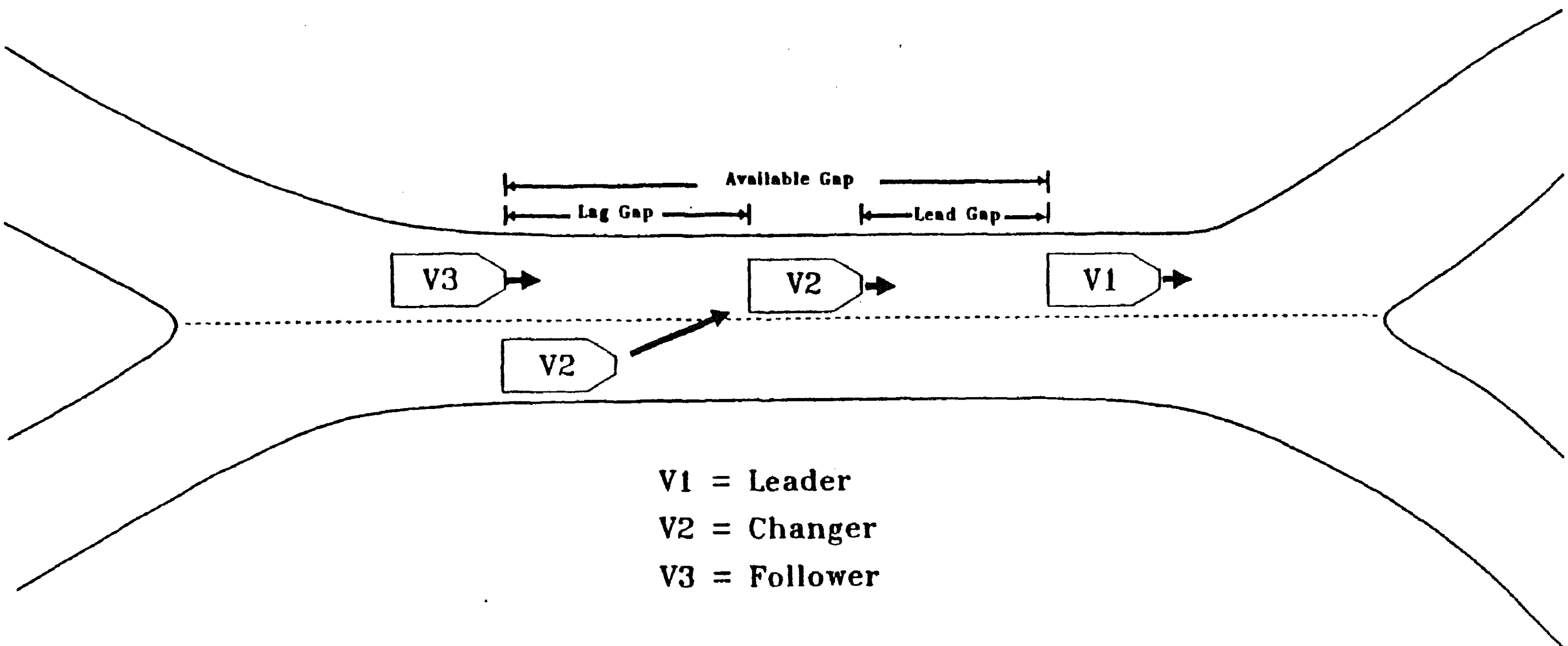


Figure 5.6 A Typical Lane Changing Maneuver

$$B = Ln(1 + \text{Lane weaving volume/Total weaving volume})/L \quad (5.25)$$

Substituting A and B in equation (5.23)

$$LCF = e^{Ln(1 + \text{Lane weaving volume/Total weaving volume})*X/L} \quad (5.26)$$

Figure 5.7 presents the general form of the lane changing factor.

5.3.6 Level of Service Criteria

In NFWSIM the level of service (LOS), for weaving and non-weaving traffic, is determined in accordance with the criteria developed and presented in Chapter 4. Table 4.17 shows the level of service criteria established for basic weave and is embedded in the model.

5.4 Vehicle and Driver Attributes

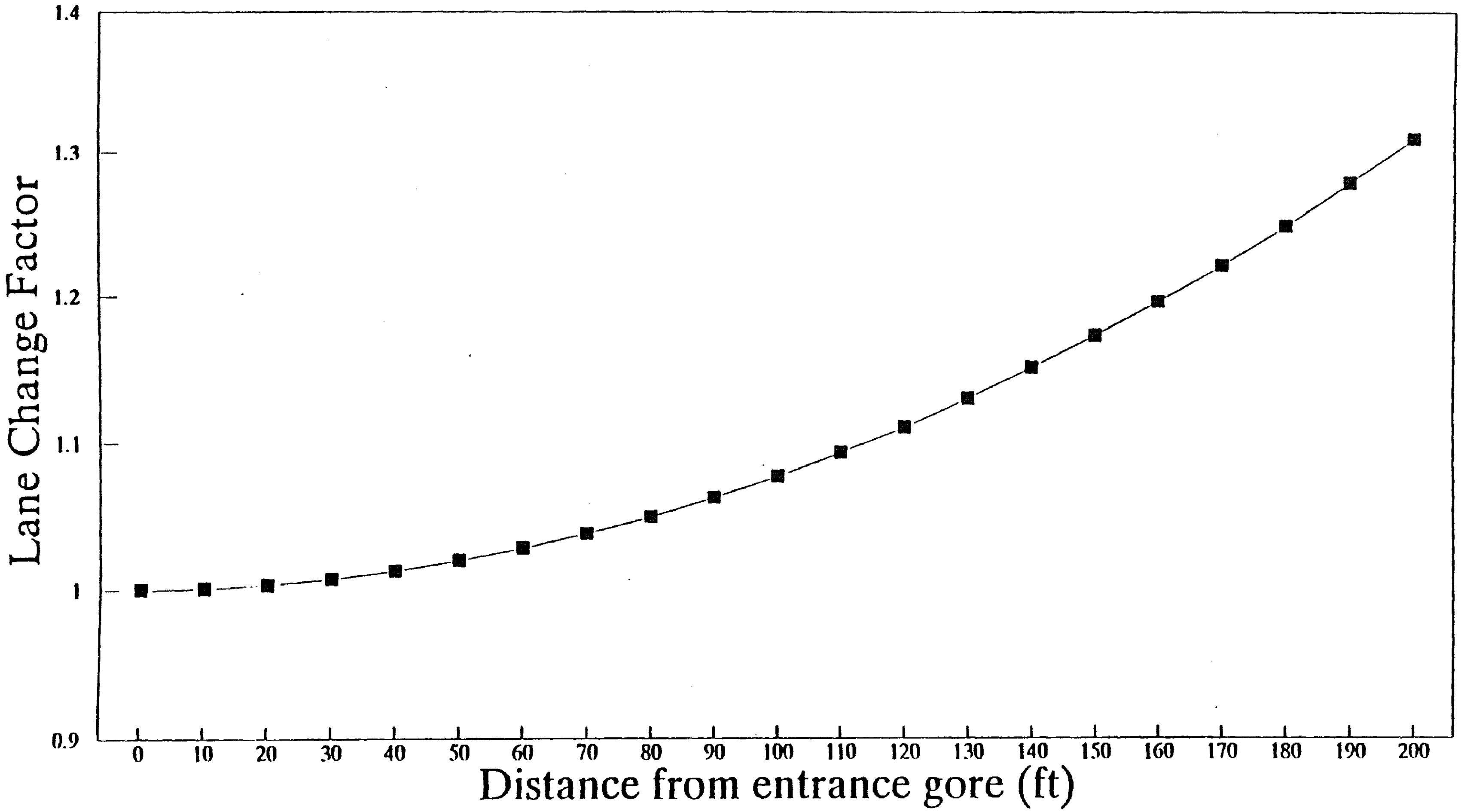


Figure 5.7 General Form of Lane Change Factor

- Vehicle length
- Vehicle type
- Origin (entry lane) of the vehicle
- Destination (exit lane) of the vehicle
- Status of the vehicle (weaving / non-weaving)

Temporary Attributes

- The current lane of the vehicle
- Current acceleration of the vehicle (computed form car-following model)
- Current speed of the vehicle
- Current position of the vehicle
- Current space headway of the vehicle

5.5 Structure and Methodology of NFWSIM

NFWSIM is designed to simulate at the microscopic level the operation of traffic at non-freeway weaving areas.

The Basic Model

NFWSIM simulates the movement of an individual vehicle-driver unit through a weaving section. The longitudinal movement of vehicles is controlled by the car-following logic while the lateral movement (merging, lane changing) of vehicles is guided by the lane changing algorithm. The status of each vehicle is scanned and updated every second. The behavior of each vehicle-driver unit is represented through interactions with the surrounding environment, which is the geometry of the weaving area and the presence of other vehicles.

Vehicles are generated randomly from a lognormal distribution of arrival time headways, and their arrival speeds are generated from a normal distribution. A total of twenty six attributes (refer to the program listing in Appendix B) are assigned either randomly or deterministically to each generated driver-vehicle unit. The assigned attributes may be temporary or permanent, as mentioned earlier.

The general logic organization of NFWSIM is shown in Figure 5.8. The simulation program consists of a main program, thirteen subroutines, and four functions. Each subroutine is completely modular so that any change in any subroutine will not affect the remainder of the program.

5.6 Functional Structure of NFWSIM

This section presents the functional design of NFWSIM that includes input and output requirements, and the function associated with each module of the program along with their flow diagrams.

5.6.1 Simulation Input

Inherent in the formulation of a simulation model is the determination of a significant number of input and output variables. The input parameters required for a simulation run of NFWSIM are all free-format and are listed below. The majority of the input parameters have a built-in default value, which is used if no other value is specified. The default values for respective input parameters are shown in parenthesis.

1. Simulation Run Parameters

- Simulation time (5 minutes)
- Warm-up time (60 seconds)

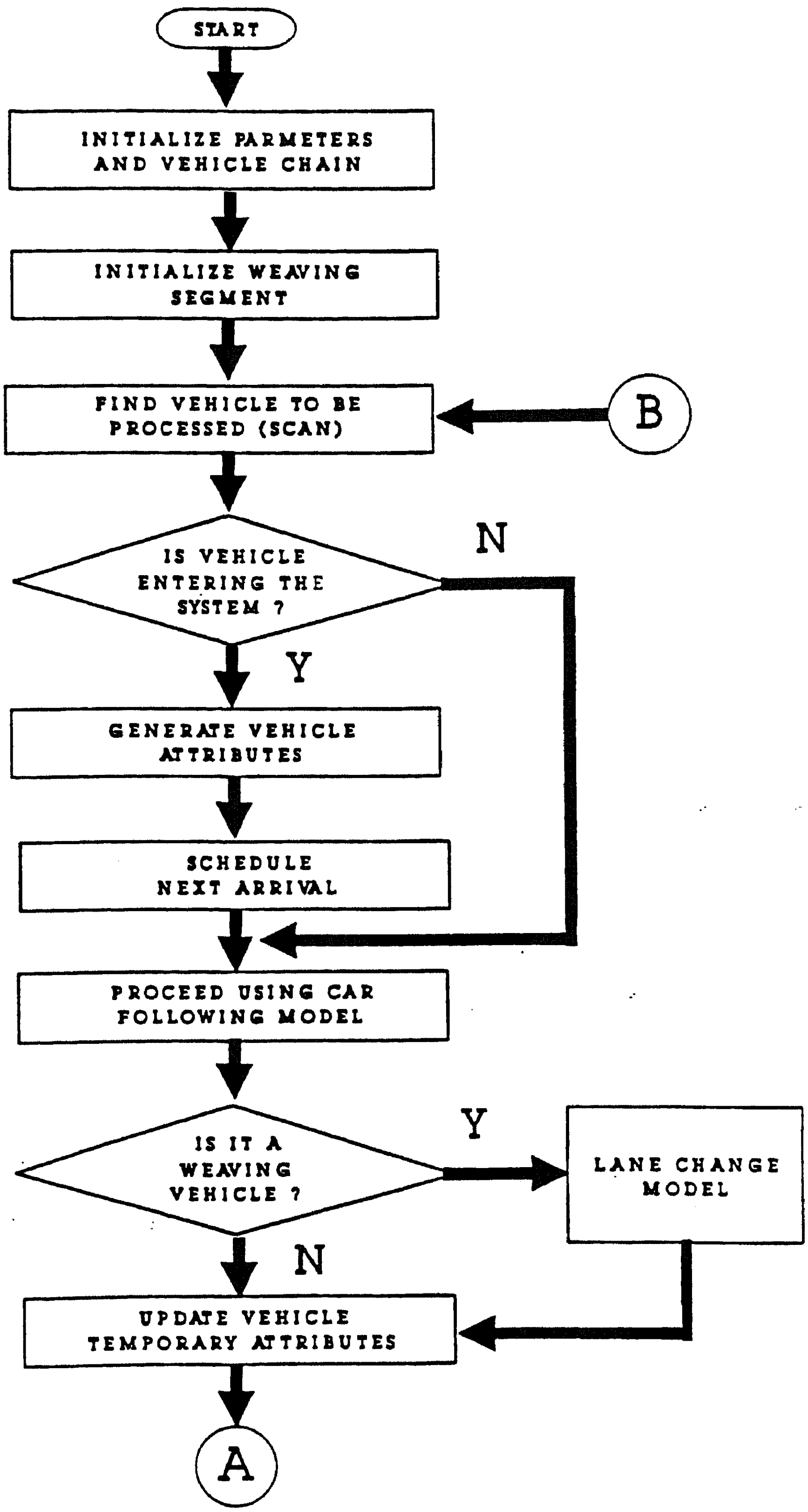
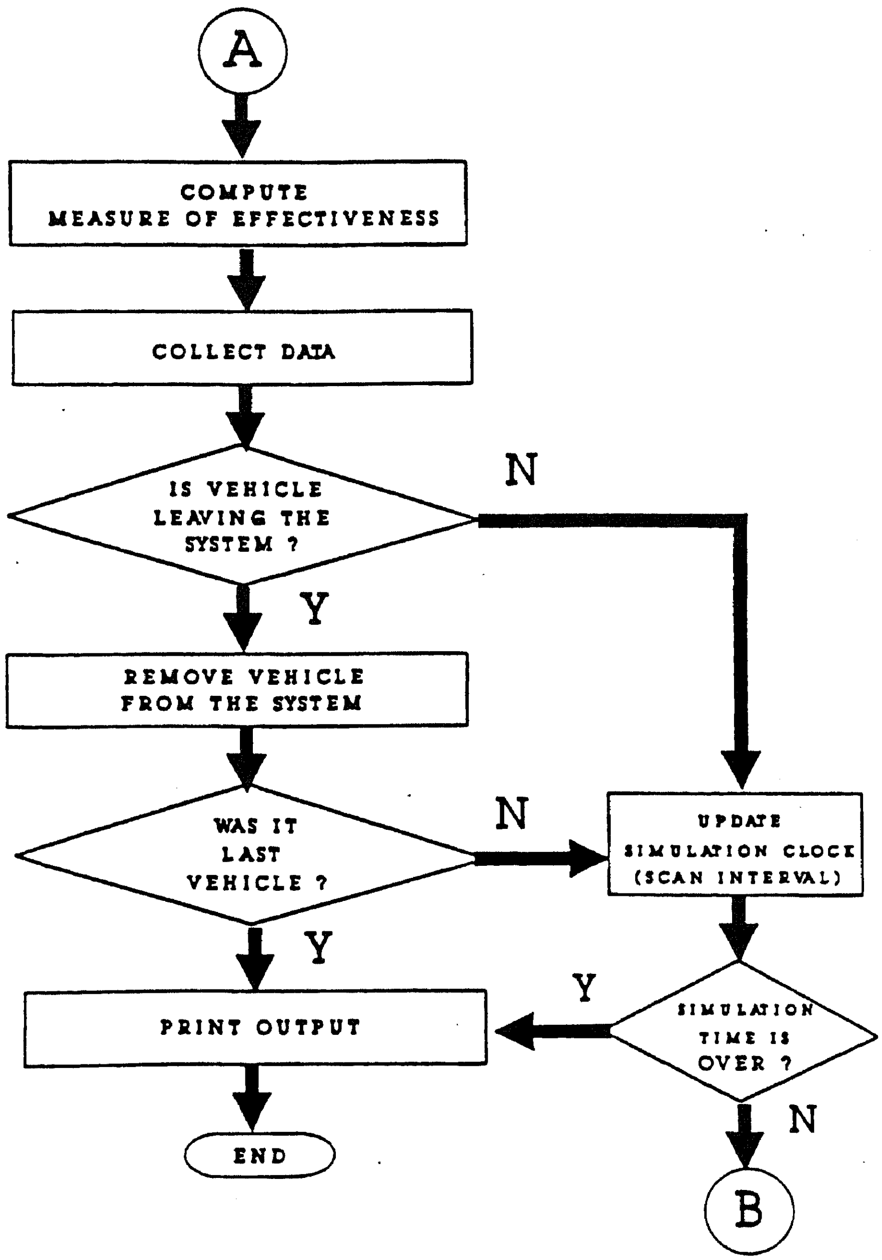


Figure 5.8 General Logic Organization of NFWSIM Model

Figure 5.8 (Continued)



- Upstream buffer length (100 ft.)
- Downstream buffer length (200 ft.)
- Analysis time (5 min.)
- Random number seed (1)

2. Weaving Section Parameters

- Length of the weaving section (350 ft.)
- Grade (0)
- Number of lanes in weaving section (2)

3. Traffic Parameters

- Approach volume in vehicle per hour
- Proportion of total approach volume weaving
- Proportion of single unit trucks (0.02) and trailer trucks (0.02) for each approach

4. Driver Policy

- Average acceleration rate (4 mph/sec)
- Average deceleration rate (7 mph/sec)
- Minimum deceleration rate (3 mph/sec)
- Maximum weaving speed (45 mph)
- Maximum nonweaving speed (45 mph)
- Mean break reaction time (0.75 sec)
- Gap acceptance characteristics

5. Vehicle Characteristics:

- Maximum acceleration rate (7 mph/sec)

- Maximum deceleration rate (13.23 mph/sec)
- Average length of passenger car (19 ft.)
- Average length of single unit truck (40 ft.)
- Average length of trailer truck (52 ft.)

5.6.2 Simulation Output

The SLAM II processor generates echo report, intermediate and SLAM II summary reports, and graphs.

A. Echo Report

The SLAM II Echo Report provides a summary of the simulation model as interpreted by the SLAM II processor. The echo report presents a SLAM II title page, and reports of the input parameters and control statements.

B. Intermediate Report

The intermediate report presents a print out of the temporary attributes of each vehicle at a user specified time interval. The temporary vehicle attributes that are printed in the report include vehicle position, speed, acceleration, current lane, etc. with respect to time. In addition, the report gives mean, minimum, maximum, standard deviation, and number of observations for all measures of performance for one or more simulation runs, and the level of service for weaving and nonweaving vehicles. In summary, the report gives:

1. Vehicle's Temporary Attributes (Trajectory) at User Specified Intervals
2. Statistics on Measures of Performance
3. Level of Service

C. Summary Report

The Summary Report displays the statistical results for the simulation and is automatically printed at the end of each simulation run. The report consists of a general section followed by the statistical results for the simulation categorized by type. The first category of statistics is for variables based on discrete observations and include statistics collected by the COLCT statement. The second category of statistics is for time persistent variables. The summary report gives mean, standard deviation, coefficient of variation, minimum, maximum, and number of observations for each measure of performance indicated below and for each simulation run. In addition, the report presents frequency distributions, cumulative distributions, and histograms.

1. Statistics of Measure of Performance
    - Arrival headway
    - Arrival speed
    - Brake reaction time
    - Weaving and non-weaving accelerations
    - Weaving and non-weaving speeds
    - Merging points
    - Accepted gaps
2. Frequency Distributions and Cumulative Distributions for:
    - Approach specific arrival headways and speeds
    - Merging points
    - Gap acceptance
    - Weaving and non-weaving accelerations

- Weaving and non-weaving speeds

D. Graphs

Bar graphs, pie charts, and frequency histograms are generated for:

- Merging points
- Gap acceptance
- Weaving and non-weaving accelerations
- Weaving and non-weaving speeds
- Headways

5.6.3 Function of Main Program and Individual Modules

The following steps present the procedure adopted for the development of NFWSIM:

1. Writing the Main Program to dimension NSET/QSET, specifying values for NNSET, NCRDR, and NPRINT, and calling SLAM.
2. Writing the subroutine EVENT (I) to map the user-assigned event codes onto a call to the appropriate event subroutine.
3. Writing subroutine INTLC to initialize the model and read input data.
4. Writing event subroutines and functions to model the logic for the events of the model.
5. Preparing the INPUT statement required by the model.

NFWSIM consists of a main program, thirteen subroutines, and four functions. The more important model components are discussed in this section, while the description of the rest of the subroutines and functions can be found in the program listing in Appendix B.

MAIN PROGRAM

The Main Program performs the following functions:

1. Dimensions the SLAM II storage arrays NSET and QSET
2. Specifies values for the SLAM II variables, NNSET, NCRDR, and NPRINT, which are in the labeled COMMON block named SCOM1
3. Calls subroutine SLAM which provides executive control for a discrete event simulation

The key purpose of this program is to provide access to all subroutines through a call to SLAM. It assigns values to NCRDR (input device = 5), NPRNT (output device = 6), and NNSET (the dimension of NSET/QSET).

SUBROUTINE EVENT (I)

This subroutine reads the event code I and calls the appropriate event subroutine. I is the an integer code associated with the current event. The following event codes are defined in this subroutine:

Event Code 1 - Arrival at approach A (Subroutine ARRIVAL_A)

Event Code 2 - Arrival at approach B (Subroutine ARRIVAL_B)

Event Code 3 - Scanning the system every second (Subroutine SCAN)

The SLAM II processor chronologically orders the events on the event calendar. Subroutine EVENT is called when the first event on the event calendar was generated by a call to subroutine SCHDL(JEVNT,DT,A) or is an arrival to an EVENT node with the event code JEVNT. SLAM II loads the ATTRIB buffer with the attributes (A) of the current entity/event prior to calling EVENT. The event code, JEVNT, allows control to be passed to the logic appropriate to the event type. DT is the time from the current time TNOW that the event is scheduled to occur. Figure 5.9 presents the flowchart of subroutine EVENT.

SUBROUTINE INTLC

Figure 5.10 present the flowchart of subroutine INTLC. This subroutine is called by SLAM before each simulation run. It is used to perform the following functions:

1. Initialize all non-SLAM II variables
2. Read input data
3. Establish constants for the model
4. Schedule the first arrival at each of the two approaches
5. Initialize the first vehicle trajectory data
6. Print an echo of the input echo data by calling subroutine ECHO_PRINT

SUBROUTINES ARRIVAL_A AND ARRIVAL_B

Subroutines ARRIVAL_A and ARRIVAL_B generate vehicles in the system entering form approach A and approach B, respectively, according to the headway distribution. Each vehicle entering into the system will be assigned an arrival speed and reaction time and a check is made to see if the vehicle can enter the system at its assigned arrival speed and current brake reaction time. If the space headway of the arriving vehicle is less than the summation of length of the leader and a randomly assigned safety distance, the vehicle is deleted and the number of rejected arrivals is incremented.

Once a vehicle enters the system, its attributes are assigned deterministically or stochastically. The arrival time of the vehicle is recorded and the attributes are assigned. All generated and assigned attributes are filed in file 1 for approach A and in file 2 for approach B. The designations A, B, C, and D used for the simulation model are shown

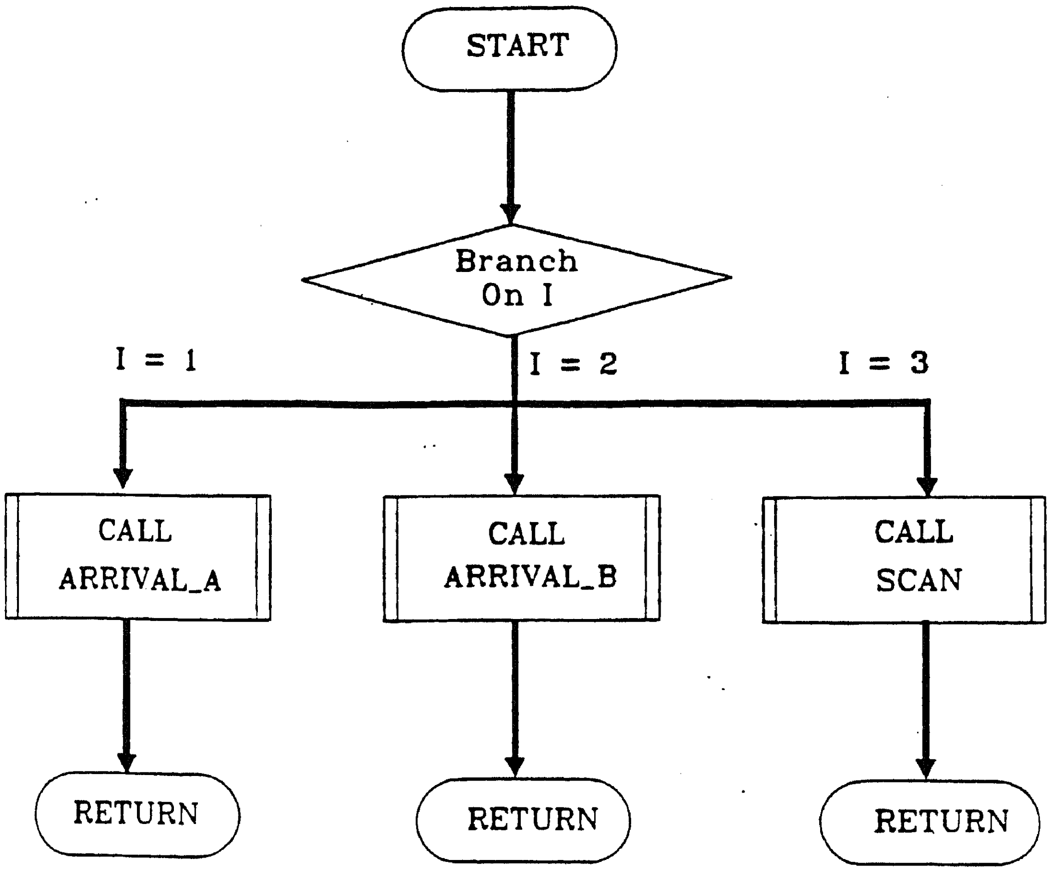


Figure 5.9 Flowchart of Subroutine EVENT

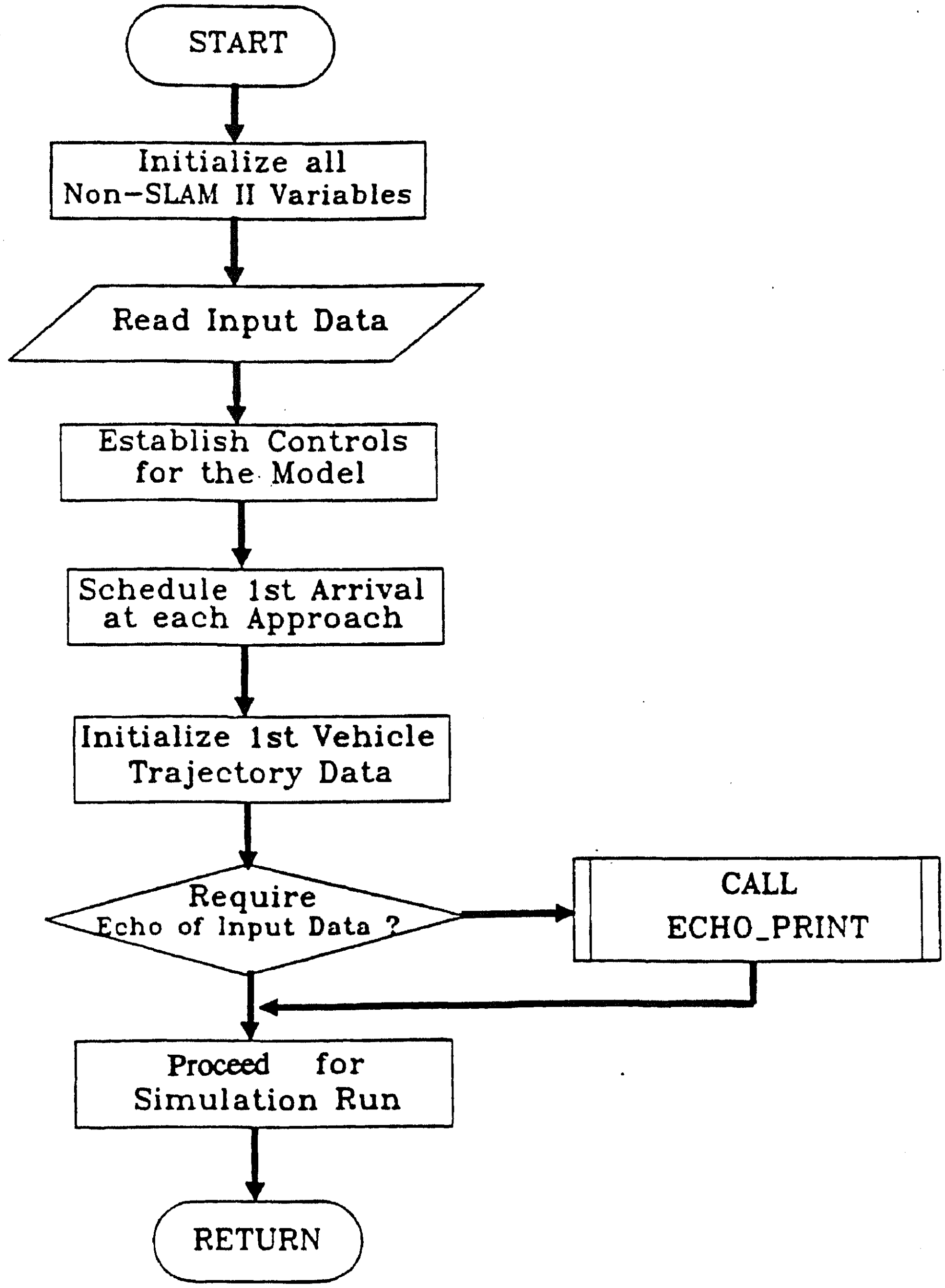


Figure 5.10 Flowchart of Subroutine INTLC

in Figure 4.1.

Finally, the next arrival is scheduled from a given arrival distribution and a call is made to subroutine STEP to allocate the nearest discrete time to the arrival event so that the arrival time coincides with a scanning event time. Figure 5.11 depicts the general logic of the subroutines.

SUBROUTINE SCAN

Figure 5.12 depicts the flowchart of subroutine SCAN, which has a key role in the simulation process. It performs the following jobs:

1. Identifies vehicles in the system
2. Processes each vehicle according to its lane and position in the system
3. Tests whether data collection is scheduled
4. Tests whether vehicle trajectories should be stored
5. Updates the speed and position of all vehicles through the simulated section
6. Tests whether vehicles after being process are out of the system
7. Schedules the next scanning event

During each scan time, all vehicles are processed according to their positions, starting with the vehicle most distant from the section entrance. Through a complete scan of the system, it updates the speed and position of all vehicles through the simulated section by calling subroutine CAR_FOLLOW. This is done in accordance with a vehicle's desired speed and destination as inhibited by the surrounding traffic and control environment. Based on the updated speed and position, a current space headway is computed and assigned to each vehicle. Statistics on vehicle attributes are collected when the vehicle is in the weaving area.

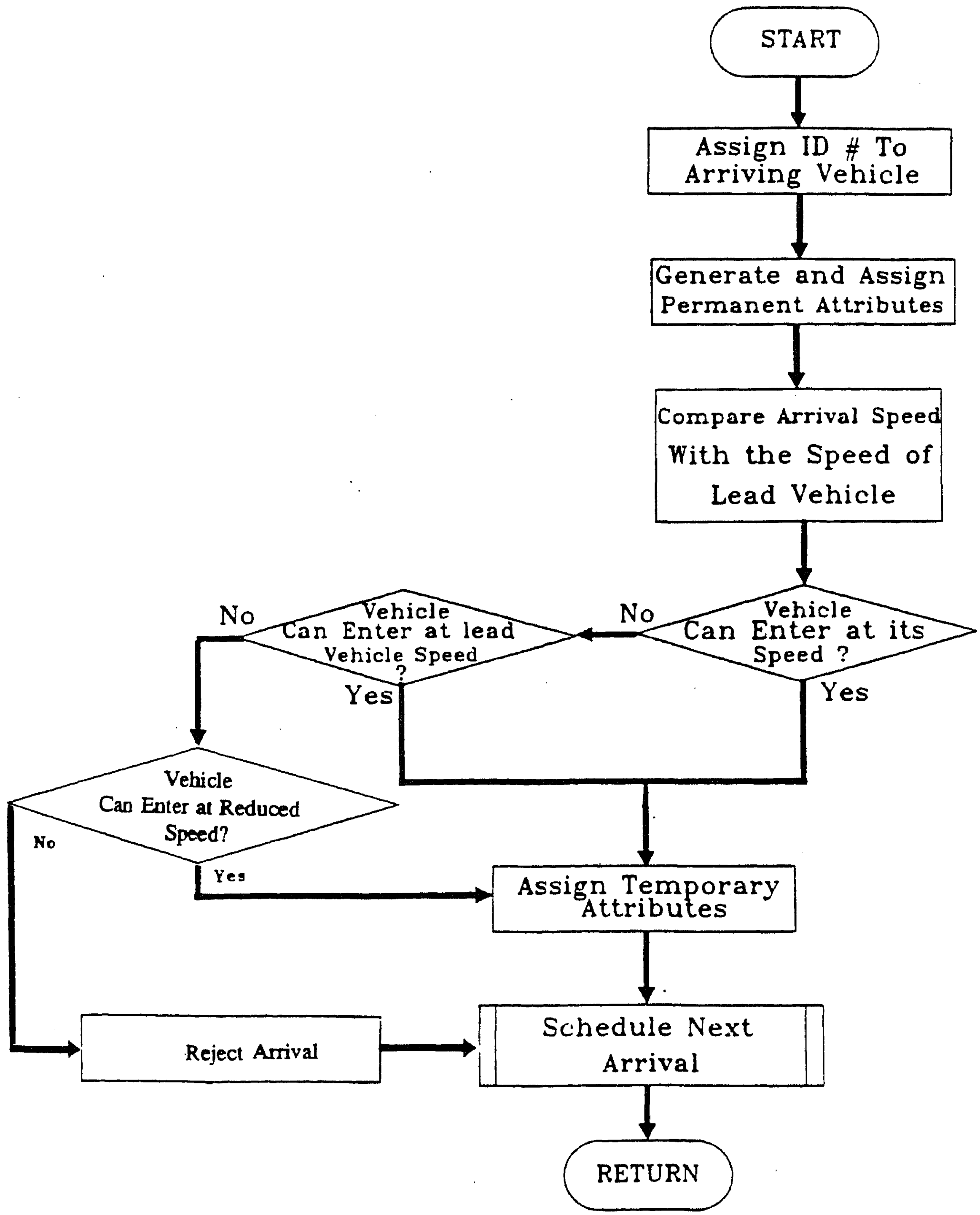


Figure 5.11 Flowchart of Subroutines ARRIVAL_A and ARRIVAL_B

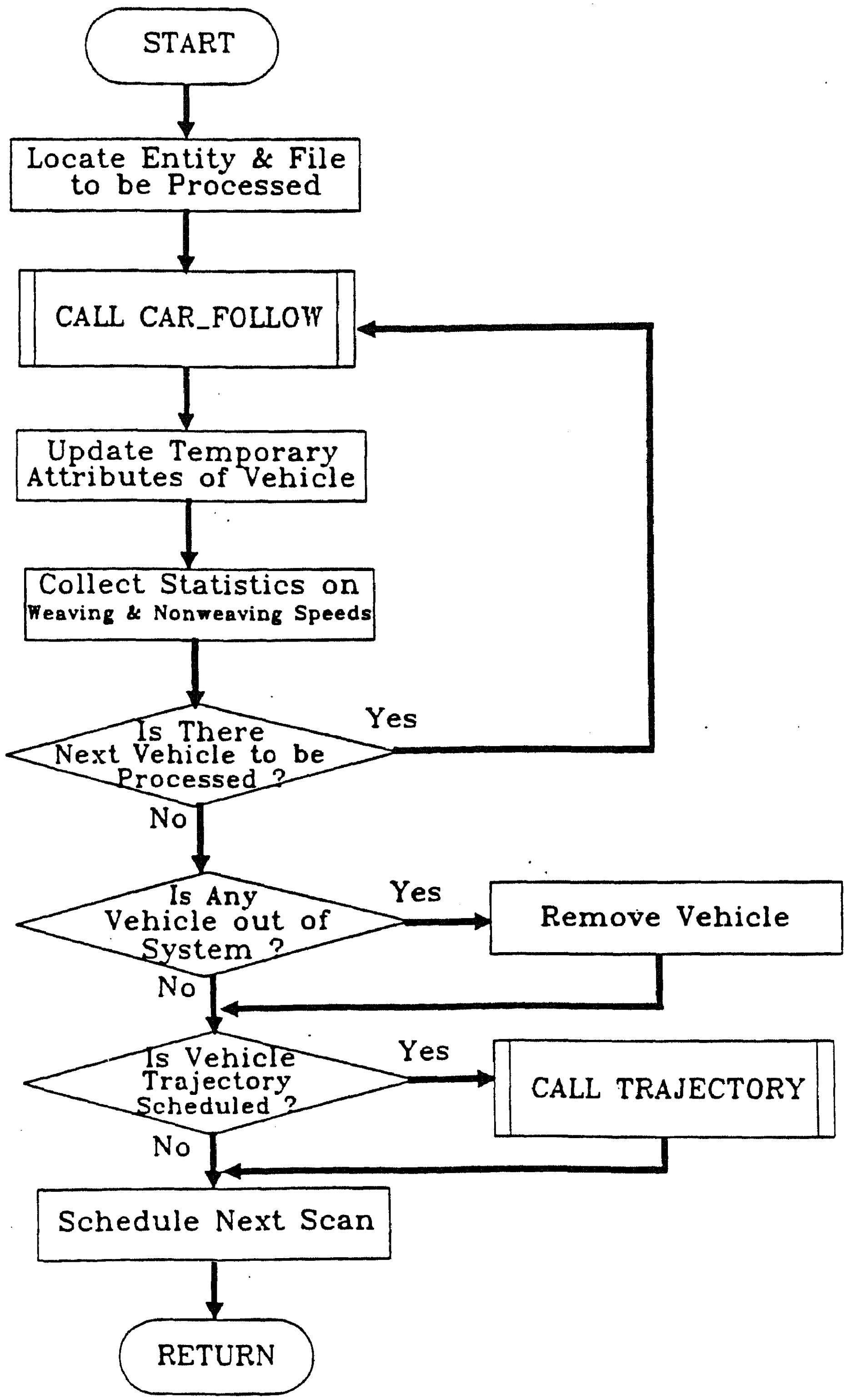


Figure 5.12 Flowchart of Subroutine SCAN

A new lane is determined and assigned to all weaving vehicles by calling subroutine LANE_CHANGE. At user specified time intervals vehicle trajectories are collected and plotted for each lane. Finally, for all the vehicles that have passed the system exit point, data on measures of effectiveness are collected. Exiting vehicles are removed from the system.

SUBROUTINE CAR_FOLLOW

This subroutine updates the speed and position of each vehicle by computing the maximum possible acceleration that a following vehicle can maintain in order to avoid collision with a leading vehicle. The new positions and speeds are computed based on the car-following algorithm discussed in section 5.3.4. Statistics on headway distribution, speed distribution, and acceleration distribution are collected. Figure 5.13 presents the flowchart of the subroutine.

SUBROUTINE ACCELERATION

This subroutine computes the acceleration/deceleration of a vehicle based on the car following algorithm. Figure 5.14 presents the flowchart of the subroutine. First, the leader vehicle is located. If there is no leader, the vehicle is treated as independent and its updated acceleration is computed based on its current speed, longitudinal grade, and vehicle type. If the vehicle has a leader, the two speeds are compared and control is passed to the appropriate algorithm.

The updated acceleration computed based by the car following algorithm is compared with a vehicle specific limiting acceleration. If the computed acceleration violates the limitation, then the limiting condition applies.

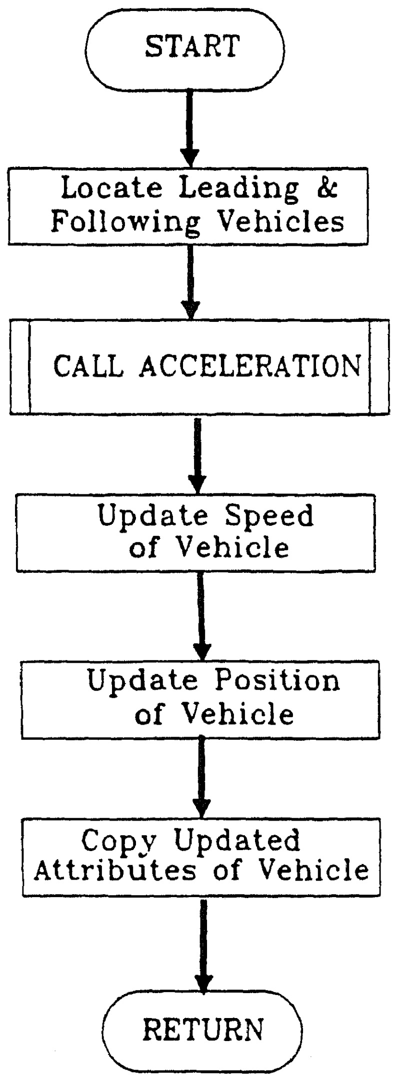


Figure 5.13 Flowchart of Subroutine CAR_FOLLOW

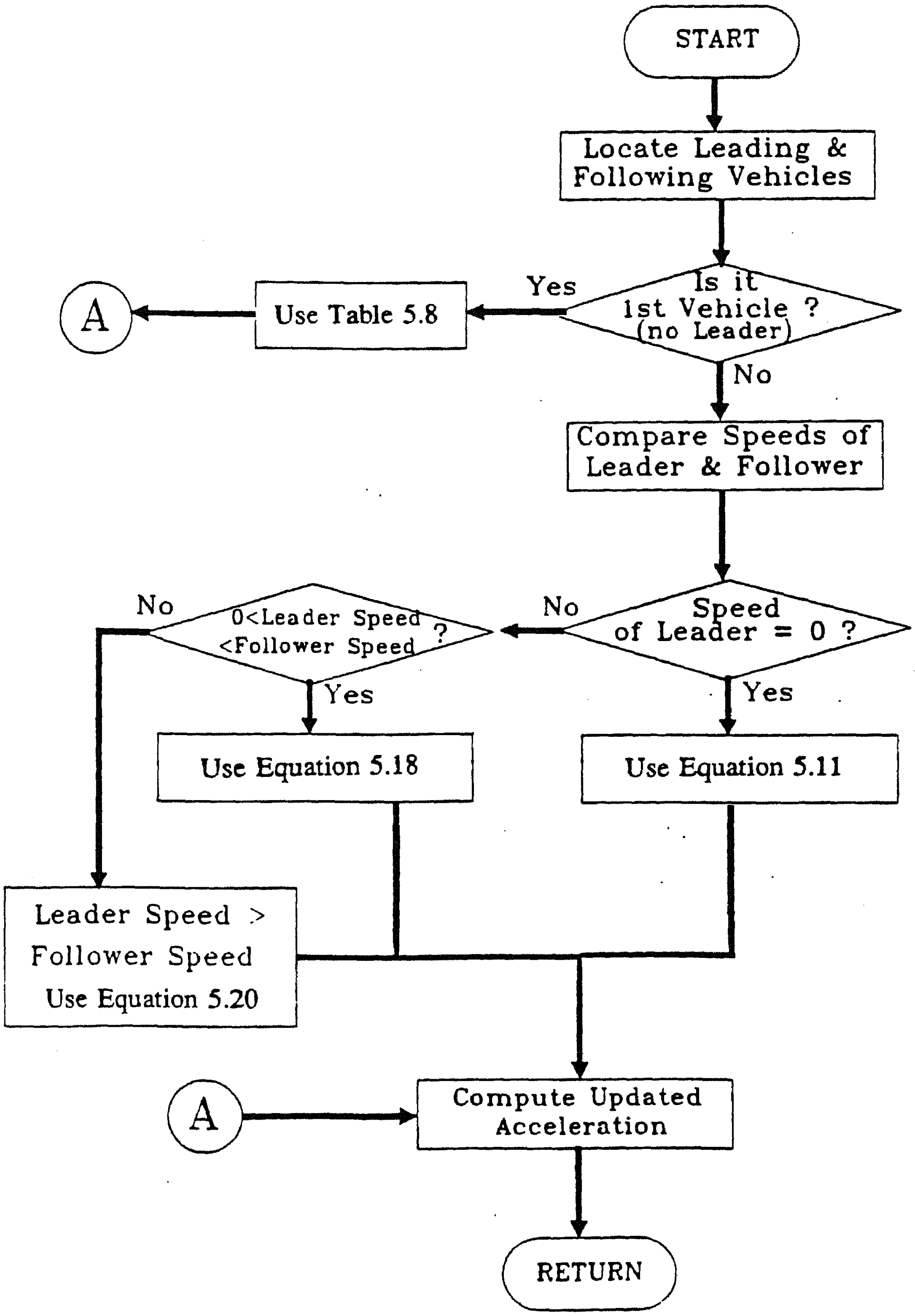


Figure 5.14 Flowchart of Subroutine ACCELERATION

SUBROUTINE LANE_CHANGE

This subroutine is used by the weaving vehicles to perform lane change maneuvers. The lane-change algorithm is described in section 5.3.5. This subroutine is called from subroutine CAR_FOLLOW if the vehicle is weaving and has not yet changed lane.

For a weaving vehicle, subroutine TEST_GAP is called to locate leader and follower of the changer in the target lane. The acceptable lead, lag, and critical gaps are updated based on the position of the changer with respect to the exit gore and then compared with the available lead, lag, and critical gaps. If the required gaps are available in the adjacent lane for the changer, the lane change maneuver is performed and the system status is updated. If the required gaps are not available, the speed and position of the changer are adjusted to improve the possibility of lane change in the future scans.

SUBROUTINE OUTPUT

Subroutine OUTPUT is called at the end of each simulation run. It is used to perform non-standard end-of-run processing and output reporting. This subroutine collects and prints statistics over simulation runs and computes and prints the level of service.

CHAPTER VI

SIMULATION MODEL VERIFICATION, SENSITIVITY ANALYSIS, AND VALIDATION

6.1 Introduction

Verification and sensitivity analysis focus on the internal consistency of a model. Verification is the process of determining whether the operational logic of the model (the computer program) corresponds to the flow chart logic. Verification includes writing the computer code to represent the model and debugging the code so that it runs to a normal termination. Sensitivity analysis is used to verify the realism of the model's results by varying the values of some input variables whose effects on the model's output are known. The objective of the sensitivity analysis is to identify the sensitive input parameters so that special care can be taken in estimating them more closely.

The following three stage approach for verification and validation of a model is suggested by Torress, J. F., et al, 1983:

- The face validity of the model should be established by a sensitivity analysis to see if the model behaves in the expected way when one or more input variables are changed.
- An attempt should be made to verify the model assumptions.
- A comparison of the input-output transformation of the model to those of the real world system should be made to see if the model represents the actual system closely enough.

Several simulation runs were made using the developed model for the purpose of testing the sensitivity of some input parameters on a number of the system's performance measures. Each submodel was tested to see if it works properly, and the overall model was executed under different conditions to investigate input and output relations. The program was debugged first to eliminate any coding errors and programming problems. Then, the logic of different components of the model, such as car-following, lane-changing, merging, and diverging were carefully reviewed. The acceleration and deceleration patterns, speed change patterns, trajectory plots, and headways obtained form the simulation model were carefully examined. The sensitivity of these parameters to changes in the input variable was studied.

6.2 Model Verification

The internal debugging and verification of the model was performed by making extensive use of the WRITE (NPRNT, *) command in the computer program, where NPRNT denotes the output device. This command causes the print out of all user specified parameters in the intermediate report. The command is used before and after any update in the system's status is expected. The process of model verification was further simplified by using the internal capabilities of the SLAM II processor.

The SLAM II processor interprets each input statement and performs extensive checks for possible input errors. If the variable ILIST on the GEN statement is specified as YES or defaulted, the processor prints out a listing of the input statements. Each statement is assigned a line number and if an input error is detected an error message is printed immediately following the statement where the error occurred.

The Trace Report is initiated by the MONTR statement using the TRACE option and causing a report summarizing each entry arrival event to be printed during execution of the simulation. The Trace Report generates a detailed account of the progress of a simulation by printing for each entry arrival event, the event time, and the attributes of the arriving entity.

6.2.1 Verifying the Logical Model

For the main program and each of the subprograms flow charts were developed that contain the logical representation of the model. Some of these flow charts were presented in Chapter 5. The verification of the logical model (flow charts) is performed by insuring that the events within the model are processed correctly, the mathematical formulas and relationships in the model are valid, and the statistics and measures of performance are calculated correctly.

6.2.2 Verifying the Computer Model

To verify the computer model, structured programming, simulation tracing, program testing, and logical relationship checks were used extensively. In addition, a comparison with the analytical models was made, and graphics were used to detect any unrealistic results in the statistics of measures of effectiveness.

6.2.2.1 Comparison to Analytic Models

The output of the simulation model, under certain conditions, was compared to the analytical models to get an indication of whether the simulation model is correct.

Average speeds and level of services obtained by the two techniques were compared to verify the results of the simulation model. For example, the following input data (similar to what was collected form LIE Exit 30 N site) was used to study the results obtained by both, simulation and analytical models:

Approach A Volume = 1000 vph with 65% weaving

Approach B Volume = 1100 vph with 100% weaving

Proportion of Trucks = 0.03

Proportion of Trailer Combinations = 0.01

Type of Terrain = Level (0% vertical grade)

Table 6.1 summarizes the results obtained form the two models. The results indicate that the behavior of the two models is similar.

6.2.2.2 Graphics

Graphics are used as a tool for both verifying the computer model and interpreting the simulation output. Statistics collected on all measure of effectiveness were plotted to detect any unrealistic results. For example, Figures 6.1 and 6.2 present the histograms of driver's brake reaction times, and vehicle arrival headways respectively, that were generated by the simulation program. Driver's brake reaction times were calibrated based on previous research (Johansson, Gunnar and Rumar, Kare, 1971) and were generated from a gama distribution with a minimum of 0.25 sec. and a maximum of 1.6 sec. Arrival headways were calibrated based on field data and were generated form a lognormal distribution with a minimum of 0.6 sec. and a maximum 12 sec. The histograms of both Figures 6.1 and 6.2 are truncated as expected and have the shape of

Table 6.1 Comparison of Simulation and Analytical Models' Results

Measure of Performance	Analytical Model	Simulation Model
Average Weaving Speed (mph)	31.69	31.01
Average Non-Weaving Speed (mph)	29.89	28.02
LOS for Weaving Speed	D	D
LOS for Non-Weaving Speeds	E	E

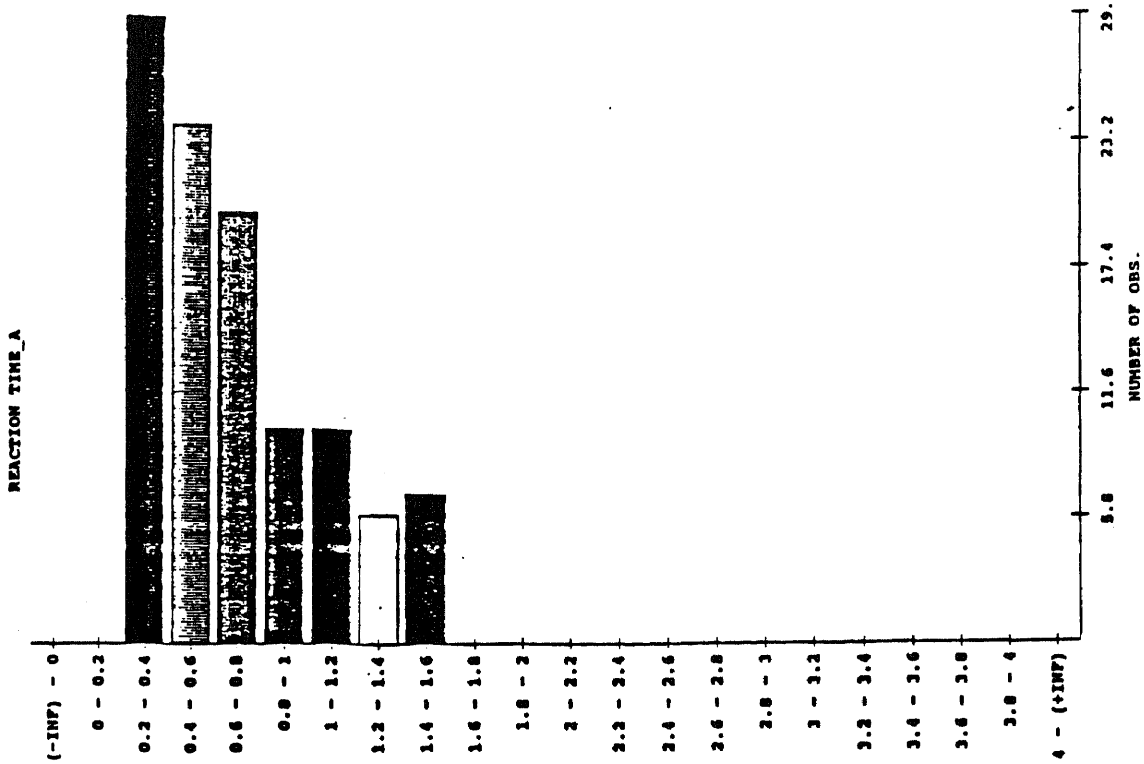


Figure 6.1 Histogram of Driver's Reaction Times (sec.)

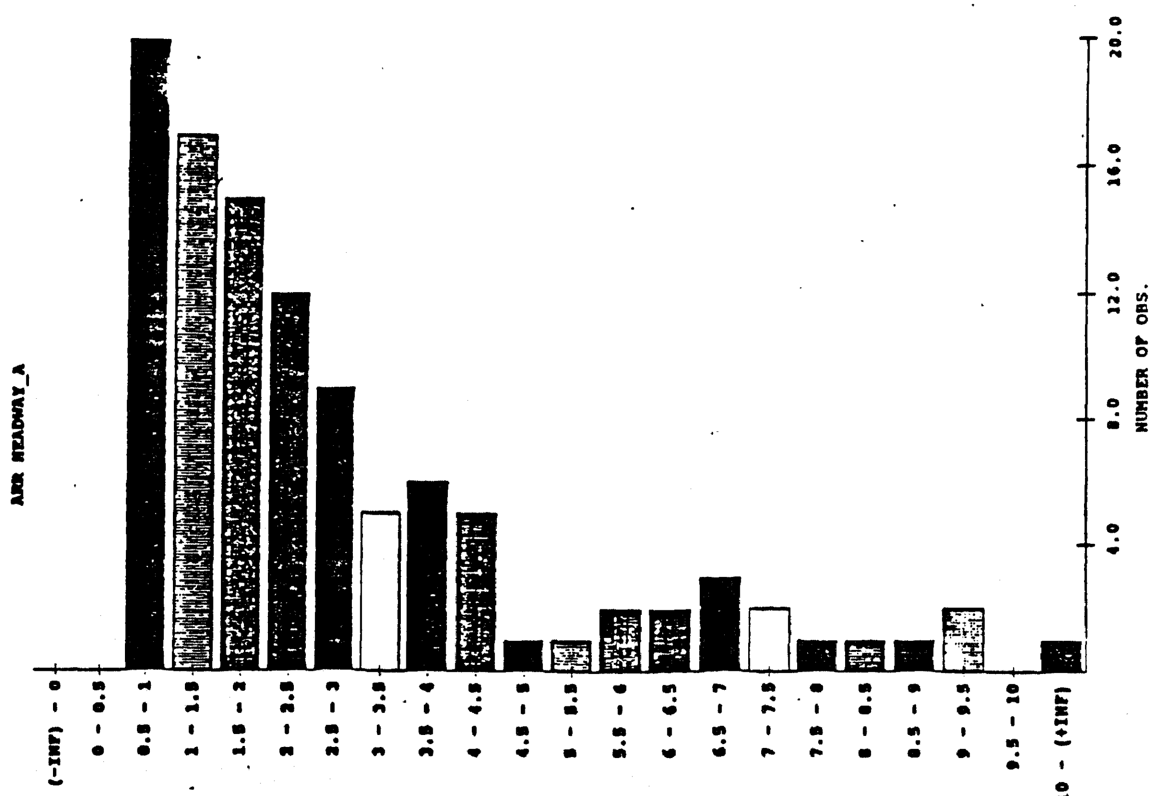


Figure 6.2 Histogram of Vehicle Arrival Headways (sec.)

the required distributions. All other measures of effectiveness were checked from their respective histograms.

6.3 Sensitivity Analysis

Sensitivity analysis is used to verify the realism of the model's results by varying the values of some input variables whose effects on the model's output are known. This exercise enables the analyst to identify the sensitive input parameters so that special care is taken in estimating them more closely. The sensitivity analysis of NFWSIM was performed by focusing on and testing the following variables:

- Driver's Brake Reaction Time (BRT - sec.)
- Maximum Emergency Deceleration Rate (DEC_MAX - mph/s)
- Traffic Composition (% Heavy Vehicles)

Numerous simulation runs were made the response variables used to study the model's sensitivity were the average weaving and non-weaving speeds. In some cases additional response variables (such as arrival headways, mean space headways, average weaving and non-weaving acceleration) were used based on the type of the variable being studied. To provide similar operating conditions for most of the variables, the following input data were used that were classified into two categories:

1. Data that Remained Unchanged for the Study of all Variables

Simulation run time	= 300 sec.
Warm-up period	= 60 sec.
Upstream buffer length	= 100 ft.
Downstream buffer length	= 200 ft.

Random number seed = 1

2. <u>Data that Remained Unchanged for the Study of Most of the Variables</u>

Approach A Volume	= 1000 vph with 52% weaving
Approach B Volume	= 950 vph with 100% weaving
Percent of Trucks	= 5
Percent of Trailers	= 3
Length of Weaving Section	= 302 ft.
Vertical grade of section	= 0%

The following sub-sections present the results of sensitivity analysis for each variable.

6.3.1 Driver's Brake Reaction Time (BRT)

As indicated earlier, driver's brake reaction times are generated in NFWSIM from a gama distribution with a mean of 0.75 sec. and a standard deviation of 0.5 sec. The results were truncated with a minimum of 0.25 sec. and a maximum of 1.6 sec. Brake reaction time has a significant effect on the vehicle's acceleration/deceleration and thereby on its speed.

Several experiments were performed by varying driver's mean brake reaction time in a range of 0.5 to 0.95 sec. Vehicles' average weaving and non-weaving speeds and average space headways were used as response variables to study the effect of variation in mean BRT. BRT is used in the CAR_FOLLOW and ACCELERATION subroutines to compute updated speeds and acceleration of vehicles. It is obvious from the logical relations employed in NFWSIM that if the mean BRT is increased, mean space headway should increase and average speeds should decrease. This trend was indeed verified by the results of the simulation runs that are presented in Table 6.2.

Table 6.2 shows that changing BRT form 0.5 to 0.95 sec. results in an 18% decrease in mean weaving speeds, 19% decrease in mean non-weaving speeds, and 18.5% increase in mean space headways. The fact that the change in the weaving and non-weaving speeds is almost equal is attributed to the reason that NFWSIM is developed for basic weave, and a change in the speed of lane-changing vehicles will result in corresponding change in the speed of a non-weaving vehicles also. This finding was further verified from the field data and is reflected in the Level of Service (LOS) criteria established for non-freeway weaving areas and presented in Chapter 4.

6.3.2 Maximum Emergency Deceleration Rate (DEC_MAX)

The maximum emergency deceleration rate as computed in section 5.3.3 for non-freeway weaving conditions is -13.2 mph/sec. Average weaving and non-weaving speeds were selected as response variables to study the sensitivity of DEC_MAX and the results are presented in Table 6.3. DEC_MAX varied from -10 mph/sec. to -15 mph/sec.

DEC_MAX is used in the stopping sight distance computations of subroutine ACCELERATION. Logically, an increase in the maximum emergency deceleration rate should decrease the average weaving and non-weaving speeds and vice versa. Although this was verified by the simulation results, the affect was not significant (elasticity is about -0.12).

Table 6.2 Results of Sensitivity Analysis for Driver's Brake Reaction Time

Average Brake Reaction Time (sec.)	Mean Speed		Mean Space Headway (ft.)
	Weaving (mph)	Non-Weaving (mph)	
0.50	36.26	37.31	92.7
0.60	35.23	36.12	95.3
0.70	33.97	34.63	98.4
0.75	32.31	32.96	101.3
0.80	31.98	32.27	103.2
0.90	30.58	31. 36	109.5
.95	29.67	30.12	110.0

Table 6.3 Results of Sensitivity Analysis for Maximum Emergency Deceleration Rate

Maximum Emergency Deceleratio (mph/s)	Average Speed	
	Weaving (mph)	Non-Weaving (mph)
-10.0	34.81	35.29
-13.2	34.26	34.72
-15.0	32.70	33.10

6.4 Model Validation

When the computer simulation model is properly calibrated and has been verified the next step is to determine if its output is an accurate, and therefore valid, representation of the real system. Several approaches have been recommended in the literature on how to validate simulation models. Comparing the performance measures generated by the simulation model to the equivalent performance measures taken form the real system is the most often used approach of validating a simulation model.

6.4.1 Comparison of Model Output to the Real System

The comparison between the model output and the field results is a statistical comparison and the difference in performance measures must be tested for statistical significance. A 95% confidence interval is used for all statistical comparisons. **Mann-Whitney U** and **Mean Tests** of the TRANSTAT software were used to perform the distribution comparisons. In addition, summary statistics and cumulative frequency plots were generated.

The following traffic parameters were targeted for comparison:

- Arrival headway distributions
- Arrival speed distributions
- Weaving speed distributions
- Non-weaving speed distributions
- Merging point distributions

To get a more accurate estimate of the performance measures, five independent replications were made for each traffic condition using different random number seeds.

The following observed data were selected to perform the comparison:

1. High Volume

Site:	Exit 30 N on Long Island Expressway (AM)
Weaving Section Length:	302 ft.
Approach A Volume	1637
Approach B Volume	1714
Weaving from Approach A	60%
Weaving from Approach B	100%
Percent of Trucks	3%
Percent of Trailers	2%

2. Medium Volume

Site:	Newark Airport Site
Weaving Section Length:	329 ft.
Approach A Volume	1521
Approach B Volume	1149
Weaving from Approach A	80%
Weaving from Approach B	60%
Percent of Trucks	4%
Percent of Trailers	2%

3. Low Volume

Site:	Exit 30 N on Long Island Expressway (PM)
Weaving Section Length:	302 ft.
Approach A Volume	831

Approach B Volume	1145
Weaving from Approach A	65%
Weaving from Approach B	100%
Percent of Trucks	4%
Percent of Trailers	1%

6.4.1.1 High Volume Site

Statistical test results for Exit 30 N on Long Island Expressway (AM) are presented in the subsequent sections. No comparison of non-weaving speeds and non-weaving accelerations could be performed due to very small sample size obtained from the observed data.

A. Arrival Headway Distributions

There was excellent agreement between the observed and simulated arrival headways and statistical tests revealed no significant difference between the mean values of the distributions. Table 6.4 presents the results of statistical tests of the comparison, and Figure 6.3 presents cumulative frequency plot of the simulated and observed distributions.

B. Arrival Speed Distributions

As indicated in Table 6.5, the Rank Sum test output revealed no significant difference between the observed and simulated arrival speed distributions. However, the Mean test revealed a significant statistical difference between the distributions. Figure 6.4 presents the cumulative frequency plot of the two distributions.

Table 6.4 Results of Statistical Tests of Comparison of Simulated Versus Observed Arrival Headway Distributions (Site: LIEAM - High Volume)

SUMMARY STATISTICS
Arrival Headway (Second - LIEAM)

	Simulated Data	Field Data
NO. OF OBSERVATIONS	115	112
MINIMUM OBSERVATIONS	0.6000	0.8800
MAXIMUM OBSERVATIONS	12.0000	11.5322
SAMPLE MEAN	2.6002	2.6844
5 % TRIMMED MEAN	2.6118	2.8556
BROADENED MEAN	1.6925	2.1486
SAMPLE MEDIAN	2.0960	2.1451
LOWER FOURTH	1.2629	1.2622
UPPER FOURTH	3.0783	3.3253
STANDARD DEVIATION	2.0056	1.9965
SAMPLE MODE	0.6000	0.8800
COEFF. OF SKEWNESS	2.1827	1.9131
COEFF. OF KURTOSIS	8.8002	7.1300
COEFF. OF VARIATION	0.7713	0.7437

RANK SUM TEST OUTPUT
COMPARING: hlam.sim (Simulated Data)
WITH: hlam.fld (Field Data)

VALUE OF TEST STATISTIC = 0.4790861

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

MEANS TEST OUTPUT
COMPARING: hlam.sim (Simulated Data)
WITH: hlam.fld (Field Data)

VALUE OF TEST STATISTIC = -1.192404

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

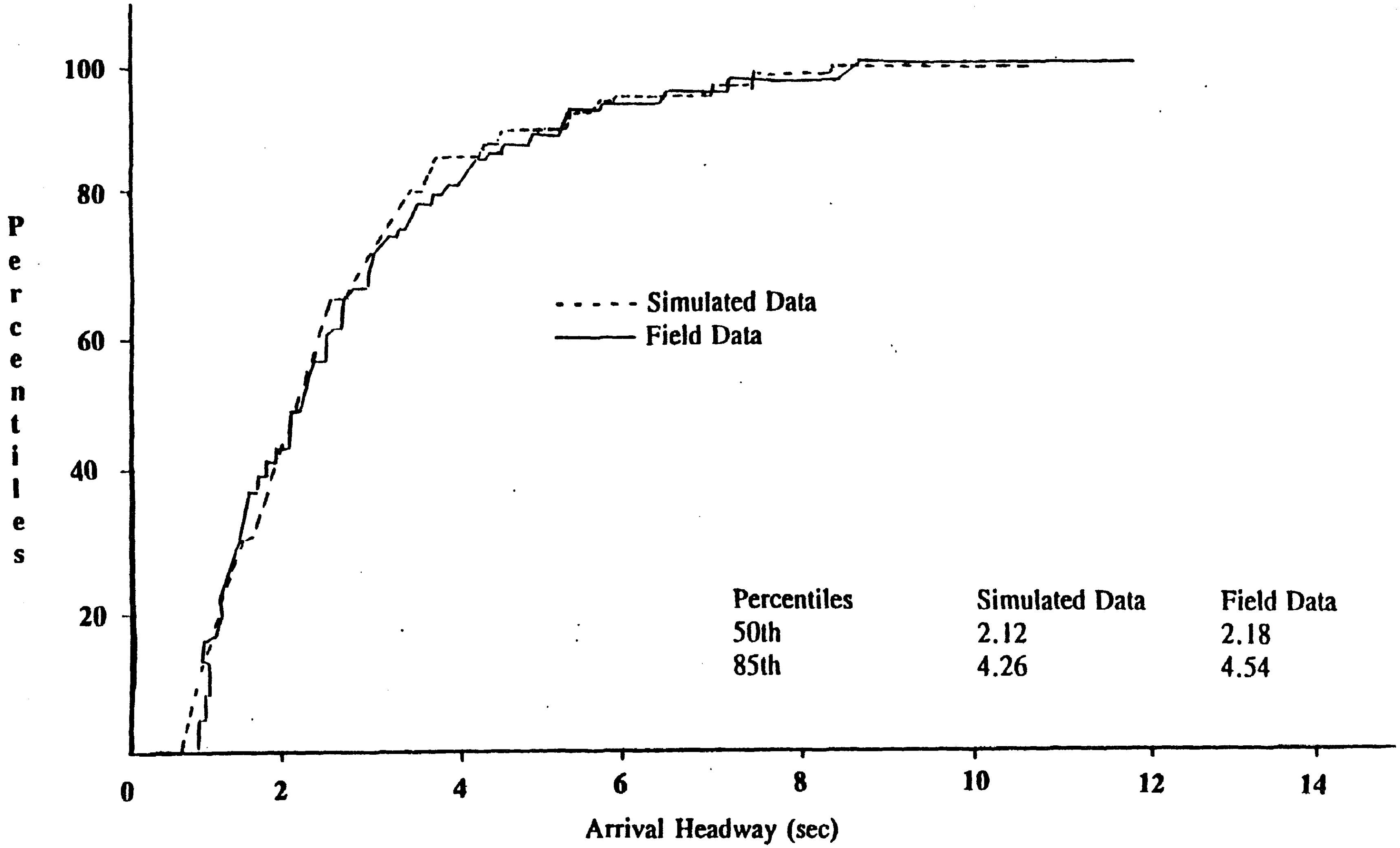


Figure 6.3 Cumulative Frequency Plot of Simulated Versus Observed Arrival Headway Distributions (Site: LIEAM - High Volume)

Table 6.5 Results of Statistical Tests of Comparison of Simulated Versus Observed Arrival Speed Distributions (Site: LIEAM - High Volume)

SUMMARY STATISTICS
Arrival Speed (mph - LIEAM)

	Simulated Data	Field Data
NO. OF OBSERVATIONS	115	63
MINIMUM OBSERVATIONS	15.0000	19.6842
MAXIMUM OBSERVATIONS	39.8004	49.0729
SAMPLE MEAN	27.1806	28.3306
5 % TRIMMED MEAN	27.3205	28.1635
BROADENED MEAN	21.7459	22.4887
SAMPLE MEDIAN	27.1269	27.9699
LOWER FOURTH	23.3590	25.9943
UPPER FOURTH	30.6035	29.9606
STANDARD DEVIATION	4.7282	4.5409
SAMPLE MODE	15.0000	19.6842
COEFF. OF SKEWNESS	0.0629	1.5747
COEFF. OF KURTOSIS	2.6386	8.9584
COEFF. OF VARIATION	0.1740	0.1603

RANK SUM TEST OUTPUT
COMPARING: aslam.sim (Simulated Data)
WITH: aslam.fld (Field Data)

VALUE OF TEST STATISTIC = 1.352125

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

MEANS TEST OUTPUT
COMPARING: aslam.sim (Simulated Data)
WITH: aslam.fld (Field Data)

VALUE OF TEST STATISTIC = -2.204294

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
REASONABLE EVIDENCE THAT DISTRIBUTIONS DIFFER

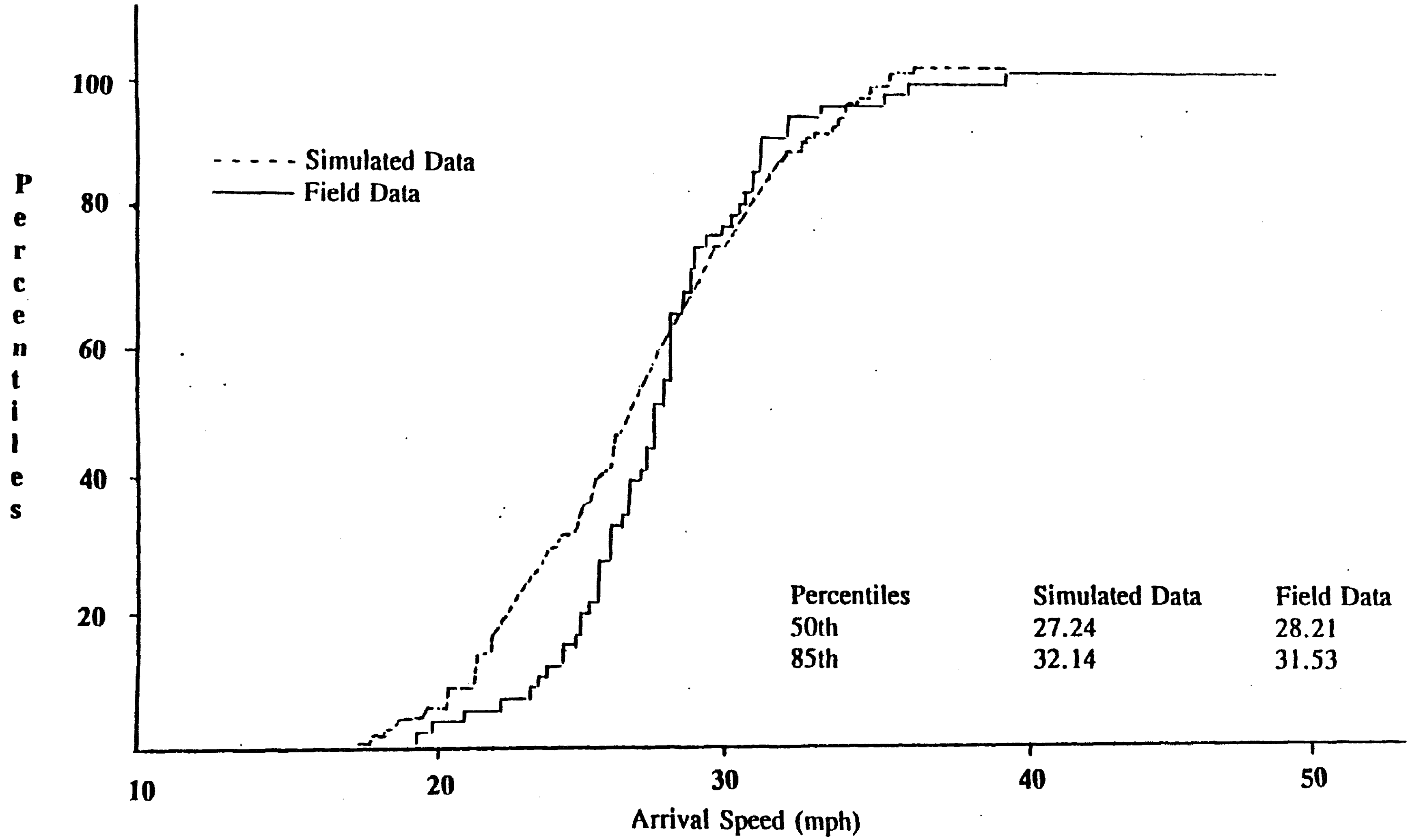


Figure 6.4 Cumulative Frequency Plot of Simulated Versus Observed Arrival Speed Distributions (Site: LIEAM - High Volume)

C. Weaving Speed Distributions

The results of the comparison between simulated and observed weaving speeds is presented in Table 6.6, and as it indicated, there is good agreement between the simulation output and field data. Graphical plots of the cumulative distributions are presented in Figure 6.5.

D. Merging Point Distributions

The statistical test results presented in Table 6.7 show good agreement between the simulated and observed merging point distributions. Figure 6.6 presents the cumulative frequency plot of the two distributions.

6.4.1.2 Medium and Low Volume Sites

The comparison tests performed for the weaving and nonweaving speeds and their results are summarized in Table 6.8.

The test results indicate that the observed and simulated measures of effectiveness are in close agreement and the model is valid.

Table 6.6 Results of Statistical Tests of Comparison of Simulated Versus Observed Weaving Speed Distributions (Site: LIEAM - High Volume)

SUMMARY STATISTICS
Weaving Speed (mph - LIEAM)

	Simulated Data	Field Data
NO. OF OBSERVATIONS	1764	349
MINIMUM OBSERVATIONS	0.0000	0.0000
MAXIMUM OBSERVATIONS	54.5422	59.8910
SAMPLE MEAN	25.0127	25.4478
5 % TRIMMED MEAN	25.7535	25.5234
BROADENED MEAN	24.7508	19.3398
SAMPLE MEDIAN	24.7589	24.1210
LOWER FOURTH	16.3336	17.7300
UPPER FOURTH	33.2560	32.3830
STANDARD DEVIATION	11.9821	12.3264
SAMPLE MODE	0.0000	0.0000
COEFF. OF SKEWNESS	0.1213	0.4729
COEFF. OF KURTOSIS	2.5033	3.1807
COEFF. OF VARIATION	0.4790	0.4844

RANK SUM TEST OUTPUT
COMPARING: wslam.sim (Simulated Data)
WITH: wslam.fld (Field Data)

VALUE OF TEST STATISTIC = 0.1155159

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

MEANS TEST OUTPUT
COMPARING: wslam.sim (Simulated Data)
WITH: wslam.fld (Field Data)

VALUE OF TEST STATISTIC = -0.8419305

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

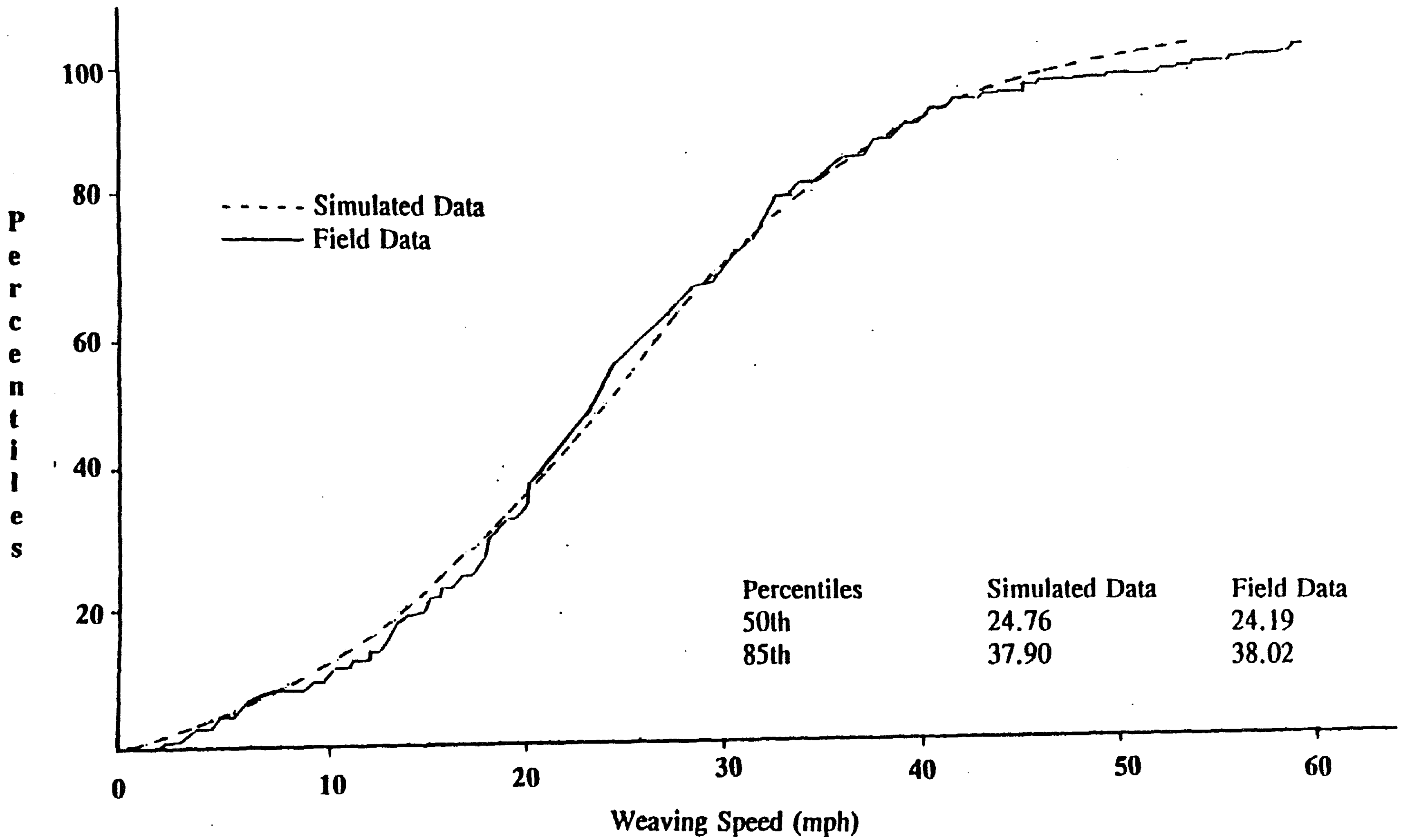


Figure 6.5 Cumulative Frequency Plot of Simulated Versus Observed Weaving Speed Distributions (Site: LIEAM - High Volume)

SUMMARY STATISTICS
Merging Point (ft - LIEAM)

	Simulated Data	Field Data
NO. OF OBSERVATIONS	260	45
MINIMUM OBSERVATIONS	16.1835	25.5430
MAXIMUM OBSERVATIONS	221.7147	255.8660
SAMPLE MEAN	114.6540	121.5389
5 % TRIMMED MEAN	114.3107	116.6979
BROADENED MEAN	112.8168	102.8380
SAMPLE MEDIAN	113.2867	128.5250
LOWER FOURTH	62.1552	68.8230
UPPER FOURTH	163.4868	157.7450
STANDARD DEVIATION	59.3848	59.0559
SAMPLE MODE	16.1835	25.5430
COEFF. OF SKEWNESS	0.1148	0.1228
COEFF. OF KURTOSIS	1.8668	2.2492
COEFF. OF VARIATION	0.5179	0.4859

RANK SUM TEST OUTPUT
COMPARING: mlam.sim (Simulated Data)
WITH: mlam.fld (Field Data)

VALUE OF TEST STATISTIC = 0.7469597

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

MEANS TEST OUTPUT
COMPARING: mlam.sim (Simulated Data)
WITH: mlam.fld (Field Data)

VALUE OF TEST STATISTIC = -7.560293E-02

ALPHA	CRITICAL VALUE (MOD)
0.01	2.57
0.05	1.96
0.10	1.51

BASED ON THE ABOVE INFORMATION, THERE IS
LITTLE EVIDENCE THAT DISTRIBUTIONS DIFFER

Table 6.7 Results of Statistical Tests of Comparison of Simulated Versus Observed Merging Point Distributions (Site: LIEAM - High Volume)

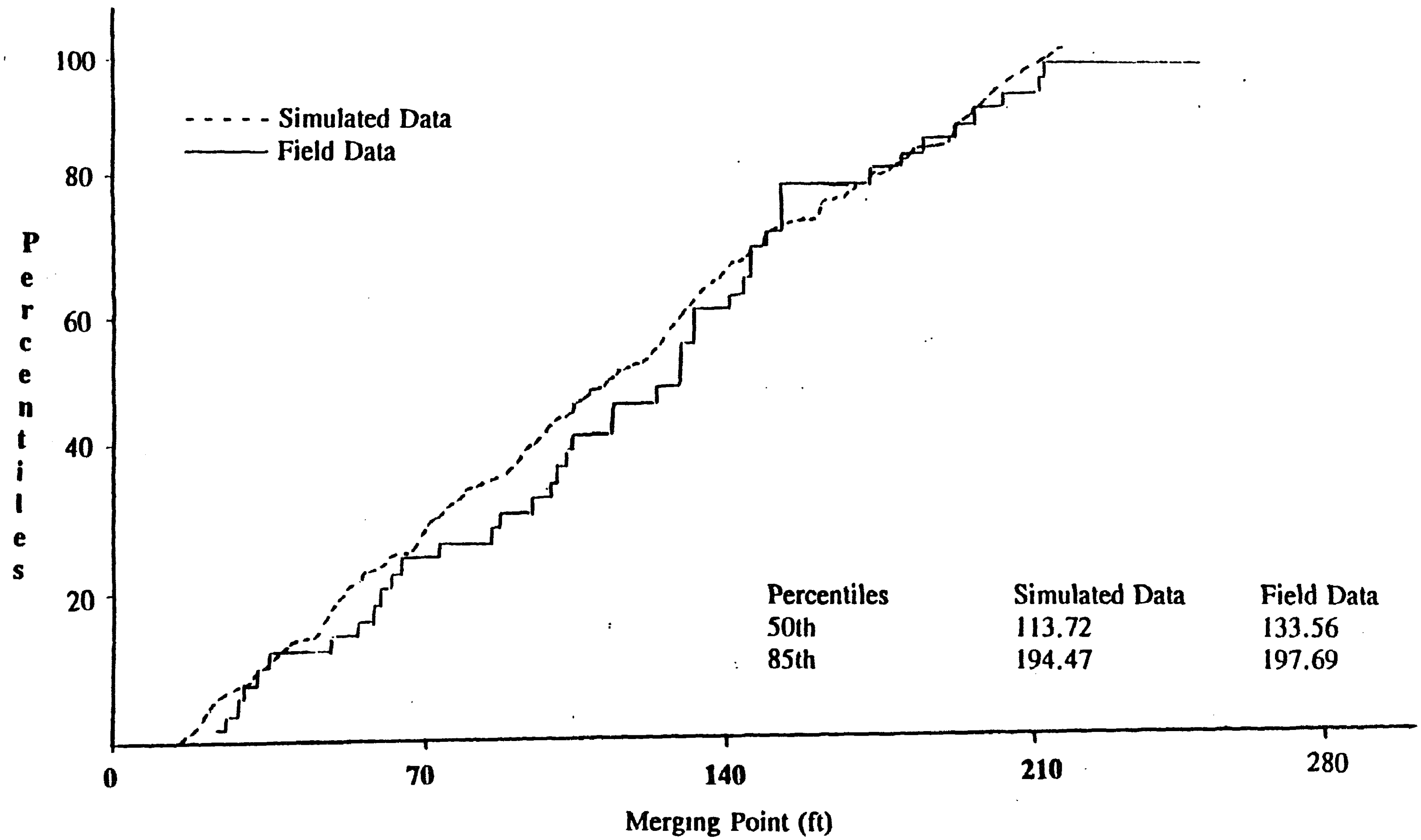


Figure 6.6 Cumulative Frequency Plot of Simulated Versus Observed Merging Point Distributions (Site: LIEAM - High Volume)

Table 6.8 Comparison Test Results for Medium and Low Volume Sites

Measure of Effectiveness	Medium Volume Site						Comparison Test (95% Confidence)	
	Simulated Data			Field Data				
	Mean	Standard Deviation	No. of Observations	Mean	Standard Deviation	No. of Observations	Rank Sum	Means
Weaving Speeds	33.21	10.68	1151	32.95	11.20	132	Pass	Pass
Non-Weaving Speeds	34.64	9.95	350	34.75	10.59	42	Pass	Pass
Measure of Effectiveness	**Low Volume Site**						**Comparison Test (95% Confidence)**	
	Simulated Data			Field Data				
	Mean	Standard Deviation	No. of Observations	Mean	Standard Deviation	No. of Observations	Rank Sum	Means
Weaving Speeds	32.53	10.71	940	33.74	10.62	140	Pass	Pass
Non-Weaving Speeds	32.28	11.01	164	31.54	11.56	68	Pass	Pass

CHAPTER VII

SUMMARY AND CONCLUSIONS

7.1 Summary

The Highway Capacity Manual covers adequately the operation of weaving areas on freeways. Weaving on non-freeway facilities, however, has not been addressed as yet. An extensive search and site visit effort indicated that the vast majority of non-freeway weaving situations can be classified into two broad categories: 1) Basic weave and 2) Ramp weave.

This dissertation presented: 1) A new analytical procedure for the analysis of the level of service and operation of both categories of non-freeway weaving and 2) A simulation model for the study of the dynamics of traffic flow for basic weave only.

The analytical models for non-freeway weaving were calibrated and validated based on the data obtained from several sites selected in the states of New Jersey and New York. Separate level of service criteria and capacities were established for each weaving category. A FORTRAN program is written that automatically computes speeds and LOS for weaving and non-weaving vehicles based on input volumes and weaving section geometry.

Traffic operations on weaving areas are a typically complex system. Intense lane-changing maneuvers at weaving sections create turbulence that often leads to congestion. A comprehensive review of the literature on existing simulation models revealed that although some simulation models like INTRAS, FRESIM, and WEAVESIM could be applied to study freeway weaving operations, no attempt was made to simulate the traffic operations on non-freeway weaving areas before.

To understand the microscopic traffic behavior at non-freeway weaving sections, a realistic microscopic simulation model (NFWSIM) was developed in the SLAM II simulation programming language. For the calibration of NFWSIM, self written simple computer programs were used to reduce data. For the reduction and validation data, an innovative video-photogrammetry and image processing technique was used. This technique, currently at its developmental stage, generated data 50 percent of which were unrealistic. As a result of data filtering and truncation, a small sample size was available to perform the validation of the model at the microscopic level. Whereas, on the macroscopic level a large data base was used to perform the model's validation. Sensitivity analysis and validation indicated that the model behaves reasonably and reliably. The validation was based on data collected from several sites, and it was performed by using the exogenous data collected at the sites as input to the model and comparing the simulated and observed measures of effectiveness.

In NFWSIM, vehicles are generated randomly at the system entry points. Periodic updating of each vehicle's status is performed at one second intervals. The behavior of each vehicle-driver unit is represented through interactions with the surrounding environment, which consists of the geometry of the weaving area and the presence of other vehicles. Each vehicle behaves as an individual entity having a set of attributes which control its performance through the system. These attributes are assigned either stochastically or deterministically. The longitudinal movement of vehicles is controlled by a car-following algorithm, while the lateral movement is guided by a lane changing algorithm.

The model input includes some traffic characteristics, simulation parameters, and roadway parameters describing the geometry of the simulated section. The outputs of the model include: 1) An echo report of the input parameters, 2) Intermediate reports containing vehicle trajectories and level of service, and 3) A summary report which includes statistics on the measures of performance, and plots of their cumulative frequencies and histograms.

7.2 Conclusions

For the successful operation of a weaving area, the speeds of the several traffic steams (weaving and non-weaving) must be nearly equal. Uniformity of operating speeds can be obtained by proper proportioning of the geometric characteristics of the weaving area: 1) The angle of approach, 2) the length, 3) the width, and 4) the deflection angle.

The angle of approach affects the entering traffic speed, the angle of weaving, and the place of weaving. Operational angles of approach of up to 35° (physical angle of 30°) and less, work well and assure proper sight angles and easy merging maneuvers for vehicles. Drivers in this case can easily observe the other traffic stream and by slight adjustments in speed and lateral position can meet gaps needed for merging and/or lane changing. When the approach angle is greater than 30°, the minor approach vehicles tend to yield to the major approach vehicles, and in an attempt to search for a proper gap they virtually come to a halt. This situation creates considerable differences in speeds of the constituting weaving and non-weaving traffic steams, resulting in the reduction of capacity and overall level of service.

The length of the weaving section constrains the time and space in which the driver must make all required lane changes. Thus, as the length of a weaving area decreases, the intensity of lane-changing, and the resulting level of turbulence, increase.

The width of the weaving section must be sufficient to allow the traffic that is going to weave to spread out laterally, thus creating the necessary gaps between vehicles and allowing weaving to take place throughout the length and width of the weaving section. The width must also be sufficient to carry the through traffic with minimum interference with the weaving vehicles.

A higher deflection angle of the horizontal curve of a weaving section, would make the operation of weaving vehicles more complex and difficult by creating an additional steering control task for drivers. This will reduce the speeds of weaving vehicles, which in turn, will affect the overall operation of the section.

Several experiments were conducted using NFWSIM to achieve a better understanding of traffic characteristics and to identify sensitive variables for non-freeway weaving area operations. Results of model validation revealed that the observed and simulated measures of effectiveness were in close agreement and the model is valid.

7.3 Limitations and Recommendations for Future Research

The analytical models were developed for only two broad categories of non-freeway weaving. However, weaving under non-freeway conditions may occur under numerous forms. Unfortunately, it is not practical to obtain data for all possible lane configurations. Therefore, the use of the models is limited to certain lane configurations and traffic conditions.

NFWSIM was developed for basic weave only and the major portion of the calibration data for the model were obtained from Exit 30 N on Long Island Expressway site. The model could be calibrated for sites with varying operating and geometric conditions. In addition, more experiments and an extensive data collection effort would further validate the analytical as well as simulation models. Furthermore, more simulation experiments are required to test the sensitivity of NFWSIM for input parameters such as volume, composition, geometry, and upstream traffic condition. With some modifications, NFWSIM can incorporate ramp weave also.

The image processing technique employed to reduce microscopic data for the validation of the simulation model is currently at a developmental stage. Currently, the data reduction is performed by manual digitizing. This is a very time consuming and relatively unreliable process. In the future this technique can be automated and become very reliable and efficient.

APPENDIX A

CAPACITY ANALYSIS AND

LEVEL OF SERVICE PROGRAM

LISTING OF LEVEL OF SERVICE PROGRAM

```
C ************************* PREAMBLE **************************
C
C PROGRAMMER:      MUHAMMAD SHAHID IQBAL
C
C DATE:            DECEMBER, 1993
C
C PROGRAM NAME:    NFWLOS.EXE
C
C PROGRAM VERSION: 1.0
C
C ORGANIZATION:    CENTER FOR TRANSPORTATION STUDIES AND RESEARCH
C                  NEW JERSEY INSTITUTE OF TECHNOLOGY
C
C PROJECT:         LEVEL OF SERVICE ON NON-FREEWAY WEAVING AREAS
C
C CLIENT:          REGION II TRANSPORTATION RESEARCH CONSORTIUM
C
C PURPOSE:         THIS PROGRAM CALCULATES LEVEL OF SERVICE ON
C              NON-FREEWAY WEAVING AREA FOR TWO CATEGORIES OF
C              WEAVING SITUATION (BASIC WEAVE, AND RAMP WEAVE)
C              BASED ON THE FOLLOWING INPUT DATA:
C
C              1. TYPE OF WEAVING (BASIC OR RAMP)
C              2. WEAVING AND NON-WEAVING VOLUMES (VW AND VNW)
C              3. PEAK HOUR FACTOR (PHF)
C              4. NUMBER OF LANES IN THE WEAVING SECTION (N)
C              5. WIDTH OF WEAVING SECTION IN FT. (W)
C              5. LENGTH OF WEAVING SECTION IN FT. (L)
C              6. PROPORTION OF HEAVY VEHICLES (PT,PB,& PRV)
C              7. TYPE OF TERRAIN
C
C
C ************************* MAIN PROGRAM **********************
C
      PROGRAM WEAVE
C
      CHARACTER PROJECT*40, ANALYST*20, FNAME*20, CH, C
C
      INTEGER VW, VNW, TYPE, PAGE
      REAL    L
C
      COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
     +        SW, SNW, ALPHA, DELTA, CF, FLA
      COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
      COMMON/UCOM3/ PROJECT, ANALYST
C
$LARGE
$NOTRUNCATE
$DEBUG
C INITIALIZE VARIABLES (ASSIGN DEFAULT VALUES)
```

```
C
      IRUN  = 0
      PAGE  = 1
      LINE  = 0
    2 IRUN  = IRUN + 1
      TYPE  = 1
      ITERR = 1
      VW    = 600
      VNW   = 600
      N     = 2
      PHF   = 1.00
      W     = 24.0
      L     = 450.0
      ALPHA = 30.0
      DELTA = 0.0
      PT    = 0.0
      PB    = 0.0
      PRV   = 0.0
      CF    = 1.0
      FLA   = 1.0
      CALL MENU
      CALL  INPUT
      FNAME = 'RESULT.OUT'
      OPEN (2, FILE = FNAME)
      CALL HEADER
      IF (TYPE.EQ.1) GOTO 10
      CALL RAMP
      GOTO 20
   10 CALL BASIC
   20 CALL REPORT
      WRITE (*,*) ('=', J = 1, 78)
      WRITE (2,*) ('=', J = 1, 78)
      WRITE (2,22)
   22 FORMAT (//)
   25 WRITE (*,30)
   30 FORMAT (//2X, 'DO YOU WANT TO MAKE MORE RUNS (Y/N) >'\)
      READ (*, 40) CH
   40 FORMAT (A)
      IF (CH.EQ.'Y'.OR.CH.EQ.'y') GO TO 2
      IF (CH.EQ.'N'.OR.CH.EQ.'n') GO TO 50
      IF (CH.NE.'Y'.OR.CH.NE.'N'.OR.CH.NE.'y'.OR.CH.NE.'n')
     +GO TO 25
   50 CLOSE (2, STATUS = 'KEEP')
   52 WRITE (*,55)
   55 FORMAT (//2X, 'DO YOU NEED HARD COPY (Y/N) >'\)
      READ (*, 60) C
   60 FORMAT (A)
      IF (C.EQ.'Y'.OR.C.EQ.'y') THEN
      WRITE(*,*)'AT DOS PROMPT PRINT "RESULT.OUT" FILE'
      GO TO 65
      END IF
      IF (C.EQ.'N'.OR.C.EQ.'n') GO TO 65
C
      IF (C.NE.'Y'.OR.C.NE.'N'.OR.C.NE.'y'.OR.C.NE.'n') GO TO 52
```

```
  65 STOP
     END
C
C ---------------------------------------------------------------

C
C ********************** SUBROUTINE MENU *************************
C
     SUBROUTINE MENU
C
     COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
    +SW, SNW, ALPHA, DETTA, CF, FLA
     COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
C
C THIS SUBROUTINE PRINTS THE MAIN MENU
C
     WRITE (6,20)
  20 FORMAT('1',//////////////// 20X,
     + 'LEVEL OF SERVICE ON NON-FREEWAY WEAVING AREAS'
     +///////////)
C WAIT FOR A KEY TO BE PRESSED
     READ (*,*)
C
     WRITE (6,10)
  10 FORMAT('1', 'This Program is a Production of:'
    +//////,14X,
    +'THE CENTER FOR TRANSPORTATION STUDIES AND RESEARCH'
    +//, 22X, 'NEW JERSEY INSTITUTE OF TECHNOLOGY'//,27X,
    +'NEWARK, NEW JERSEY 07102'////,
    +20X,'COPYRIGHT NOVEMBER, 1993 BY CTSR, NJIT'/,
    +30X,'ALL RIGHTS RESERVED'/////,
    +' For any technical assistance contact:'//,
    +' Muhammad Shahid Iqbal',40X,'(201) 596-3355')
C
C WAIT FOR A KEY TO BE PRESSED
     READ (*,*)
     WRITE (6,30)
  30 FORMAT (//////////////////////)
     RETURN
     END
C
C
C
C ********************** SUBROUTINE INPUT *************************
C
C THIS SUBROUTINE READS USER INPUT AND DISPLAYS DEFAULT VALUES OF
C VARIABLES
C ---------------------------------------------------------------
     SUBROUTINE INPUT
C
     CHARACTER PROJECT*40, ANALYST*20
C
     INTEGER VW, VNW, TYPE
     REAL L
C
```

```
      COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
     +SW, SNW, ALPHA, DELTA, CF, FLA
      COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
      COMMON/UCOM3/ PROJECT, ANALYST
C
      WRITE (*,*) ('=', J = 1, 78)
C
      WRITE (*,5)
    5 FORMAT('1',33X,'INPUT MENU')
C
      WRITE (*,*) ('=', J = 1, 78)
C
      IF (IRUN.NE.1) GO TO 9
C
      WRITE (*,6)
    6 FORMAT (/2X,'NAME OF PROJECT (MAX. 40 CHARACTER) >'\)
      READ(*,'(A40)') PROJECT
      WRITE (*,7)
    7 FORMAT (/2X,'NAME OF ANALYST (MAX. 20 CHARACTER) >'\)
      READ(*,'(A20)') ANALYST
C
    9 WRITE (*,10) TYPE
      READ  (*,'(I2)') ITYPE
C
   10 FORMAT (/2X,'1. BASIC, 2. RAMP  <',I3,'>:'\)
      IF (ITYPE.EQ.0) GO TO 15
C
      IF (ITYPE.LT.1.OR.ITYPE.GT.2) GO TO 9
C
      TYPE = ITYPE
C
   15 WRITE (*,20) ITERR
      READ  (*,'(I2)') IITERR
C
   20 FORMAT (/2X,'1. LEVEL, 2. ROLLING, 3. MOUNTAINOUS <'
     +,I3,'>:'\)
C
      IF (IITERR.EQ.0) GO TO 25
      IF (IITERR.LT.1.OR.IITERR.GT.3) GO TO 15
C
      ITERR = IITERR
C
   25 WRITE (*,30) VW
      READ  (*,'(I6)') IVW
C
   30 FORMAT (/2X,'WEAVING VOLUME (VPH)  <',I4,'>:'\)
C
      IF (IVW.EQ.0) GO TO 35
      VW = IVW
C
   35 WRITE (*,40) VNW
      READ  (*,'(I6)') IVNW
C
   40 FORMAT (/2X,'NON-WEAVING VOLUME (VPH) <',I4,'>:'\)
C
```

```
      IF (IVW.EQ.0) GO TO 45
      VNW = IVNW
C
   45 WRITE (*,50) N
      READ  (*,'(I3)') IN
C
   50 FORMAT (/2X,'NO. OF LANES <',I2,'>:'\)
C
      IF (IN.EQ.0) GO TO 55
      N = IN
C
   55 WRITE (*,60) PHF
      READ  (*,'(F6.2)') PHF1
C
   60 FORMAT (/2X,'PEAK HOUR FACTOR <',F6.2,'>:'\)
C
      IF (PHF1.EQ.0) GO TO 65
      PHF = PHF1
C
   65 WRITE (*,70)
      READ  (*,'(F6.0)') W1
C
   70 FORMAT (/2X,'WIDTH OF WEAVING SECTION (FT) <24.0>:'\)
C
      IF (W1.EQ.0) GO TO 71
      W = W1
C
   71 WRITE (*,72)
      READ  (*,'(F6.0)') ALP1
C
   72 FORMAT (/2X,'APPROACH ANGLE (DEGREES) <30.0>:'\)
C
      IF (ALP1.EQ.0) GO TO 73
      ALPHA = ALP1
C
   73 WRITE (*,74)
      READ  (*,'(F6.0)') DEL1
C
   74 FORMAT (/2X,'DEFLECTION ANGLE (DEGREES) <0.0>:'\)
C
      IF (DEL1.EQ.0) GO TO 75
      DELTA = DEL1
C
   75 WRITE (*,80)
      READ  (*,'(F6.0)') XL
C
   80 FORMAT (/2X,'LENGTH OF WEAVING SECTION (FT) <450.0>:'\)
C
      IF (XL.EQ.0) GO TO 85
      L = XL
C
   85 WRITE (*,90)
      READ  (*,'(F3.2)') PT1
C
   90 FORMAT (/2X,'PERCENT OF TRUCKS <0>:'\)
```

```
C
      IF (PT1.EQ.0) GO TO 95
      PT = PT1
C
   95 WRITE (*,100)
      READ  (*,'(F3.2)') PB
C
  100 FORMAT (/2X,'PERCENT OF BUSES <0>:'\)
C
      WRITE (*,110)
      READ  (*,'(F3.2)') PRV1
C
  110 FORMAT (/2X,'PERCENT OF RECREATIONAL VEHICLES <0>:'\)
C
      PRV = PRV1
C
  114 WRITE (*,115)
      READ  (*,'(F6.0)') CF
C
  115 FORMAT (/2X,'1. COMMUTER SITE, 2. NOT A COMMUTER SITE <1.0>:'\)
C
      IF (CF.EQ.0.) GO TO 116
C
      IF (CF.LT.1.OR.CF.GT.2.) GO TO 114
C
  116 CF = 1.0
      IF (TYPE.EQ.2) THEN
      WRITE (*,120)
      READ  (*,'(F6.0)') FLA
C
  120 FORMAT (/2X,'1. NO LANE ADDITION FROM ON RAMP',
     +1X,'2. LANE ADDITION FROM ON RAMP <1.0>:'\)
C
      IF (FLA.EQ.0.) GO TO 121
      IF (FLA.LT.1.OR.FLA.GT.2.) GO TO 116
      END IF
C
  121 FLA = 1.0
      WRITE (*,*) ('=', J = 1, 78)
C
C WAIT FOR A KEY TO BE PRESSED
      WRITE (*,125)
      LINE = LINE + 18
  125 FORMAT (2X,'PRESS <ENTER> TO CONTINUE')
      READ (*,*)
      RETURN
      END
C
C
C ********************** SUBROUTINE HEADER ************************
C
      SUBROUTINE HEADER
C
C THIS SUBROUTINE PRINTS A HEADING ON EACH NEW PAGE
C
```

```
      INTEGER   PAGE
      CHARACTER PROJECT*40, ANALYST*20
C
      COMMON/UCOM2/IW, INW, PAGE, LINE, IRUN
      COMMON/UCOM3/ PROJECT, ANALYST
C
      CALL GETDAT (iyr, imon, iday)
C
C GETS THE DATE FROM SYSTEM CLOCK
C
      WRITE(*,10) PAGE, imon, iday, iyr
      WRITE(2,10) PAGE, imon, iday, iyr
C
   10 FORMAT(1X, 'PAGE', I4, 56X,I2,' -',I2,' -',I5/)
C
      WRITE(*,20) PROJECT, ANALYST, IRUN
      WRITE(2,20) PROJECT, ANALYST, IRUN
   20 FORMAT(2X, 'PROJECT: ',A40/, 2X, 'RUN BY : ', A20/,
     +       2X, 'RUN NO.:', I2)
C
      WRITE (*,*) ('=', J = 1, 78)
      WRITE (2,*) ('=', J = 1, 78)
C
      WRITE(*,30)
      WRITE(2,30)
C
   30 FORMAT (18X,
     +'NON-FREEWAY WEAVING CAPACITY SOFTWARE',16X,'REL. 1.0'/,18X,
     +' NEW JERSEY INSTITUTE OF TECHNOLOGY')
C
      WRITE (*,*) ('=', J = 1, 78)
      WRITE (2,*) ('=', J = 1, 78)
C
      PAGE = PAGE + 1
      LINE = LINE + 6
      RETURN
      END
C
C
C ---------------------------------------------------------------
C
C
C ************************** BASIC ********************************
C
      SUBROUTINE BASIC
C
C THIS SUBROUTINE CALCULATES WEAVING AND NON-WEAVING SPEED FOR
C BASIC WEAVE AND DETERMINES LEVEL OF SERVICE
C
C ASSIGN TRUCK, BUSES, AND RV'S FACTOR ACCORDING TO TYPE OF TERRAIN
C
      INTEGER VW, VNW, TYPE, PAGE
      REAL L
C
      COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
```

```
     + SW, SNW, ALPHA, DELTA, CF, FLA
      COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
C
      IF (ITERR.EQ.1) THEN
         ET  = 1.7
         EB  = 1.5
         ERV = 1.6
C
      ELSE IF (ITERR.EQ.2) THEN
         ET  = 4.0
         EB  = 3.0
         ERV = 3.0
C
      ELSE IF (ITERR.EQ.3) THEN
         ET  = 8.0
         EB  = 5.0
         ERV = 4.0
      END IF
C
C CALCULATE HEAVY VEHICLE FACTOR (FHV)
C
      FHV = 1 / (1+PT*(ET-1)+PB*(EB-1)+PRV*(ERV-1))
C
C CONVERT ALL TRAFFIC VOLUMES TO PEAK FLOW RATES UNDER IDEAL
C CONDITION
C
      V1  = (VW+VNW)/(PHF*FHV)
      VW1 = VW/(PHF*FHV)
C
C COMPUTE WEAVING AND NON-WEAVING SPEEDS
C
      ALPHA1 = ALPHA*0.017453292
      DELTA1 = DELTA*0.017453292

      D  = (L*COS(ALPHA1))**1.49
      E  = (N*COS(DELTA1))**4.99
      C1 = V1/N
      C2 = VW1/L
      SW =15.0+30.0/(1.0+6.02*CF*C1**0.79*C2**0.25/D)
      SNW=15.0+30.0/(1.0+5.35*CF*C2**0.37/E)
C
C DETERMINE LEVEL OF SERVICE
C
C LEVEL OF SERVICE FOR WEAVING VEHICLES
C
      IF (SW.GE.42.) IW = 1
      IF (SW.LT.42.0.AND.SW.GE.38.) IW = 2
      IF (SW.LT.38.0.AND.SW.GE.33.) IW = 3
      IF (SW.LT.33.0.AND.SW.GE.30.) IW = 4
      IF (SW.LT.30.0.AND.SW.GE.25.) IW = 5
      IF (SW.LT.25.)                IW = 6
C
C LEVEL OF SERVICE FOR NON-WEAVING VEHICLES
C
      IF (SNW.GE.45.) INW = 1
```

```
      IF (SNW.LT.45.0.AND.SNW.GE.40.) INW = 2
      IF (SNW.LT.40.0.AND.SNW.GE.35.) INW = 3
      IF (SNW.LT.35.0.AND.SNW.GE.30.) INW = 4
      IF (SNW.LT.30.0.AND.SNW.GE.25.) INW = 5
      IF (SNW.LT.25.0)                INW = 6
C
      RETURN
      END
C
C
C ************************** RAMP ********************************
C
      SUBROUTINE RAMP
C
C THIS SUBROUTINE CALCULATES WEAVING AND NON-WEAVING SPEED FOR
C BASIC WEAVE AND DETERMINES LEVEL OF SERVICE
C
C ASSIGN TRUCK, BUSES, AND RV'S FACTOR ACCORDING TO TYPE OF TERRAIN
C
      INTEGER VW, VNW, TYPE
      REAL L
C
      COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
     +SW, SNW, ALPHA, DELTA, CF, FLA
      COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
C
      IF (ITERR.EQ.1) THEN
         ET  = 1.7
         EB  = 1.5
         ERV = 1.6
C
      ELSE IF (ITERR.EQ.2) THEN
         ET  = 4.0
         EB  = 3.0
         ERV = 3.0
C
      ELSE IF (ITERR.EQ.3) THEN
         ET  = 8.0
         EB  = 5.0
         ERV = 4.0
      END IF
C
C CALCULATE HEAVY VEHICLE FACTOR (FHV)
C
      FHV = 1 / (1+PT*(ET-1)+PB*(EB-1)+PRV*(ERV-1))
C
C CONVERT ALL TRAFFIC VOLUMES TO PEAK FLOW RATES UNDER IDEAL
C CONDITION
C
      V1  = (VW+VNW)/(PHF*FHV)
      VW1 = VW/(PHF*FHV)
C
C COMPUTE WEAVING AND NON-WEAVING SPEEDS
C
      ALPHA1 = ALPHA*0.017453292
```

```
      DELTA1 = DELTA*0.017453292
      C1 = V1/N
      C2 = VW1/L
      F  = (W*COS(ALPHA1)*COS(DELTA1))**8.5
      G  = (W*COS(ALPHA1))**7.28
      SW =15.0+25.0/(1.0+5.3E+9*CF*FLA*C1**0.41*C2**0.17/F)
      SNW=15.0+40.0/(1.0+9200*CF*FLA*C1**1.75/G)
      WRITE (*,*) 'F',F,'G',G,'CF',CF,
     +'FLA',FLA,'SW',SW,'SNW',SNW
C
C DETERMINE LEVEL OF SERVICE
C
C LEVEL OF SERVICE FOR WEAVING VEHICLES
C
      IF (SW.GT.38.)                IW = 1
      IF (SW.LE.38.0.AND.SW.GE.33.) IW = 2
      IF (SW.LT.33.0.AND.SW.GE.30.) IW = 3
      IF (SW.LT.30.0.AND.SW.GE.25.) IW = 4
      IF (SW.LT.25.0.AND.SW.GE.20.) IW = 5
      IF (SW.LT.20.)                IW = 6
C
C LEVEL OF SERVICE FOR NON-WEAVING VEHICLES
C
      IF (SNW.GT.50.)                  INW = 1
      IF (SNW.LE.50.0.AND.SNW.GE.45.) INW = 2
      IF (SNW.LT.45.0.AND.SNW.GE.40.) INW = 3
      IF (SNW.LT.40.0.AND.SNW.GE.35.) INW = 4
      IF (SNW.LT.35.0.AND.SNW.GE.25.) INW = 5
      IF (SNW.LT.25.)                  INW = 6
C
      RETURN
      END
C
C
C ********************** SUBROUTINE REPORT ************************
C
      SUBROUTINE REPORT
C ----------------------------------------------------------------
C THIS SUBROUTINE PRINTS REPORT ON SCREEN AND ON USER SPECIFIED
C OUTPUT FILE
C
      CHARACTER PROJECT*40, ANALYST*20
C
      INTEGER TYPE, VW, VNW, PAGE
      REAL L
C
      COMMON/UCOM1/TYPE, VW, VNW, PHF, N, W, L, PT, PB, PRV, ITERR,
     +SW, SNW, ALPHA, DELTA, CF, FLA
      COMMON/UCOM2/ IW, INW, PAGE, LINE, IRUN
      COMMON/UCOM3/ PROJECT, ANALYST
C
      IF (TYPE.EQ.1 )      THEN
      WRITE  (*,3)
      WRITE  (2,3)
      ELSE IF (TYPE.EQ.2 ) THEN
```

```
      WRITE  (*,4)
      WRITE  (2,4)
      END IF
      IF (ITERR.EQ.1) THEN
      WRITE  (*,5)
      WRITE  (2,5)
      ELSE IF (ITERR.EQ.2) THEN
      WRITE  (*,6)
      WRITE  (2,6)
      ELSE IF (ITERR.EQ.3) THEN
      WRITE  (*,7)
      WRITE  (2,7)
      END IF
      IF (TYPE.EQ.2.AND.FLA.EQ.2.) THEN
      WRITE  (*,8)
      WRITE  (2,8)
      END IF
      IF (CF.EQ.2.) THEN
      WRITE  (*,9)
      WRITE  (2,9)
      END IF
C
    3 FORMAT (10X,
     + 'TYPE OF WEAVE                  =   BASIC')
    4 FORMAT (10X,
     + 'TYPE OF WEAVE                  =   RAMP' )
    5 FORMAT (10X,
     + 'TYPE OF TERRAIN                =   LEVEL')
    6 FORMAT (10X,
     + 'TYPE OF TERRAIN                =   ROLLING')
    7 FORMAT (10X,
     + 'TYPE OF TERRAIN                =   MOUNTAINOUS')
    8 FORMAT (10X,
     + 'LANE CONFIGURATION                =   LANE ADD. FR. RAMP')
    9 FORMAT (10X,
     + 'DRIVER POPULATION                =   NOT REG. COMM.')
C
      WRITE (*,10) VW, VNW, PHF, N, W, ALPHA, DELTA, L, PT, PB, PRV
      WRITE (2,10) VW, VNW, PHF, N, W, ALPHA, DELTA, L, PT, PB, PRV
C
   10 FORMAT (
     + 10X, 'NO. OF WEAVING VEHICLES            = ',I6/,
     + 10X, 'NO. OF NON-WEAVING VEHICLES         = ',I6/,
     + 10X, 'PHF                        = ',3X,F6.2/,
     + 10X, 'NO. OF LANES IN THE WEAVING SECTION = ',1X,I3/,
     + 10X, 'WIDTH OF WEAVING SECTION          = ',1X,F6.0, 1X,
     + ' FT.'/,
     + 10X, 'APPROACH ANGLE                  = ',1X,F6.0, 1X,
     + ' DEGREES'/,
     + 10X, 'DEFLECTION ANGLE                = ',1X,F6.0, 1X,
     + ' DEGREES'/,
     + 10X, 'LENGTH OF WEAVING SECTION          = ',2X,F6.0,
     + ' FT.'/,
     + 10X, 'PROPORTION OF TRUCKS              = ',3X,F3.2/,
     + 10X, 'PROPORTION OF BUSES               = ',3X,F3.2/,
```

```
     + 10X, 'PROPORTION OF RVS                    = ',3X,F3.2)
C
      WRITE (*,*) ('=', J = 1, 78)
      WRITE (2,*) ('=', J = 1, 78)
C
     READ (*,*)
C
     CALL HEADER
C
     WRITE (6,20) SW, SNW
     WRITE (2,20) SW, SNW
  20 FORMAT (//
     + 10X, 'WEAVING SPEED                            = '
     + ,2X,F6.2,
     + ' MPH'//,
     + 10X, 'NON-WEAVING SPEED                        = '
     + ,2X,F6.2,
     + ' MPH'/)
C
     IF (IW.EQ.1)      THEN
     WRITE (6,30)
     WRITE (2,30)
     ELSE IF (IW.EQ.2)  THEN
     WRITE (6,40)
     WRITE (2,40)
     ELSE IF (IW.EQ.3)  THEN
     WRITE (6,50)
     WRITE (2,50)
     ELSE IF (IW.EQ.4)  THEN
     WRITE (6,60)
     WRITE (2,60)
     ELSE IF (IW.EQ.5)  THEN
     WRITE (6,70)
     WRITE (2,70)
     ELSE IF (IW.EQ.6)  THEN
     WRITE (6,80)
     WRITE (2,80)
     END IF
C
     IF (INW.EQ.1)      THEN
     WRITE (6,35)
     WRITE (2,35)
     ELSE IF (INW.EQ.2) THEN
     WRITE (6,45)
     WRITE (2,35)
     ELSE IF (INW.EQ.3) THEN
     WRITE (6,55)
     WRITE (2,55)
     ELSE IF (INW.EQ.4) THEN
     WRITE (6,65)
     WRITE (2,65)
     ELSE IF (INW.EQ.5) THEN
     WRITE (6,75)
     WRITE (2,75)
     ELSE IF (INW.EQ.6) THEN
```

```
      WRITE (6,85)
      WRITE (2,85)
      END IF
C
   30 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   A')
   35 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   A'/)
   40 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   B')
   45 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   B'/)

   50 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   C')
   55 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   C'/)
   60 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   D')
   65 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   D'/)
   70 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   E')
   75 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   E'/)
   80 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR WEAVING VEHICLES        =   F')
   85 FORMAT (/10X,
     +'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES    =   F'/)
C
      RETURN
      END
```

SAMPLE OUTPUT FILE

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PROJECT: NON-FREEWAY WEAVING AREAS
RUN BY : SI
RUN NO.: 1

==

NON-FREEWAY WEAVING CAPACITY SOFTWARE REL. 1.0
NEW JERSEY INSTITUTE OF TECHNOLOGY

==

TYPE OF WEAVE	=	BASIC
TYPE OF TERRAIN	=	LEVEL
NO. OF WEAVING VEHICLES	=	600
NO. OF NON-WEAVING VEHICLES	=	600
PHF	=	0.97
NO. OF LANES IN THE WEAVING SECTION	=	2
WIDTH OF WEAVING SECTION	=	24. FT.
APPROACH ANGLE	=	30.0 DEGREES
DEFLECTION ANGLE	=	10.0 DEGREES
LENGTH OF WEAVING SECTION	=	450. FT.
PROPORTION OF TRUCKS	=	0.02
PROPORTION OF BUSES	=	0.01
PROPORTION OF RVS	=	0.00

==

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PROJECT: NON-FREEWAY WEAVING AREAS
RUN BY : SI
RUN NO.: 1

==

NON-FREEWAY WEAVING CAPACITY SOFTWARE REL. 1.0
NEW JERSEY INSTITUTE OF TECHNOLOGY

==

WEAVING SPEED	=	41.15 MPH
NON-WEAVING SPEED	=	39.88 MPH
LEVEL OF SERVICE FOR WEAVING VEHICLES	=	B
LEVEL OF SERVICE FOR NON-WEAVING VEHICLES	=	C

==

APPENDIX B

NFWSIM SIMULATION PROGRAM

LISTING AND SELECTED OUTPUT

LISTING OF SIMULATION PROGRAM

```
C  ******************************************************************************************
C ************************************NFWSIM *******************************************
C ******************NON FREEWAY WEAVING SIMULATION MODEL ******************
C **************************MODEL 1 - BASIC WEAVE ***********************************
C  ******************************************************************************************
C       NOTATION USED FOR WEAVING SECTION
C                          B ----------------------> D
C                                        X
C                          A ----------------------> C
C THE FOLLOWING GENERAL RULES WERE FOLLOWED TO DEVELOP THE MODEL:
C 1. WRITING THE MAIN PROGRAM TO DIMENSION NSET/QSET, SPECIFYING
C    VALUES FOR NNSET, NCRDR, NPRINT, AND NTAPE, AND CALLING SLAM.
C 2. WRITING THE SUBROUTINE EVENT(I) TO MAP THE USER-ASSIGNED EVENT
C    CODES ONTO A CALL TO THE APPROPRIATE EVENT SUBROUTINE.
C 3. WRITING SUBROUTINE INTLC TO INITIALIZE THE MODEL.
C 4. WRITING EVENT SUBROUTINES TO MODEL THE LOGIC FOR  THE  EVENTS  OF
C    THE MODEL.
C 5. PREPARING THE INPUT STATEMENT REQUIRED BY THE MODEL.
C  ******************************************************************************************
C ******************************MAIN PROGRAM ***************************************
C ------------------------------------------------------------------------------------------
C MAIN PROGRAM IS USED TO PERFORM THE FOLLOWING FUNCTIONS:
C 1. TO DIMENSION THE SLAM II STORAGE ARRAYS NSET AND QSET.
C 2. TO SPECIFY VALUES FOR THE SLAM II VARIABLES NNSET,  NCRDR, NPRNT,
C    AND NTAPE WHICH ARE IN THE LABELED COMMON BLOCK NAMED SCOM1.
C 3. TO CALL SUBROUTINE SLAM WHICH PROVIDES EXECUTIVE CONTROL FOR A

C    DISCRETE EVENT SIMULATION.
C ------------------------------------------------------------------------------------------
    PROGRAM MAIN
C ------------------------------------------------------------------------------------------
    DIMENSION NSET (20000)
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
   +,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
    COMMON QSET(20000)
    EQUIVALENCE(NSET(1), QSET(1))
    NNSET=20000                        ! THE DIMENSION OF NSET/QSET
    NCRDR=5                            ! INPUT DEVICE
    NPRNT=6                            ! OUTPUT DEVICE
    NTAPE=7                            ! A SCRATCH FILE (NO LONGER USED)
    CALL SLAM
    STOP
    END
C  ******************************************************************************************
    SUBROUTINE EVENT (I)
C ------------------------------------------------------------------------------------------
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
   +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C ------------------------------------------------------------------------------------------
  THIS SUBROUTINE READS THE USER-ASSIGNED EVENT CODE I AND CALL THE
C APPROPRIATE EVENT SUBROUTINE, AND EVENT ROUTINES TO SPECIFY THE
```

```
C CHANGES THAT OCCUR AT EVENT TIMES.
C THE FOLLOWING EVENT CODES ARE DEFINED IN THIS SUBROUTINE:
C 1. EVENT CODE 1 - ARRIVAL AT APPROACH A (SUBROUTINE ARRIVAL_A)
C 2. EVENT CODE 2 - ARRIVAL AT APPROACH B (SUBROUTINE ARRIVAL_B)
C 3. EVENT CODE 3 - SCANNING THE SYSTEM AT EACH 1 SECOND INTERVAL
C    (SUBROUTINE SCAN)
C ------------------------------------------------------------------------
      GO TO (1, 2, 3), I          ! I IS THE USER-DEFINED INTEGER
                                  ! CODE ASSOCIATED WITH THE CURRENT
                                  ! EVENT
    1 CALL ARRIVAL_A
      RETURN
    2 CALL ARRIVAL_B
      RETURN
    3 CALL SCAN
      RETURN
      END
C ************************************************************************
      SUBROUTINE INTLC
C ------------------------------------------------------------------------
C THIS SUBROUTINE IS CALLED BY SLAM BEFORE EACH SIMULATION RUN. IT IS
C USED TO PERFORM THE FOLLOWING FUNCTIONS:
C 1. INITIALIZE ALL NON-SLAM II VARIABLES.
C 2. READ INPUT DATA.
C 3. ESTABLISH CONSTANTS FOR THE MODEL.
C 4. SCHEDULE FIRST ARRIVAL AT EACH APPROACH.
C 5. INITIALIZE FIRST VEHICLE TRAJECTORY DATA.
C 6. PRINT USER INPUT ECHO DATA.
C ------------------------------------------------------------------------
C ESTABLISH NAMED COMMON AND DIMENSION VARIABLES
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR, VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN, BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED, AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     + SAVE (26), FS
C ------------------------------------------------------------------------
$LARGE                            ! SPECIFIES HUGE MEMORY MODEL
$NOTRUNCATE                       ! DISABLES ALL VARIABLES AND PROG-
                                  ! RAMS/SUBPROGRAMS NAME TRUNCATION
$DEBUG                            ! CAUSES ADDITIONAL DEBUGGING
$NOTSTRICT                        ! ENABLES THE SPECIFIC MICROSOFT
                                  ! FORTRAN FEATURES NOT FOUND IN THE
                                  ! FORTRAN 77 FULL LANGUAGE STANDARD
C ******************************* GLOSSARY *******************************
C ------------------------------------------------------------------------
C LENGTH                          = LENGTH OF THE WEAVING SECTION (FT)
C IWIDTH                          = WIDTH OF THE WEAVING SECTION (FT)
C L_UP                            = UPSTREAM BUFFER LENGTH (FT)
```

```
C L_DN               = DOWNSTREAM BUFFER LENGTH (FT)
C GRADE              = VERTICAL GRADE OF THE WEAVING SECTION (%)
C NLANE              = NUMBER OF LANES IN THE WEAVING SECTION (#)
C LCAR               = AVERAGE LENGTH OF PASSENGER CAR (FT)
C LTRUCK             = AVERAGE LENGTH OF SINGLE UNIT TRUCK (FT)
C LTRAILER           = AVERAGE LENGTH OF TRAILER TRUCK (FT)
C ACE_MAX            = MAXIMUM ACCELERATION RATE (MPH/SEC)
C DEC_MAX            = MAXIMUM DECELERATION RATE (MPH/SEC)
C IVOL_A             = APPROACH A VOLUME (VPH)
C IVOL_B             = APPROACH B VOLUME (VPH)
C TRUCK_PR           = PERCENTAGE OF SINGLE UNIT TRUCKS (%)
C TRAILER_PR         = PERCENTAGE OF TRAILER TRUCKS
C VOL_PR_AC          = PERCENTAGE OF  APPROACH A VOLUME EXITING THROUGH C
C VOL_PR_BD          = PERCENTAGE OF  APPROACH B VOLUME EXITING THROUGH D
C AV_ACE             = AVERAGE ACCELERATION RATE (MPH/SEC)
C AV_DEC             = AVERAGE DECELERATION RATE (MPH/SEC)
C DEC_MIN            = MINIMUM DECELERATION RATE(MPH/SEC)
C SPEED_MAX          = MAXIMUM SPEED IN THE WEAVING SECTION (MPH)
C AV_BR_TIME         = AVERAGE BRAKE REACTION TIME (SEC)
C BR_TIME_MIN        = MINIMUM BRAKE REACTION TIME (SEC)
C BR_TIME_MIN        = MAXIMUM BRAKE REACTION TIME (SEC)
C SIGMA_BR_TIME      = STANDARD DEVIATION OF BRAKE REACTION TIME (SEC)
C AR_HDWY_MIN        = MINIMUM ARRIVAL HEADWAY (SEC)
C AR_HDWY_MAX        = MAXIMUM ARRIVAL HEADWAY (SEC)
C SIGMA_AR_HDWY      = STANDARD DEVIATION OF ARRIVAL HEADWAY
C ISCAN              = SCANNING INTERVAL (SEC)
C ITRAJ              = SCANNING INTERVAL FOR VEHICLE TRAJECTORY DATA (SEC)
C WARM_TIME          = SIMULATION WARM-UP TIME (MIN)
C ISEED              = RANDOM NUMBER SEED (#)
C ECHO_DATA          = IF REQUIRE LIST OF ECHO DATA, ENTER 1
C AV_AR_HDWY         = MEAN ARRIVAL HEADWAY
C AR_SPEED_MIN       = MINIMUM ARRIVAL SPEED (MPH)
C AR_SPEED_MAX       = MAXIMUM ARRIVAL SPEED (MPH)
C SIGMA_AR_SPEED     = STANDARD DEVIATION OF ARRIVAL SPEED (MPH)
C AV_AR_SPEED        = MEAN ARRIVAL SPEED (MPH)
C ID_NO_A            = INTEGER VEHICLE NUMBER FOR APPROACH A
C ID_NO_B            = INTEGER VEHICLE NUMBER FOR APPROACH B
C FS                 = SPEED CONVERSION FACTOR (1.47)
C ------------------------------------------------------------------------
C ******************************READ INPUT DATA **********************************
C                    ===============
C SIMULATION RUN PARAMETERS
C =========================
   READ(NCRDR,*) WARM_TIME, ISEED, ISCAN, ITRAJ, L_UP, L_DN
C WEAVING SECTION PARAMETERS
C ==========================
   READ(NCRDR,*) LENGTH, IWIDTH, GRADE, NLANE
C TRAFFIC PARAMETERS
C ==================
C VOLUME DATA
C -----------
   READ(NCRDR,*)IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,
   +VOL_PR_BC
C SPEED DATA
C ----------
```

```
C   ARRIVAL SPEED
C   -------------
    READ(NCRDR,*) AV_AR_SPEED, SIGMA_AR_SPEED, AR_SPEED_MIN,
    +AR_SPEED_MAX
C   ARRIVAL HEADWAY
C   ---------------
    READ(NCRDR,*)AV_AR_HDWY,SIGMA_AR_HDWY,AR_HDWY_MIN,AR_HDWY_MAX
C DRIVER POLICY
C -------------
    READ(NCRDR,*) AV_BR_TIME,BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME,
    +AV_ACE, AV_DEC, DEC_MIN
C VEHICLE CHARACTERISTICS
C -----------------------
    READ(NCRDR,*) LCAR, LTRUCK, LTRAILER, DEC_MAX, ACE_MAX
C ECHO OF INPUT DATA REQUIRED?
C ---------------------------
    READ(NCRDR,*) ECHO_DATA      ! IF ECHO_DATA=1 (INPUT DATA ECHO REQUIRED),
                                 ! ELSE (NOT REQUIRED)
C PRINT ECHO OF INPUT DATA
    IF (ECHO_DATA.EQ.1.) CALL ECHO_PRINT
C     MFA = 1                    ! SET AVAILABILITY POINTER, MFA = 1
C SCHEDULE FIRST ARRIVAL AT EACH APPROACH
    FS      = 1.47               ! SPEED CONVERSION FACTOR
    ID_NO_A = 0
    ID_NO_B = 0
    N_VEH_A = IVOL_A
    N_VEH_B = IVOL_B
C TEST WEATHER SYSTEM IS INITIALLY LOADED
C SEARCH FILE NO. 1 FOR APPROACH A ARRIVAL
C IF FILE IS EMPTY GENERATE IST ARRIVAL
    NUMBER_A = NNQ (1)
    IF (NUMBER_A.EQ.0) GO TO 20
    NTRY_A = MMFE (1)
    CALL COPY (-NTRY_A, 1, ATRIB)
    TIME_FIRST (1) = ATRIB (2)
    CALL SCHDL (1, TIME_FIRST (1), ATRIB)
    GO TO 30
C SCHEDULE FIRST VEHICLE ARRIVAL AT APPROACH A
  20 AV_HDWY       = AV_AR_HDWY
    SIGMA_HDWY    = SIGMA_AR_HDWY
    AV_AR_HDWY    = 6.1754 - IVOL_A/308.925
    SIGMA_AR_HDWY = 4.8828 - IVOL_A/450.204
    IF (AV_AR_HDWY.LT.AR_HDWY_MIN.OR.
    +   AV_AR_HDWY.GT.AR_HDWY_MAX) THEN
    AV_AR_HDWY    = AV_HDWY
    SIGMA_AR_HDWY = SIGMA_HDWY
    END IF
    ARR_TIME_A = RLOGN (AV_AR_HDWY, SIGMA_AR_HDWY, ISEED)
C TRUNCATE
    IF (ARR_TIME_A.GT.AR_HDWY_MAX) ARR_TIME   = AR_HDWY_MAX
    IF (ARR_TIME_A.LT.AR_HDWY_MIN) ARR_TIME   = AR_HDWY_MIN
C COINCIDE ARRIVAL HEADWAY WITH THE NEAREST DISCRETE INTERVAL
    CALL STEP (ARR_TIME_A, A_NEXT)
    WRITE (NPRNT, *)'INTLC(A) ARR_TIME_A, A_NEXT',ARR_TIME_A, A_NEXT
    CALL SCHDL (1, A_NEXT, ATRIB)
```

```
 30 NUMBER_B = NNQ (2)
    IF (NUMBER_B.EQ.0) GO TO 40
    NTRY_B = MMFE (2)
    CALL COPY (-NTRY_B, 2, ATRIB)
    TIME_FIRST (2) = ATRIB (2)
    CALL SCHDL (2, TIME_FIRST (2), ATRIB)
    GO TO 50
 40 SIGMA_HDWY    = SIGMA_AR_HDWY
    AV_AR_HDWY    = 6.1754 - IVOL_A/308.925
    SIGMA_AR_HDWY = 4.8828 - IVOL_A/450.204
    IF (AV_AR_HDWY.LT.AR_HDWY_MIN.OR.
    +    AV_AR_HDWY.GT.AR_HDWY_MAX) THEN
    AV_AR_HDWY    = AV_HDWY
    SIGMA_AR_HDWY = SIGMA_HDWY
    END IF
    ARR_TIME_B = RLOGN (AV_AR_HDWY, SIGMA_AR_HDWY, ISEED)
C TRUNCATE
    IF (ARR_TIME_B.GT.AR_HDWY_MAX) ARR_TIME_B = AR_HDWY_MAX
    IF (ARR_TIME_B.LT.AR_HDWY_MIN) ARR_TIME_B = AR_HDWY_MIN
C COINCIDE ARRIVAL HEADWAY WITH THE NEAREST DISCRETE INTERVAL
    CALL STEP (ARR_TIME_B, A_NEXT)
    CALL SCHDL (2, A_NEXT, ATRIB)
    WRITE (NPRNT, *)'INTLC(B) ARR_TIME_B, A_NEXT',ARR_TIME_B,A_NEXT
C  50 WRITE (NPRNT, *)'INTLC NNQ(1),NNQ(2), MMFE(1),MMFE(2),
C    +MMLE(1), MMLE(2)',NNQ(1),NNQ(2),MMFE(1),MMFE(2),MMLE(1),MMLE(2)
C SCHEDULE SCAN
  50 CONTINUE
    CALL SCHDL (3, 0., ATRIB)
    RETURN
    END
C ******************************************************************************************
C -------------------------------------------------------------------------------
    SUBROUTINE ECHO_PRINT
C -------------------------------------------------------------------------------
C THIS SUBROUTINE IS CALLED FROM SUBROUTINE INTLC IF THE USER DESIRES
C ECHO OF INPUT DATA
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
    +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
    COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
    COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
    COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
    COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
    +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
    COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
    COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
    COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
    COMMON/UCOM8/ID_NO_A,ID_NO_B,TIME_FIRST(2),N_VEH_A,N_VEH_B,SAVE(26),FS
C -------------------------------------------------------------------------------
    WRITE(NPRNT,10)
    WRITE(NPRNT,20)
    WRITE(NPRNT,30)
  10 FORMAT('1',15X,
    +'NFWSIM - NON-FREEWAY WEAVING SIMULATION MODEL')
  20 FORMAT(16X,'***********************************************'//)
  30 FORMAT(28X,
```

```
     +'USER INPUT ECHO DATA'/28X,'*******************'/)
C SIMULATION RUN PARAMETERS
C ==========================
      WRITE(NPRNT,40)
   40 FORMAT(/'SIMULATION RUN PARAMETERS'/,
     +'============================'/)
      WRITE(NPRNT,50) WARM_TIME, ISEED, ISCAN, ITRAJ, L_UP, L_DN
   50 FORMAT(/,4X,'WARMUP TIME                    = ',F5.2, ' SEC',
     +       /4X,'RANDOM NUMBER SEED             = ',I3,
     +       /4X,'SCAN INTERVAL                  = ',I3, ' SEC',
     +       /4X,'TRAJ. COLLECTION TIME          = ',I3, ' SEC',
     +       /4X,'UP STREAM BUFFER LENGTH        = ',I4, ' FT',
     +       /4X,'DOWN STREAM BUFFER LENGTH      = ',I4, ' FT')
C WEAVING SECTION PARAMETERS
C ===========================
      WRITE(NPRNT,55)
   55 FORMAT(//,'WEAVING SECTION PARAMETERS'/,
     +'=============================='/)
      WRITE(NPRNT,60) LENGTH, IWIDTH, GRADE, NLANE
   60 FORMAT(/,4X,'WEAVING SECTION LENGTH         = ',I5, ' FT',
     +       /4X,'WEAVING SECTION WIDTH          = ',I5, ' FT',
     +       /4X,'VERTICAL GRADE OF SECTION      = ',F3.0,' %',
     +       /4X,'NUMBER OF LANES                = ',I2)
C TRAFFIC PARAMETERS
C ==================
C VOLUME DATA
C -----------
      WRITE(NPRNT,70)
   70 FORMAT(//,'TRAFFIC PARAMETERS'/,
     +'=================='//,
     +2X,'VOLUME DATA'/,2X,'-----------'/)
      WRITE(NPRNT,80)IVOL_A, IVOL_B, TRUCK_PR, TRAILER_PR,
     +VOL_PR_AD, VOL_PR_BC
   80 FORMAT(/4X,'APPROACH A VOLUME              = ',I5, ' VEH.',
     +       /4X,'APPROACH B VOLUME              = ',I5, ' VEH.',
     +       /4X,'TRUCK PROPORTION               = ',F5.2,
     +       /4X,'TRAILER PROPORTION             = ',F5.2,
     +       /4X,'PROPOR. OF VOL. WEAVING (A-D)  = ',F5.2,
     +       /4X,'PROPOR. OF VOL. WEAVING (B-C)  = ',F5.2/)
C SPEED DATA
C ----------
C  ARRIVAL SPEED
C  -------------
      WRITE(NPRNT,90)
   90 FORMAT(/,'SPEED DATA'/,'----------'//,
     +2X,'ARRIVAL SPEED'/,2X,'-------------'//)
      WRITE(NPRNT,100) AV_AR_SPEED, SIGMA_AR_SPEED, AR_SPEED_MIN,
     +AR_SPEED_MAX
  100 FORMAT( 4X,'MEAN ARRIVAL SPEED             = ',F5.2, ' MPH',
     +       /4X,'STD. DEV. OF ARRIVAL SPEED     = ',F5.2, ' MPH',
     +       /4X,'MINIMUM ARRIVAL SPEED          = ',F5.2, ' MPH',
     +       /4X,'MAXIMUM ARRIVAL SPEED          = ',F5.2, ' MPH'/)
C  ARRIVAL HEADWAY
C  ---------------
      WRITE(NPRNT,110)
```

```
 110 FORMAT(/,2X,'ARRIVAL HEADWAY'/,2X,'---------------')
     WRITE(NPRNT,120) AV_AR_HDWY, SIGMA_AR_HDWY, AR_HDWY_MIN,
     +AR_HDWY_MAX
 120 FORMAT(/4X,'MEAN ARRIVAL HEADWAY       = ',F4.2, ' SEC',
     +       /4X,'STD. DEV. OF ARRIVAL HDWAY = ',F4.2, ' SEC',
     +       /4X,'MINIMUM ARRIVAL HEADWAY    = ',F4.2, ' SEC',
     +       /4X,'MAXIMUM ARRIVAL HEADWAY    = ',F5.2, ' SEC'/)
C DRIVER POLICY
C -------------
     WRITE(NPRNT,130)
 130 FORMAT(/,'DRIVER POLICY'/,'=============')
     WRITE(NPRNT,140) AV_BR_TIME,BR_TIME_MIN,BR_TIME_MAX,
     +SIGMA_BR_TIME,AV_ACE, AV_DEC, DEC_MIN
 140 FORMAT(/4X,'AVERAGE BRAKE REACTION TIME = ',F4.2, ' SEC',
     +       /4X,'MINIMUM BRAKE REACTION TIME = ',F4.2, ' SEC',
     +       /4X,'MAXIMUM BRAKE REACTION TIME = ',F4.2, ' SEC',
     +       /4X,'STD. DEV. BRAKE REAC.  TIME = ',F4.2, ' SEC',
     +       /4X,'AVERAGE ACCELERATION RATE   = ',F4.2, ' MPH/S',
     +       /4X,'AVERAGE DECELERATION RATE   = ',F5.2, ' MPH/S',
     +       /4X,'MINIMUM DECELERATION RATE   = ',F5.2, ' MPH/S'/)
C VEHICLE CHARACTERISTICS
C -----------------------
     WRITE(NPRNT,150)
 150 FORMAT(/'VEHICLE CHARACTERISTICS'/,
     +'======================='/)
     WRITE(NPRNT,160) LCAR, LTRUCK, LTRAILER, DEC_MAX,ACE_MAX
 160 FORMAT( 4X,'AVERAGE LENGTH OF CAR       = ',I4, ' FT',
     +       /4X,'AVERAGE LENGTH OF TRUCK     = ',I4, ' FT',
     +       /4X,'AVERAGE LENGTH OF TRAILER   = ',I4, ' FT',
     +       /4X,'MAXIMUM EMERGENCY DEC. RATE = ',F6.2, ' MPH/S',
     +       /4X,'MAXIMUM ACCELERATION RATE   = ',F4.2, ' MPH/S'//)
     RETURN
     END
C  ******************************************************************************************
C ------------------------------------------------------------------------------------------
     SUBROUTINE ARRIVAL_A
C ------------------------------------------------------------------------------------------
C THIS SUBROUTINE PERFORMS THE FOLLOWING FUNCTIONS:
C 1. GENERATES VEHICLES AT APPROACH A BASED ON ARRIVAL HEADWAY
C    DISTRIBUTION.
C 2. ASSIGN ARRIVAL SPEEDS TO VEHICLES STOCHASTICALLY.
C 3. ASSIGNS REST OF THE TEMPORARY AND PERMANENT ATTRIBUTES TO EACH
C    ARRIVING
C    VEHICLE EITHER DETERMINISTICALLY OR STOCHASTICALLY.
C 4. FILES ALL VEHICLES IN THE SYSTEM QUEUE
C ------------------------------------------------------------------------------------------
     COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
     COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
     COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
     COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
     COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
     COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
     COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX, AV_AR_HDWY,SIGMA_AR_HDWY
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      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C ---------------------------------------------------------------------
      OR_APPR = 1.                  ! VEHICLE IS ENTERING FROM APPROACH A
      ID_NO_A = ID_NO_A + 1         ! ASSIGN ID NO. TO ARRIVING VEHICLE
      ID_NO   = ID_NO_A + ID_NO_B
      ENTRY_TIME = TNOW
C ASSIGN RANDOMLY GENERATED SAFETY DISTANCE TO EACH VEHICLE
      R       = DRAND (ISEED)
      SD      = 10*R + 5            ! SAFETY DISTANCE (VARIES 5-10 FT)
C GENERATE DRIVER REACTION TIME FROM TRUNCATED GAMA DISTRIBUTION
      ALFA = (AV_BR_TIME/SIGMA_BR_TIME)**2
      BETA = AV_BR_TIME/ALFA
      REAC_TIME = GAMA (BETA, ALFA, ISEED)
C CHECK FOR MINIMUM AND MAXIMUM LIMITS
      IF (REAC_TIME.LT.BR_TIME_MIN) REAC_TIME = BR_TIME_MIN
      IF (REAC_TIME.GT.BR_TIME_MAX) REAC_TIME = BR_TIME_MAX
      CALL COLCT (REAC_TIME,1)
C GENERATE ARRIVAL SPEED FORM TRUNCATED NORMAL DISTRIBUTION
      DO 5 J  = 1, 10
      AR_SPEED = RNORM (AV_AR_SPEED, SIGMA_AR_SPEED, ISEED)
C CHECK FOR MINIMUM AND MAXIMUM LIMITS
      IF (AR_SPEED.LT.AR_SPEED_MIN) AR_SPEED = AR_SPEED_MIN
      IF (AR_SPEED.GT.AR_SPEED_MAX) AR_SPEED = AR_SPEED_MAX
      NUMBER_A     = NNQ (1)
      IF (NUMBER_A.EQ.0) GO TO 10
      INEXT_A      = MMLE (1)
      CALL COPY (-INEXT_A,1,ATRIB)
      SPEED_L      = ATRIB (21)     ! SPEED AT LAST SCAN
      LAST_LENGTH   = ATRIB (5)
      SPACE_HDWY    = ATRIB (19)    ! VEHICLE SPACE HEADWAY
      FRICTION      = FACTOR (AR_SPEED)
C TEST WHETHER VEHICLE CAN ENTER AT ITS ASSIGNED ARRIVAL SPEED
      SR = 0.
      IF (AR_SPEED.GT.SPEED_L) SR = 1.
      S = 30*(FRICTION + GRADE/100.)
      R = SR*(AR_SPEED**2 - SPEED_L**2)/S
      AHEAD = LAST_LENGTH + 1.47*AR_SPEED*REAC_TIME + R
      IF (AHEAD.LE.ATRIB(19)) GO TO 10      ! VEHICLE CAN ENTER AT ITS
    5 CONTINUE                              ! OWN SPEED
C TEST WHETHER VEHICLE CAN ENTER AT LEAD VEHICLE SPEED
      AHEAD_L = LAST_LENGTH + 1.47 * SPEED_L * REAC_TIME
      IF (AHEAD_L.LE.ATRIB(19)) THEN
      ARR_SPEED = SPEED_L
      GO TO 20
      ELSE
      GO TO 90
      END IF                                ! ASSIGN SAFE ARRIVAL SPEED
C VEHICLE CAN ENTER AT ITS ASSIGNED ARRIVAL SPEED
   10 ARR_SPEED = AR_SPEED
   20 CONTINUE
      CALL COLCT(ARR_SPEED,2)
C ASSIGN TYPE OF VEHICLE TO ARRIVING VEHICLE
      RANNUM = DRAND (ISEED)        ! RETURNS A RANDOM NUMBER UNIFORMLY
```

```
                                        ! DISTRIBUTED BETWEEN 0 AND 1 USING
                                        ! RANDOM NUMBER STREAM ISEED
   IF (RANNUM.LE.TRAILER_PR) THEN
     ITYPE    = 3
     LENGTH_V = LTRAILER
     WIDTH    = 8.5
     HIGHT    = 13.5
   END IF
   CUM_TRUCK = TRUCK_PR + TRAILER_PR
   IF (RANNUM.GT.TRAILER_PR.AND.RANNUM.LE.CUM_TRUCK) THEN
     ITYPE    = 2
     LENGTH_V = LTRUCK
     WIDTH    = 8.5
     HIGHT    = 13.5
   ELSE
     ITYPE    = 1
     LENGTH_V = LCAR
     WIDTH    = 7.
     HIGHT    = 4.25
   END IF
C ASSIGN DESTINATION TO ARRIVING VEHICLE
   RANNUM = DRAND (ISEED)
   IF (RANNUM.LT.VOL_PR_AD) THEN
    DEST_APPR  = 4.                 ! DESTINATION=D
    VEH_STATUS = 1.                 ! WEAVING VEHICLE
   ELSE
    DEST_APPR  = 3.                 ! DESTINATION=C
    VEH_STATUS = 2.                 ! NON-WEAVING VEHICLE
   END IF
C ASSIGN ACCEPTABLE GAP TO WEAVING VEHICLES DEPENDING ON VEHICLE TYPE
   IF (VEH_STATUS.EQ.2.) GO TO 70   ! IF NON-WEAVING ASSIGN 0.0
   A = 11.325
   B = 0.1188
   RANNUM = DRAND (ISEED)
   ACC_GAP = (A + ALOG(RANNUM/(1-RANNUM)))/B
   G_LAG  = 15.                     ! MINIMUM LAG GAP
   G_LEAD = 10.                     ! MINIMUM LEAD GAP
   GAP_MIN = G_LAG + LENGTH_V + G_LEAD ! MINIMUM CRITICAL GAP
   IF (ACC_GAP.LT.GAP_MIN) ACC_GAP = GAP_MIN
   CALL COLCT(ACC_GAP,3)
   GO TO 80
 70 ACC_GAP = 0.0
 80 CONTINUE
C INITIALIZE ALL REMAINING ATTRIBUTES
   EXIT_TIME     = 0.
   TIME_IN_SYST  = 0.
   CURR_LANE     = 1.
   VEH_POSITION1 = 0.
   VEH_POSITION2 = 0.
   VEH_SPEED1    = ARR_SPEED
   VEH_SPEED2    = ARR_SPEED
   VEH_ACCE      = 0.
   ADJ_UP        = 0.
   ADJ_DN        = 0.
C ASSIGN ATTRIBUTES TO ARRIVING VEHICLES
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C PERMANENT ATTRIBUTES
C ====================
     ATRIB (1) = ID_NO_A           ! INTEGER VEHICLE INDEX ASSIGNED SEQUENTIALLY
                                   ! TO EACH ARRIVING VEHICLE
     ATRIB (2)  = ENTRY_TIME       ! ARRIVAL TIME OF THE VEH. TO THE SYSTEM (SEC)
     ATRIB (3)  = REAC_TIME        ! DRIVER REACTION TIME (SEC)
     ATRIB (4)  = ARR_SPEED        ! VEHICLE ARRIVAL SPEED (MPH)
     ATRIB (5)  = LENGTH_V         ! LENGTH OF VEHICLE (FT)
     ATRIB (6)  = WIDTH            ! WIDTH OF VEHICLE (FT)
     ATRIB (7)  = HIGHT            ! HIGHT OF VEHICLE (FT)
     ATRIB (8)  = ITYPE            ! TYPE OF VEHICLE; 1=CAR, 2=TRUCK, 3=TRAILER
     ATRIB (9)  = OR_APPR          ! ORIGIN (ENTRY APPROACH) OF VEH. (A=1 OR B=2)
     ATRIB (10) = ADJ_UP           ! UPWARD SPEED ADJUSTMENT FOR CHANGING VEH.
     ATRIB (11) = DEST_APPR        ! DESTINATION (EXIT APPROACH) OF VEH. (C=3/D=4)
     ATRIB (12) = ADJ_DN           ! DOWNWARD SPEED ADJUSTMENT FOR CHANG. VEH.
     ATRIB (13) = VEH_STATUS       ! STATUS OF VEHICLE (WEAVING/NON-WEAVING)
     ATRIB (14) = ACC_GAP          ! CRITICAL GAP FOR ON RAMP VEHICLES
     ATRIB (15) = EXIT_TIME        ! VEHICLE EGRESS TIME (SEC)
     ATRIB (16) = TIME_IN_SYST     ! TIME FOR WHICH VEH. REMAINED IN THE SYSTEM
     ATRIB (24) = ID_NO            ! INTEGER VEHICLE NO.
     ATRIB (25) = MFA              ! POINTER TO 1ST AVAILABLE SPACE
     ATRIB (26) = SD               ! SAFETY DISTANCE
C TEMPORARY ATTRIBUTES
C ====================
     ATRIB (17)= CURR_LANE         ! CURRENT LANE OF VEHICLE
     ATRIB (18)= VEH_POSITION1     ! VEH. POSITION AT THE END OF LAST SCAN (FT)
     ATRIB (19)= VEH_POSITION2     ! VEH. POSITION AT THE END OF CURRENT SCAN (FT)
     ATRIB (20)= VEH_SPEED1        ! VEH. SPEED AT THE END OF LAST SCAN TIME (MPH)
     ATRIB (21)= VEH_SPEED2        ! VEH. SPEED AT THE END OF CURRENT SCAN (MPH)
     ATRIB (22)= VEH_ACCE          ! CURRENT ACCELERATION OF VEHICLE (MPH/SEC)
     ATRIB (23)= SPACE_HDWY        ! CURRENT SPACE HEADWAY OF VEHICLE (FT)
     CALL FILEM(1,ATRIB)
C SCHEDULE SUBSEQUENT ARRIVALS
  90 AV_HDWY       = AV_AR_HDWY
     SIGMA_HDWY    = SIGMA_AR_HDWY
     AV_AR_HDWY    = 6.1754 - IVOL_A/308.925
     SIGMA_AR_HDWY = 4.8828 - IVOL_A/450.204
     IF (AV_AR_HDWY.LT.AR_HDWY_MIN
    +  .OR.AV_AR_HDWY.GT.AR_HDWY_MAX) THEN
       AV_AR_HDWY    = AV_HDWY
       SIGMA_AR_HDWY = SIGMA_HDWY
     END IF
     ARR_TIME = RLOGN (AV_AR_HDWY, SIGMA_AR_HDWY, ISEED)
C TRUNCATE ARRIVAL HEADWAY DISTRIBUTION
     IF (ARR_TIME.LT.AR_HDWY_MIN) ARR_TIME = AR_HDWY_MIN
     IF (ARR_TIME.GT.AR_HDWY_MAX) ARR_TIME = AR_HDWY_MAX
C COINCIDE ARRIVAL HEADWAY WITH THE NEAREST DISCRETE INTERVAL
     CALL STEP (ARR_TIME, A_NEXT)
     CALL SCHDL (1, A_NEXT, ATRIB)
     CALL COLCT (ARR_TIME,4)
     RETURN
     END
C  ****************************************************************************************
     SUBROUTINE ARRIVAL_B
C ---------------------------------------------------------------------------------------
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C THIS SUBROUTINE PERFORMS THE FOLLOWING FUNCTIONS:
C 1. GENERATES VEH. AT APPROACH A BASED ON ARRIVAL HEADWAY DISTRIBUTION.
C 2. ASSIGN ARRIVAL SPEEDS TO VEHICLES STOCHASTICALLY.
C 3. ASSIGNS REST OF THE TEMPORARY AND PERMANENT ATTRIBUTES TO EACH
C    ARRIVING VEHICLE EITHER DETERMINISTICALLY OR STOCHASTICALLY.
C 4. FILES ALL VEHICLES IN THE SYSTEM QUEUE
C ------------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C ------------------------------------------------------------------------
      OR_APPR = 2.                    ! VEHICLE IS ENTERING FROM APPROACH B
      ID_NO_B = ID_NO_B + 1           ! ASSIGN ID NO. TO ARRIVING VEHICLE
      ID_NO   = ID_NO_B + ID_NO_A
      ENTRY_TIME = TNOW
C ASSIGN RANDOMLY GENERATED SAFETY DISTANCE TO EACH VEHICLE
      R        = DRAND (ISEED)
      SD       = 10*R + 5             ! SAFETY DISTANCE (VARIES 5-10 FT)
C GENERATE DRIVER REACTION TIME FROM TRUNCATED GAMA DISTRIBUTION
      ALFA = (AV_BR_TIME/SIGMA_BR_TIME)**2
      BETA = AV_BR_TIME/ALFA
      REAC_TIME = GAMA (BETA, ALFA, ISEED)
C CHECK FOR MINIMUM AND MAXIMUM LIMITS
      IF (REAC_TIME.LT.BR_TIME_MIN) REAC_TIME = BR_TIME_MIN
      IF (REAC_TIME.GT.BR_TIME_MAX) REAC_TIME = BR_TIME_MAX
      CALL COLCT (REAC_TIME,5)
C GENERATE ARRIVAL SPEED FORM TRUNCATED NORMAL DISTRIBUTION
      DO   5 J = 1, 10
      AR_SPEED = RNORM (AV_AR_SPEED, SIGMA_AR_SPEED, ISEED)
C CHECK FOR MINIMUM AND MAXIMUM LIMITS
      IF (AR_SPEED.LT.AR_SPEED_MIN) AR_SPEED = AR_SPEED_MIN
      IF (AR_SPEED.GT.AR_SPEED_MAX) AR_SPEED = AR_SPEED_MAX
      NUMBER_B     = NNQ (2)
      IF (NUMBER_B.EQ.0) GO TO 10
      INEXT_B      = MMLE (2)
      CALL COPY (-INEXT_B,1,ATRIB)
      SPEED_L      = ATRIB (21)
      LAST_LENGTH   = ATRIB (5)
      SPACE_HDWY    = ATRIB (19)
      FRICTION      = FACTOR (AR_SPEED)
C TEST WHETHER VEHICLE CAN ENTER AT ITS ASSIGNED ARRIVAL SPEED
      SR = 0.
      IF (AR_SPEED.GT.SPEED_L) SR = 1.
      S = 30*(FRICTION + GRADE/100.)
      R = SR*(AR_SPEED**2 - SPEED_L**2)/S
      AHEAD = LAST_LENGTH + 1.47*AR_SPEED*REAC_TIME + R
```

```
      IF (AHEAD.LE.ATRIB(19)) GO TO 10      ! VEHICLE CAN ENTER AT ITS
    5 CONTINUE                              ! OWN SPEED
C TEST WHETHER VEHICLE CAN ENTER AT LEAD VEHICLE SPEED
      AHEAD_L = LAST_LENGTH + 1.47 * SPEED_L * REAC_TIME
      IF (AHEAD_L.LT.ATRIB(19)) THEN
      ARR_SPEED = SPEED_L
      GO TO 20
      ELSE
      GO TO 90
      END IF                                ! ASSIGN SAFE ARRIVAL SPEED
C VEHICLE CAN ENTER AT ITS ASSIGNED ARRIVAL SPEED
   10 ARR_SPEED = AR_SPEED
   20 CONTINUE
      CALL COLCT(ARR_SPEED,6)
C ASSIGN TYPE OF VEHICLE TO ARRIVING VEHICLE
      RANNUM = DRAND (ISEED)                ! RETURNS A RANDOM NUMBER UNIFORMLY
                                            ! DISTRIBUTED BETWEEN 0 AND 1 USING
                                            ! RANDOM NUMBER STREAM ISEED
      IF (RANNUM.LE.TRAILER_PR) THEN
         ITYPE    = 3
         LENGTH_V = LTRAILER
         WIDTH    = 8.5
         HIGHT    = 13.5
      END IF
      CUM_TRUCK = TRUCK_PR + TRAILER_PR
      IF (RANNUM.GT.TRAILER_PR.AND.RANNUM.LE.CUM_TRUCK) THEN
         ITYPE    = 2
         LENGTH_V = LTRUCK
         WIDTH    = 8.5
         HIGHT    = 13.5
      ELSE
         ITYPE    = 1
         LENGTH_V = LCAR
         WIDTH    = 7.
         HIGHT    = 4.25
      END IF
C ASSIGN DESTINATION TO ARRIVING VEHICLE
      RANNUM = DRAND (ISEED)
      IF (RANNUM.LT.VOL_PR_BC) THEN
       DEST_APPR  = 3.                      ! DESTINATION = C
       VEH_STATUS = 1.                      ! WEAVING VEHICLE
      ELSE
       DEST_APPR  = 4.                      ! DESTINATION = D
       VEH_STATUS = 2.                      ! NON-WEAVING VEHICLE
      END IF
C     ASSIGN ACCEPTABLE GAP TO WEAVING VEHICLES DEPENDING ON VEHICLE TYPE
      IF (VEH_STATUS.EQ.2.) GO TO 70        ! IF NON-WEAVING ASSIGN 0.0
      A = 11.325
      B = 0.1188
      RANNUM = DRAND (ISEED)
      ACC_GAP = (A + ALOG(RANNUM/(1-RANNUM)))/B
      G_LAG   = 15.                         ! MINIMUM LAG GAP
      G_LEAD  = 10.                         ! MINIMUM LEAD GAP
      GAP_MIN = G_LAG + LENGTH_V + G_LEAD ! MINIMUM CRITICAL GAP
      IF (ACC_GAP.LT.GAP_MIN) ACC_GAP = GAP_MIN
```

```
      CALL COLCT(ACC_GAP,7)
      GO TO 80
   70 ACC_GAP = 0.0
   80 CONTINUE
C INITIALIZE ALL REMAINING ATTRIBUTES
      EXIT_TIME     = 0.
      TIME_IN_SYST  = 0.
      CURR_LANE     = 2.
      VEH_POSITION1 = 0.
      VEH_POSITION2 = 0.
      VEH_SPEED1    = ARR_SPEED
      VEH_SPEED2    = ARR_SPEED
      VEH_ACCE      = 0.
      ADJ_UP        = 0.
      ADJ_DN        = 0.
C ASSIGN ATTRIBUTES TO ARRIVING VEHICLES
C PERMANENT ATTRIBUTES
C =====================
      ATRIB (1) = ID_NO_B          ! INTEGER VEHICLE INDEX ASSIGNED SEQUENTIALLY
                                   ! TO EACH ARRIVING VEHICLE
      ATRIB (2)  = ENTRY_TIME      ! ARRIVAL TIME OF THE VEH. TO THE SYSTEM (SEC)
      ATRIB (3)  = REAC_TIME       ! DRIVER REACTION TIME (SEC)
      ATRIB (4)  = ARR_SPEED       ! VEHICLE ARRIVAL SPEED (MPH)
      ATRIB (5)  = LENGTH_V        ! LENGTH OF VEHICLE (FT)
      ATRIB (6)  = WIDTH           ! WIDTH OF VEHICLE (FT)
      ATRIB (7)  = HIGHT           ! HIGHT OF VEHICLE (FT)
      ATRIB (8)  = ITYPE           ! TYPE OF VEHICLE; 1=CAR, 2=TRUCK, 3=TRAILER
      ATRIB (9)  = OR_APPR         ! ORIGIN (ENTRY APPROACH) OF VEH. (A=1 OR B=2)
      ATRIB (10) = ADJ_UP          ! UPWARD SPEED ADJUSTMENT FOR CHANGING VEH.
      ATRIB (11) = DEST_APPR       ! DESTINATION (EXIT APPROACH) OF VEH. (C=3/D=4)
      ATRIB (12) = ADJ_DN          ! DOWNWARD SPEED ADJUSTMENT FOR CHANG. VEH.
      ATRIB (13) = VEH_STATUS      ! STATUS OF VEHICLE (WEAVING/NON-WEAVING)
      ATRIB (14) = ACC_GAP         ! CRITICAL GAP FOR ON RAMP VEHICLES
      ATRIB (15) = EXIT_TIME       ! VEHICLE EGRESS TIME (SEC)
      ATRIB (16) = TIME_IN_SYST    ! TIME FOR WHICH VEH. REMAINED IN THE SYSTEM
      ATRIB (24) = ID_NO           ! INTEGER VEHICLE NO.
      ATRIB (25) = MFA
      ATRIB (26) = SD              ! SAFETY DISTANCE
C TEMPORARY ATTRIBUTES
C =====================
      ATRIB (17)= CURR_LANE        ! CURRENT LANE OF VEHICLE
      ATRIB (18)= VEH_POSITION1    ! VEH. POSITION AT THE END OF LAST SCAN  (FT)
      ATRIB (19)= VEH_POSITION2    ! VEH. POSITION AT THE END OF CURRENT SCAN (FT)
      ATRIB (20)= VEH_SPEED1       ! VEH. SPEED AT THE END OF LAST SCAN TIME (MPH)
      ATRIB (21)= VEH_SPEED2       ! VEH. SPEED AT THE END OF CURRENT SCAN (MPH)
      ATRIB (22)= VEH_ACCE         ! CURRENT ACCELERATION OF VEHICLE (MPH/SEC)
      ATRIB (23)= SPACE_HDWY       ! CURRENT SPACE HEADWAY OF VEHICLE (FT)
      CALL FILEM(2,ATRIB)
C SCHEDULE SUBSEQUENT ARRIVALS
   90 AV_HDWY        = AV_AR_HDWY
      SIGMA_HDWY     = SIGMA_AR_HDWY
      AV_AR_HDWY     = 6.1754 - IVOL_B/308.925
      SIGMA_AR_HDWY = 4.8828 - IVOL_B/450.204
      IF (AV_AR_HDWY.LT.AR_HDWY_MIN
     +   .OR.AV_AR_HDWY.GT.AR_HDWY_MAX) THEN
```

```
      AV_AR_HDWY    = AV_HDWY
      SIGMA_AR_HDWY = SIGMA_HDWY
    END IF
    ARR_TIME = RLOGN (AV_AR_HDWY, SIGMA_AR_HDWY, ISEED)
C TRUNCATE ARRIVAL HEADWAY DISTRIBUTION
    IF (ARR_TIME.LT.AR_HDWY_MIN) ARR_TIME = AR_HDWY_MIN
    IF (ARR_TIME.GT.AR_HDWY_MAX) ARR_TIME = AR_HDWY_MAX
C COINCIDE ARRIVAL HEADWAY WITH THE NEAREST DISCRETE INTERVAL
    CALL STEP (ARR_TIME, A_NEXT)
    CALL SCHDL (2, A_NEXT, ATRIB)
    CALL COLCT (ARR_TIME,8)
    RETURN
    END
C ---------------------------------------------------------------------------
*****************************************************************************
    SUBROUTINE STEP (ARR_TIME, A_NEXT)
C ---------------------------------------------------------------------------
C SUBROUTINE STEP ALLOCATES NEAREST DISCRETE TIME TO ARRIVAL EVENT


C ---------------------------------------------------------------------------
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
   +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
    COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
    TIME = 0.
    DO 5 ICOUNT = 1, 10000
    TIME = 1. + TIME
    IF (ARR_TIME.GT.TIME) GO TO 5
    TIME_LAST = TIME - 1.
    GO TO 10
  5 CONTINUE
 10 X = ABS (ARR_TIME - TIME_LAST)
    Y = ABS (ARR_TIME - TIME)
    IF (X - Y) 20, 20, 30
 20 A_NEXT = TIME_LAST
    GO TO 40
 30 A_NEXT = TIME
 40 RETURN
    END
C ***************************************************************************
C ---------------------------------------------------------------------------
    SUBROUTINE SCAN
C ---------------------------------------------------------------------------
C THE SCAN SUBROUTINE HAS A KEY ROLE IN THE SIMULATION PROCESS.  ITS
C FUNCTIONS ARE:
C 1. IDENTIFY VEHICLES IN THE SYSTEM
C 2. PROCESS EACH VEHICLE ACCORDING TO ITS LANE AND POSITION IN THE SYSTEM
C 3. TEST WEATHER A DATA COLLECTION IS SCHEDULED
C 4. TESTS WHETHER VEHICLE TRAJECTORIES SHOULD BE STORED
C 5. UPDATES SPEED AND POSITION OF ALL VEHICLES THROUGH THE SIMULATED
C    SECTION
C 6. TESTS WHETHER VEHICLES AFTER BEING PROCESSED ARE OUT OF THE SYSTEM
C 7. SCHEDULES NEXT SCANNING EVENT
C ---------------------------------------------------------------------------
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
```

```
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C -----------------------------------------------------------------------
C TEST WHETHER ANY VEHICLES ARE IN SYSTEM'S QUEUE
      IA       = NNQ  (1)
      IB       = NNQ  (2)
C IF BOTH FILES ARE EMPTY, GENERATE NEXT SCAN
      IF (IA.EQ.0.AND.IB.EQ.0.) GO TO 70
      IF (IA.EQ.0.) THEN                 ! NO VEHICLE IN FILE 1, LOCATE POINTER
                                         ! TO FIRST ENTITY IN FILE 2
      NRANK_B  = NFIND(1,2,19,2,-0.1,0.0)
      IPOINT   = LOCAT(NRNAK_B, 2)
      CALL COPY (-IPOINT, 2, ATRIB)
      DIST     = ATRIB (19)
      IF (DIST.EQ.0.) IPOINT = MMFE (2)
      IFILE    = 2
      GO TO 30
      END IF
      IF (IB.EQ.0.) THEN                 ! NO VEHICLE IN FILE 2, LOCATE POINTER
                                         ! TO FIRST ENTITY IN FILE 1
      NRANK_A  = NFIND(1,1,19,2,-0.1,0.0)
      IPOINT   = LOCAT(NRNAK_A, 1)
      CALL COPY (-IPOINT, 1, ATRIB)
      DIST     = ATRIB (19)
      IF (DIST.EQ.0.) IPOINT = MMFE (1)
      IFILE    = 1
      GO TO 30
      END IF
C IF BOTH FILES HAVE ENTITIES THEN LOCATE ENTITY WITH GREATER DISTANCE
C TRAVELED
      NRANK_A  = NFIND(1,1,19,2,-0.1,0.0)
      IPOINT_A = LOCAT(NRNAK_A,1)
      CALL COPY (-IPOINT_A, 1, ATRIB)
      DIST_A   = ATRIB (19)
      IF (DIST_A.EQ.0.) IPOINT_A = MMFE (1)
      NRANK_B  = NFIND(1,2,19,2,-0.1,0.0)
      IPOINT_B = LOCAT(NRNAK_B,2)
      CALL COPY (-IPOINT_B, 2, ATRIB)
      DIST_B     = ATRIB (19)
      IF (DIST_B.EQ.0.) IPOINT_B = MMFE (2)
   20 CALL COPY  (-IPOINT_A, 1, ATRIB)
      DIST_A     = ATRIB (19)
      CALL COPY  (-IPOINT_B, 2, ATRIB)
      DIST_B     = ATRIB (19)
      IF         (DIST_A.GE.DIST_B) THEN
      IPOINT   = IPOINT_A
```

```
      IFILE    = 1
      DIST     = DIST_A
      ELSE IF    (DIST_B.GT.DIST_A) THEN
      IPOINT   = IPOINT_B
      IFILE    = 2
      DIST     = DIST_B
      END IF
   30 CALL RMOVE(-IPOINT, IFILE, ATRIB)
      IF (ATRIB(13).EQ.1.AND.ATRIB(19).EQ.0.) N_WE = N_WE + 1
      ATRIB (18) = ATRIB (19)                ! UPDATE LAST SCAN
      ATRIB (20) = ATRIB (21)                ! ATTRIBUTES
      CALL FILEM (IFILE, ATRIB)              ! COPY UPDATED ATTRIBUTES
C LOCATE LEADING VEHICLE TO BE PROCESSED
      NRANK_L = NFIND(1,IFILE,19,1,DIST,0.0)
      ILEAD    = LOCAT(NRANK_L,IFILE)
      IF (NRANK_L.EQ.0.) ILEAD = 0
      ICOUNT = 0
      CALL CAR_FOLLOW (IPOINT, ILEAD, IFILE, LFILE, ICOUNT)
      IF (ICOUNT.EQ.1) N_WED = N_WED+1   ! COUNT WEAVED VEHICLES
      IF (ICOUNT.EQ.1) CALL COPY (-IPOINT, LFILE, ATRIB)
      IF (ICOUNT.EQ.0) CALL COPY (-IPOINT, IFILE, ATRIB)
C COLLECT STATISTICS ON WEAVING AND NON-WEAVING SPEEDS
      VEH_STATUS = ATRIB (13)                ! VEHICLE STATUS (WEAVING/NON-WEAVING)
      VEH_SPEED2 = ATRIB (21)                ! UPDATED SPEED
      VEH_ACCE   = ATRIB (22)                ! VEHICLE ACCELERATION
      DISTANCE   = ATRIB (19)                ! DISTANCE TRAVELLED
      LTH        = L_UP + LENGTH
      LENGTH_T   = L_UP + LENGTH + L_DN! TOTAL LENGTH = (UP-STREAM BUFFER
                                             ! LENGTH) + (LENGTH OF WEAVING SECTION)
                                             ! + (DOWN-STREAM BUFFER LENGTH)
      IF (DISTANCE.GE.LENGTH_T) THEN
      TSYS = TNOW - ATRIB (2)                ! TIME IN THE SYSTEM
      CALL COLCT (TSYS, 14)                  ! COLLECT STATISTICS
      END IF
      IF (VEH_STATUS.EQ.1.)  THEN            ! THIS IS WEAVING VEHICLE
      IF (DISTANCE.GE.L_UP.AND.DISTANCE.LE.LTH) THEN
      CALL COLCT (VEH_SPEED2, 9)
      CALL COLCT (VEH_ACCE   ,10)
      END IF
      END IF
      IF (VEH_STATUS.EQ.2.)  THEN            ! THIS IS NON-WEAVING VEHICLE
      IF (DISTANCE.GE.L_UP.AND.DISTANCE.LE.LTH) THEN
      CALL COLCT (VEH_SPEED2, 11)
      CALL COLCT (VEH_ACCE   , 12)
      END IF
      END IF
      IF (ICOUNT.EQ.1) THEN
      PT_MERGE   = DISTANCE - L_UP
      CALL COLCT (PT_MERGE, 15)              ! COLLECT STATISTICS
      END IF
C LOCATE NEXT VEHICLE TO BE PROCESSED
      IF (IFILE.EQ.2) THEN
      INEXT_A  = IPOINT_A
      NRANK_B  = NFIND(1,2,19,-2,DIST,0.0)
      IF (NRANK_B.EQ.0) GO TO 31
```

```
      INEXT_B  = LOCAT(NRANK_B,2)
      END IF
   31 CONTINUE
      IF (IFILE.EQ.1) THEN
      INEXT_B  = IPOINT_B
      NRANK_A  = NFIND(1,1,19,-2,DIST,0.0)
      IF (NRANK_A.EQ.0) GO TO 32
      INEXT_A  = LOCAT(NRANK_A,1)
      END IF
   32 IF (NRANK_A.EQ.0.AND.NRANK_B.EQ.0) GO TO 35
      IF (NRANK_A.EQ.0) THEN
      IPOINT   = INEXT_B
      IFILE    = 2
      CALL COPY (-IPOINT, 2, ATRIB)
      DIST     = ATRIB (19)
      GO TO 30
      END IF
      IF (NRANK_B.EQ.0) THEN
      IPOINT   = INEXT_A
      IFILE    = 1
      CALL COPY (-IPOINT, 1, ATRIB)
      DIST     = ATRIB (19)
      GO TO 30
      END IF
      IPOINT_A = INEXT_A
      IPOINT_B = INEXT_B
      GO TO 20                          ! BOTH FILES HAVE ENTITIES
C TEST IF ANY VEHICLES ARE OUT OF THE SYSTEM
   35 CONTINUE
   40 IF (NNQ(1).GT.0.) THEN
      CALL COPY (1,1,ATRIB)             ! CHECK FILE 1
      IF (ATRIB(19).LE.LENGTH_T) GO TO 50
C IF THE VEHICLE IS OUT OF THE SYSTEM, REMOVE IT FORM FILE AND UPDATE
C RANKING
      CALL RMOVE (1,1,ATRIB)
      IF (NNQ(1).GT.0.) GO TO 40
      END IF
   50 IF (NNQ(2).GT.0.) THEN            ! CHECK FILE 2
      CALL COPY (1,2,ATRIB)
      IF (ATRIB(19).LE.LENGTH_T) GO TO 60
C IF THE VEHICLE IS OUT OF THE SYSTEM, REMOVE IT FORM FILE AND UPDATE
C RANKING
      CALL RMOVE (1,2,ATRIB)
      IF (NNQ(2).GT.0.) GO TO 50
      END IF
C NOW TEST WHETHER VEHICLE TRAJECTORIES SHOULD BE STORED IN THIS SCAN
   60 TIME = TNOW
      REMAINDER = MOD (TIME, ITRAJ)
      IF (REMAINDER.NE.0.) GO TO 70
      CALL TRAJECTORY (TIME)
C NOW GENERATE NEXT SCAN
   70 CALL SCHDL (3, 1., ATRIB)
      RETURN
      END
C  *****************************************************************************************
```

```
      SUBROUTINE CAR_FOLLOW (IPOINT, ILEAD, IFILE, LFILE, ICOUNT)
C ---------------------------------------------------------------------
C THE CAR_FOLLOW SUBROUTINE UPDATES THE SPEED AND POSITION OF EACH
C VEHICLE BY COMPUTING THE MAXIMUM POSSIBLE RATE OF ACCELERATION.
C ---------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     + SAVE (26), FS
      COMMON/UCOM9/GAP_LEAD,GAP_LAG,CRITICAL,FLAG_LD,FLAG_LG,FLAG_CR
C ---------------------------------------------------------------------
C COPY ATTRIBUTES IN ARRAY ATRIB
      CALL COPY (-IPOINT, IFILE, ATRIB)
      DO 10 J  = 1, 26
      SAVE (J) = ATRIB (J)
   10 CONTINUE
      CALL ACCELERATION (IPOINT, ILEAD, IFILE, ACC_F_ES, POS_L_ES)
C CHECK IF IT IS WEAVING VEHICLE
      BRT        = SAVE ( 3)           ! BRAKE REACTION TIME
      STATUS     = SAVE (13)           ! STATUS FOR W = 1, NW = 2
      OR_LANE    = SAVE ( 9)           ! ORIGINAL LANE
      CH_LANE    = SAVE (17)           ! NEW LANE
      POS_F_BS   = SAVE (18)           ! POSITION OF FOLLOWER BEFORE SCAN
      SPEED_F_BS = SAVE (20)           ! SPEED OF FOLLOWER BEFORE SCAN
      LTH        = L_UP + LENGTH
C UPDATED SPEED OF THE VEHICLE IS
      SPEED_F_ES = SPEED_F_BS + ACC_F_ES * ISCAN
C UPDATED POSITION OF THE VEHICLE IS
      X          = (ACC_F_ES*FS*ISCAN**2)/2
      POS_F_ES   = POS_F_BS + SPEED_F_BS*FS*BRT + X
      IF (SPEED_F_ES.LT.0.) THEN
      SPEED_F_ES = 0.
      ACC_F_ES   = - SPEED_F_BS
      POS_F_ES   = POS_F_BS
      END IF
C COPY UPDATED ATTRIBUTES OF THE ENTITY IN FILE (IFILE)
      SAVE (19) = POS_F_ES
      SAVE (21) = SPEED_F_ES
      SAVE (22) = ACC_F_ES
      SAVE (23) = POS_L_ES - POS_F_ES          ! FOLLOWER SPACE HEADWAY
      IF (SAVE(23).LT.0.) SAVE (23) =  LENGTH
      SP_HDWY   = SAVE (23)
C COLLECT STATISTICS ON VEHICLE SPACE HEADWAY
      IF (POS_F_ES.GE.L_UP.AND.POS_F_ES.LE.LTH) THEN
      CALL COLCT (SP_HDWY, 13)
      END IF
      CALL RMOVE(-IPOINT, IFILE, ATRIB)     ! REMOVE ENTITY, RMOVE ATTRIBUTES
```

```
      DO 20 J = 1, 26
      ATRIB (J) = SAVE (J)                  ! UPDATE ATTRIBUTES
   20 CONTINUE
      IPOINT = MFA
      CALL FILEM (IFILE, ATRIB)             ! COPY UPDATED ATTRIBUTES
C IF THE WEAVING VEHICLE HAS NOT YET CHANGED LANE, THEN CALL LANE CHANGE
C SUBROUTINE
      IF (STATUS.EQ.1.AND.POS_F_ES.GE.L_UP) THEN
         IF (OR_LANE.EQ.CH_LANE)
     +   CALL LANE_CHANGE (IPOINT,IFILE,LFILE,ICOUNT)
      END IF
      RETURN
      END
C   ***************************************************************************************
      SUBROUTINE ACCELERATION(IPOINT,ILEAD,IFILE,ACC_F_ES, POS_L_ES)
C ---------------------------------------------------------------------------
C THIS SUBROUTINE IS CALLED FROM SUBROUTINE CAR_FOLLOW, IT RETURNS
C ACCELERATION OF A VEHICLE BASED ON ITS POSITION AND SPEED WITH RESPECT TO
C ITS FOLLOWER
C ---------------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C ---------------------------------------------------------------------------
      DIMENSION PC (3,6), SU (3,6), TC (3,6)
      IF (ILEAD.EQ.0) GO TO 350                    ! THIS IS FIRST VEHICLE,
                                                   ! PASS CONTROL TO 350
      CALL COPY (-IPOINT, IFILE, ATRIB)
      DO 10 J  = 1, 26
      SAVE (J) = ATRIB (J)
   10 CONTINUE
C THIS IS FOLLOWING VEHICLE, CALCULATE ITS ACCELERATION
      ITYPE      = ATRIB(8)                  ! TYPE OF VEHICLE
      STATUS     = ATRIB(13)                 ! WEAVING=1., NON-WEAVING=2.
      BRT_F      = ATRIB(3)                  ! BRAKE REACTION TIME OF FOLLOWER
      POS_F_BS   = ATRIB(18)                 ! POSITION OF FOLLOWER BEFORE
                                             ! LAST SCAN
      POS_F_ES   = ATRIB(19)                 ! POSITION OF FOLLOWER AT END
                                             ! OF LAST SCAN
      SPEED_F_BS = ATRIB(20)*FS              ! SPEED OF FOLLOWER BEFORE  LAST
                                             ! SCAN (FPS)
      SPEED_F_ES = ATRIB(21)*FS              ! SPEED OF FOLLOWER AT END OF
                                             ! LAST SCAN (FPS)
      ADJ_UP     = ATRIB (10)                ! UPWARD SPEED ADJUSTMENT
      ADJ_DN     = ATRIB (12)                ! DOWNWARD SPEED ADJUSTMENT
      CALL COPY (-ILEAD, IFILE, ATRIB)
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      L_LEADER   = ATRIB(5)               ! LENGTH OF LEADER
      POS_L_BS   = ATRIB(18)              ! POSITION OF LEADER BEFORE LAST
                                          ! SCAN
      POS_L_ES   = ATRIB(19)              ! POSITION OF LEADER AT END  OF
                                          ! SCAN
      SPEED_L_BS = ATRIB(20)*FS           ! SPEED OF LEADER BEFORE LAST
                                          ! SCAN (FPS)
      SPEED_L_ES = ATRIB(21)*FS           ! SPEED OF LEADER AT END OF LAST
                                          ! SCAN (FPS)
      ACC_L_ES   = ATRIB(22)              ! ACCELERATION OF LEADER END OF
                                          ! SCAN
C      ACC_F_ES                           ! ACCELERATION OF FOLLOWER AT
                                          ! END OF SCAN (MPH/S)
C      DEC_MAX                            ! MAXIMUM EMERGENCY DECELERATION
                                          ! RATE (MPH/S) = 13.2 - (INPUT)
C      ISCAN                              ! TIME SCANNING INTERVAL (1 SEC.)
      SD         = ATRIB (26)             ! SAFETY DISTANCE (VARIES 5-10 FT)
      G_LEAD     = POS_L_ES - POS_F_BS
C COMPARE SPEEDS OF LEADER AND FOLLOWER
      IF (SPEED_L_ES.EQ.0.) THEN
      ICODE = 1
      ELSE IF (SPEED_L_ES.GT.0.AND.SPEED_L_ES.LT.SPEED_F_BS) THEN
      ICODE = 2
      ELSE IF (SPEED_L_ES.GT.SPEED_F_BS) THEN
      ICODE = 3
      END IF
      GO TO (100, 200, 300) ICODE
  100 CONTINUE
C CASE - 1: THE LEADER HAS COME TO A COMPLETE STOP.  THE FOLLOWER SHOULD
C         ALSO COME TO STOP WHILE MAINTAINING A  SPACE  HEADWAY  OF AT
C         LEAST EQUAL TO THE  LENGTH  OF THE LEADER  (L_LEADER) PLUS A
C         SAFETY DISTANCE (SD).
      ACC_F_ES   = -SPEED_F_BS**2/(2*FS*(POS_L_ES-POS_F_BS-L_LEADER-SD))
      A1 = ACC_F_ES
      GO TO 700
  200 CONTINUE
C CASE - 2: THE UPDATED SPEED OF THE LEADER IS GREATER THAN ZERO BUT LESS
C         THAN CURRENT SPEED OF THE FOLLOWER.  THE FOLLOWER SHOULD,
C         THEREFORE, DECELERATE TO AVOID COLLISION.
      S        = BRT_F*SPEED_F_BS
      D        = -2*DEC_MAX/(ISCAN**2)
      E        = (SPEED_F_BS**2-SPEED_L_ES**2)/(2*DEC_MAX)
      F        = POS_L_ES-POS_F_BS-SPEED_F_BS*ISCAN-SD-L_LEADER-S
      B        = (2*SPEED_F_BS+DEC_MAX*ISCAN+2*BRT_F*DEC_MAX)/ISCAN
      C        = D*(F-E)
      ACC_F_E2 = (-B + SQRT(ABS(B**2 - 4*C)))/(2*1.47)
      ACC_F_ES = ACC_F_E2
      IF (ITYPE.EQ.1.AND.ACC_F_E2.GT.7.  ) ACC_F_ES = 7.0
      IF (ITYPE.EQ.2.AND.ACC_F_E2.GT.3.66) ACC_F_ES = 3.66
      IF (ITYPE.EQ.3.AND.ACC_F_E2.GT.3.46) ACC_F_ES = 3.46
      GO TO 700
  300 CONTINUE
C CASE - 3: THE UPDATED SPEED OF THE LEADER IS GREATER THAN THE CURRENT
C         SPEED OF THE FOLLOWER
      G        = 2*BRT_F*ISCAN+ISCAN**2
```

```
      H         = SPEED_F_BS*(ISCAN+BRT_F)
      O         = POS_L_ES-POS_F_BS-L_LEADER-SD
      ACC_F_E3 = 2*(O-H)/(G*1.47)
      ACC_F_ES = ACC_F_E3
      IF (ITYPE.EQ.1.AND.ACC_F_E3.GT.7.  ) ACC_F_ES = 7.0
      IF (ITYPE.EQ.2.AND.ACC_F_E3.GT.3.66) ACC_F_ES = 3.66
      IF (ITYPE.EQ.3.AND.ACC_F_E3.GT.3.46) ACC_F_ES = 3.46
      GO TO 700
C ASSIGN MAXIMUM ACCELERATION RATE TO THE LEAD VEHICLE BASED ON ITS TYPE
C AND SPEED
  350 CALL COPY (-IPOINT, IFILE, ATRIB)
      ITYPE       = ATRIB (8)                ! TYPE OF LEADING VEHICLE
      SPEED_F_BS  = ATRIB (20)               ! SPEED OF LEADER BEFORE LAST
                                             ! SCAN (FPS)
      IF (GRADE.EQ.0.)                              II = 1
      IF (GRADE.GT.0.AND.GRADE.LE.2.)               II = 2
      IF (GRADE.GT.2.)                              II = 3
      IF (SPEED_F_BS.GE.0. AND.SPEED_F_BS.LT.5.)   JJ = 1
      IF (SPEED_F_BS.GE.5. AND.SPEED_F_BS.LT.15.)  JJ = 2
      IF (SPEED_F_BS.GE.15.AND.SPEED_F_BS.LT.30.)  JJ = 3
      IF (SPEED_F_BS.GE.30.AND.SPEED_F_BS.LT.40.)  JJ = 4
      IF (SPEED_F_BS.GE.40.AND.SPEED_F_BS.LT.50.)  JJ = 5
      IF (SPEED_F_BS.GE.50.)                        JJ = 6
      SPEED_F_BS = SPEED_F_BS*FS
      GO TO (400, 500, 600) ITYPE
  400 CONTINUE
      DATA PC/ 4.7, 4.6, 4.2, 4.5, 4.2, 4.0, 4.2, 4.0, 3.7, 3.8, 3.5,
     +         3.4, 2.8, 2.7, 2.5, 1.9, 1.7, 1.5 /
      ACC_F_ES = PC (II,JJ)
      GO TO 800
  500 CONTINUE
      DATA SU/ 2.0, 1.6, 0.7, 1.0, 0.8, 0.5, 1.0, 0.6, 0.0, 0.6, 0.6,
     +         0.0, 0.2, 0.2, 0.0, 0.0, 0.0, 0.0 /
      ACC_F_ES = SU (II,JJ)
      GO TO 800
  600 CONTINUE
      DATA TC/ 2.0, 1.6, 0.7, 1.0, 0.8, 0.5, 0.8, 0.6, 0.0, 0.4, 0.3,
     +         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0 /
      ACC_F_ES = TC (II,JJ)
      GO TO 800
  700 CONTINUE
      IF (ADJ_DN.EQ.99.) ACC_F_ES = COM_DEC (ITYPE)
      IF (ADJ_DN.NE.99.AND.STATUS.EQ.1.)ACC_F_ES= ACC_F_ES+ADJ_DN
      IF (ACC_F_ES.LT.-DEC_MAX) ACC_F_ES = -DEC_MAX
      IF (SPEED_F_BS/FS.GT.50.AND.ACC_F_ES.GT.0.) ACC_F_ES = 0.0
      IF (ADJ_UP.EQ.1.) THEN
        IF (ACC_F_ES.LE.6.0.AND.G_LEAD.GT.60) ACC_F_ES=ACC_F_ES+1.
      END IF
      IF (GRADE.GT.2.AND.ITYPE.GT.1.AND.ACC_F_ES.GT.0.)
     +   ACC_F_ES = ACC_F_ES*0.9
      IF (GRADE.GT.4.AND.ITYPE.GT.1.AND.ACC_F_ES.GT.0.)
     +   ACC_F_ES = ACC_F_ES*0.85
  800 RETURN
      END
C   ****************************************************************************************
```

```
      SUBROUTINE LANE_CHANGE (IPOINT,IFILE,LFILE,ICOUNT)
C ----------------------------------------------------------------------
C THE FUNCTION OF THIS SUBROUTINE IS:
C TO CHECK AVAILABILITY OF GAP FOR LANE CHANGING VEHICLE
C ----------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
      COMMON/UCOM9/GAP_LEAD,GAP_LAG,CRITICAL,FLAG_LD,FLAG_LG,FLAG_CR
C ----------------------------------------------------------------------
      CALL COPY (-IPOINT, IFILE, ATRIB)
      DISTANCE = ATRIB (19)
      ADJ_UP   = ATRIB (10)
      ADJ_DN   = ATRIB (12)
      WRITE (NPRNT, *) 'ADJ_UP,_DN',ADJ_UP,ADJ_DN
C CHECK FOR AVAILABLE GAPES FOR CHANGER IF IT HAS ENTERED THE SECTION
      IF (DISTANCE.GE.L_UP) CALL TEST_GAP (IPOINT,IFILE,ADJ_UP,ADJ_DN)
      IF (FLAG_LD.EQ.1.AND.FLAG_LG.EQ.1.AND.FLAG_CR.EQ.1.) THEN
         CALL RMOVE (-IPOINT, IFILE, ATRIB)
         OR_LANE    = ATRIB ( 9)
         IF (OR_LANE.EQ.1.) CH_LANE = 2.
         IF (OR_LANE.EQ.2.) CH_LANE = 1.
         IF (IFILE.EQ.1) LFILE = 2
         IF (IFILE.EQ.2) LFILE = 1
         ATRIB (17) = CH_LANE
         IPOINT     = MFA
         CALL FILEM (LFILE, ATRIB)
         ICOUNT = 1
      END IF
      IF (ADJ_UP.EQ.1.OR.ADJ_DN.NE.0.) THEN
         CALL RMOVE (-IPOINT, IFILE, ATRIB)
         ATRIB (10) = ADJ_UP
         ATRIB (12) = ADJ_DN
         IPOINT     = MFA
         CALL FILEM (IFILE, ATRIB)
      END IF
      RETURN
      END
C  ************************************************************************************
      SUBROUTINE TEST_GAP (IPOINT,IFILE,ADJ_UP,ADJ_DN)
C ----------------------------------------------------------------------
C THIS SUBROUTINE TESTS THE AVAILABILITY OF SAFE LEAD GAP, SAFE LAG GAP
C AND CRITICAL GAP FOR THE LANE CHANGING VEHICLE.  IF THE GAPS ARE NOT
C AVAILABLE, THEN IT WILL FLAG FOR EITHER UPWARD OR DOWNWARD SPEED
C ADJUSTMENT.
C ----------------------------------------------------------------------
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      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
      COMMON/UCOM9/GAP_LEAD,GAP_LAG,CRITICAL,FLAG_LD,FLAG_LG,FLAG_CR
C ---------------------------------------------------------------------
      REAL LCF
C INITIALIZE FLAGS FOR CHANGER
      FLAG_LD = 0.                         ! LEAD GAP FLAG
      FLAG_LG = 0.                         ! LAG  GAP FLAG
      FLAG_CR = 0.                         ! CRITICAL GAP FLAG
      ADJ_UP  = 0.                         ! UPWARD SPEED ADJUSTMENT
      ADJ_DN  = 0.                         ! DOWNWARD SPEED ADJUSTMENT
C COPY ATTRIBUTES OF CHANGER
      CALL COPY (-IPOINT, IFILE, ATRIB)
      DO 10 J  = 1, 26
      SAVE (J) = ATRIB (J)
   10 CONTINUE
      LENGTH_C       = SAVE  ( 5)
      DIST1          = SAVE  (18)
      DIST2          = SAVE  (19)
      SPEED1         = SAVE  (20)
      SPEED2         = SAVE  (21)
      GAP_CRI        = SAVE  (14)
      HEADWAY        = SAVE  (23)
C LOCATE LEADER OF CHANGER IN THE DESIRED LANE
      IF (IFILE.EQ.1) THEN
      NRANK_L  = NFIND(1,2,19,1,DIST2,0.0)
      NFILE    = 2
      IF (NRANK_L.EQ.0) GO TO 15
      ILEAD_C  = LOCAT(NRANK_L,2)
      ELSE IF (IFILE.EQ.2) THEN
      NRANK_L  = NFIND(1,1,19,1,DIST2,0.0)
      NFILE    = 1
      IF (NRANK_L.EQ.0) GO TO 15
      ILEAD_C  = LOCAT(NRANK_L,1)
      END IF
   15 IF (NRANK_L.EQ.0) ILEAD_C = 0            ! THERE IS NO LEADER FOR CHANGER
C LOCATE FOLLOWER OF CHANGER IN THE DESIRED LANE
      IF (IFILE.EQ.1) THEN
      NRANK_F  = NFIND(1,2,19,-2,DIST2,0.0)
      NFILE    = 2
      IF (NRANK_F.EQ.0) GO TO 18
      IFOLLOW  = LOCAT(NRANK_F,2)
      ELSE IF (IFILE.EQ.2) THEN
      NRANK_F  = NFIND(1,1,19,-2,DIST2,0.0)
      NFILE    = 1
```

```
      IF (NRANK_F.EQ.0) GO TO 18
      IFOLLOW  = LOCAT(NRANK_F,1)
      END IF
   18 IF (NRANK_F.EQ.0) IFOLLOW = 0        ! THERE'S NO FOLLOWER FOR CHANGER
C COMPUTE LEAD GAP
      IF (ILEAD_C.EQ.0) THEN
      FLAG_LD  = 1.
      GAP_LEAD = LENGTH + L_DN - DIST2
      GO TO 20
      END IF
      CALL COPY (-ILEAD_C, NFILE, ATRIB)
      LENGTH_L = ATRIB ( 5)
      DIST_L1  = ATRIB (18)
      DIST_L2  = ATRIB (19)
      SPEED_L1 = ATRIB (20)
      SPEED_L2 = ATRIB (21)
      ACC_L    = ATRIB (22)
      GAP_LEAD = DIST_L2 - LENGTH_L - DIST2
C COMPUTE LAG GAP
   20 IF (IFOLLOW.EQ.0) THEN
      FLAG_LG  = 1.
      GAP_LAG  = DIST2 - LENGTH_C
      GO TO 30
      END IF
      CALL COPY (-IFOLLOW, NFILE, ATRIB)
      BRT_F    = ATRIB ( 3)
      DIST_F1  = ATRIB (18)
      DIST_F   = ATRIB (19)
      SPEED_F1 = ATRIB (20)
      SPEED_F  = ATRIB (21)
      ACC_F    = ATRIB (22)
C PREDICT UPDATED ACCELERATION FOR FOLLOWER
      CALL ACCELERATION (IFOLLOW, ILEAD_C, NFILE, ACC_F_ES, POS_L_ES)
C UPDATED SPEED OF THE FOLLOWER IS
      SPEED_F2 = SPEED_F1 + ACC_F_ES * ISCAN
C UPDATED POSITION OF THE VEHICLE IS
      X        = (ACC_F_ES*FS*ISCAN**2)/2
      DIST_F2  = DIST_F1 + SPEED_F1*FS*BRT_F + X
      GAP_LAG = DIST2 - LENGTH_C - DIST_F2
C COMPUTE TOTAL GAP
   30 IF (FLAG_LD.EQ.0.AND.FLAG_LG.EQ.0.)     THEN
      CRITICAL = DIST_L2 - LENGTH_L - DIST_F2
      ELSE IF (FLAG_LD.EQ.0.AND.FLAG_LG.EQ.1.) THEN
      CRITICAL = DIST_L2 - L_UP
      ELSE IF (FLAG_LG.EQ.0.AND.FLAG_LD.EQ.1.) THEN
      CRITICAL = LENGTH + L_UP - DIST_F2
      ELSE IF (FLAG_LG.EQ.1.AND.FLAG_LD.EQ.1.) THEN
      CRITICAL = L_UP + LENGTH + L_DN
      END IF
C SINCE THE VEHICLE IS A WEAVING VEHICLE, THEREFORE, APPLY LANE CHANGING
C FACTOR (LCF) ON THE GENERATED CRITICAL GAP
      VAW = IVOL_A * VOL_PR_AD                ! APPROACH A WEAVING VOLUME
      VBW = IVOL_B * VOL_PR_BC                ! APPROACH B WEAVING VOLUME
      VW  = VAW + VBW                         ! TOTAL WEAVING VOLUME
      XD  = DIST2 - L_UP                      ! DISTANCE FORM ENTRANCE GORE
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      LT  = LENGTH                                ! LENGTH OF WEAVING SECTION
      IF (IFILE.EQ.1) VMW = VAW                   ! VOLUME WEAVING INTO THE LANE
      IF (IFILE.EQ.2) VMW = VBW
      LCF=MAX(EXP(LOG(1+VMW/VW)*(XD/LT)),1.)  ! LANE CHANGE FACTOR
      GAP_CRIT = GAP_CRIT / LCF
      G_LAG   = 15.                               ! MINIMUM LAG GAP
      G_LEAD  = 10.                               ! MINIMUM LEAD GAP
      IF     (DIST2.GT.0.4*LENGTH+L_UP) THEN
      G_LAG   = 5*DRAND(ISEED) + 5
      G_LEAD  = 3*DRAND(ISEED) + 5
      ELSE IF (DIST2.GT.0.6*LENGTH+L_UP) THEN
      G_LAG   = 1*DRAND(ISEED) + 5
      G_LEAD  = 1*DRAND(ISEED) + 4
      END IF
      GAP_MIN = G_LAG + LENGTH_C + G_LEAD ! MINIMUM CRITICAL GAP
      IF (DIST2.GT.0.6*LENGTH+L_UP) GAP_CRIT = GAP_MIN
      IF (GAP_CRIT.LT.GAP_MIN)     GAP_CRIT = GAP_MIN
C IF APPROPRIATE LEAD GAP IS AVAILABLE THEN FLAG_LD 'YES'
      IF (FLAG_LD.EQ.0.) THEN
        IF (GAP_LEAD.GE.G_LEAD.AND.SPEED_L2.GE.SPEED2) THEN
        FLAG_LD = 1.
        ELSE IF (GAP_LEAD.GE.G_LEAD.AND.SPEED2.GT.SPEED_L2) THEN
        A_LEAD  = FS*(SPEED2-SPEED_L2)*ISCAN + G_LEAD
        IF (GAP_LEAD.GE.A_LEAD) FLAG_LD = 1.
C IF THE LEAD GAP ISN'T APPROPRIATE THEN TEST WHETHER UPWARD/DOWNWARD
C SPEED ADJUSTMENT WILL IMPROVE THE POSSIBILITY OF LANE CHANGE IN THE NEXT
C SCAN
        ELSE IF (GAP_LEAD.LT.G_LEAD.AND.GAP_LAG.GT.G_LAG+60.) THEN
        ADJ = 99.
        A1  = DIST_F2 - CRITICAL/2.
        S1  = DIST2   - A1
        ACC = -2*(S1-SPEED2*FS*AV_BR_TIME)/FS
        IF (DIST2.LT.0.5*LENGTH+L_UP) ADJ_DN = ADJ
        IF (DIST2.GT.0.5*LENGTH+L_UP) ADJ_DN = ACC
        END IF
      END IF
      IF (ADJ_DN.LT.-4.0) ADJ_DN = -4.0
      IF (ADJ_DN.GT.0.)   ADJ_DN = 0.
C IF APPROPRIATE LAG GAP IS AVAILABLE THEN FLAG_L 'YES'
      IF (FLAG_LG.EQ.0.) THEN
        IF (GAP_LAG.GE.G_LAG.AND.SPEED2.GE.SPEED_F2) THEN
        FLAG_LG = 1.
        ELSE IF (GAP_LAG.GE.G_LAG.AND.SPEED_F2.GT.SPEED2) THEN
        A_LAG   = FS*(SPEED_F2-SPEED2)*ISCAN + G_LAG
           IF (GAP_LAG.GE.A_LAG) FLAG_LG = 1.
C IF THE LEAD GAP ISN'T APPROPRIATE THEN TEST WHETHER UPWARD/DOWNWARD
C SPEED ADJUSTMENT WILL IMPROVE THE POSSIBILITY OF LANE CHANGE IN THE NEXT
C SCAN
        ELSE IF (GAP_LAG.LT.G_LAG.AND.GAP_LEAD.GT.GAP_LEAD+55.) THEN
        ADJ_UP = 1.
        END IF
      END IF
      IF (CRITICAL.GE.GAP_CRIT) FLAG_CR = 1.
      RETURN
      END
```

```
C ******************************************************************************************
      FUNCTION FACTOR (AR_SPEED)
C ---------------------------------------------------------------------------------
C THIS FUNCTION RETURNS A FRICTION FACTOR BASED ON VEHICLE SPEED
C ---------------------------------------------------------------------------------
      IF (AR_SPEED.LE.20.)                  FACTOR = 0.65
      IF (AR_SPEED.GT.20.AND.AR_SPEED.LE.30.) FACTOR = 0.54
      IF (AR_SPEED.GT.30.AND.AR_SPEED.LE.40.) FACTOR = 0.49
      IF (AR_SPEED.GT.40.AND.AR_SPEED.LE.50.) FACTOR = 0.35
      IF (AR_SPEED.GT.50.)                  FACTOR = 0.32
      RETURN
      END
C ******************************************************************************************
      FUNCTION COM_DEC (ITYPE)
C ---------------------------------------------------------------------------------
C THIS FUNCTION RETURNS A COMFORTABLE DECELERATION RATE BASED ON
C VEHICLE TYPE
C ---------------------------------------------------------------------------------
      IF (ITYPE.EQ.1) COM_DEC = -1.0
      IF (ITYPE.EQ.2) COM_DEC = -2.0
      IF (ITYPE.EQ.3) COM_DEC = -2.5
      RETURN
      END
C ******************************************************************************************
      SUBROUTINE TRAJECTORY (TIME)
C ---------------------------------------------------------------------------------
C THIS SUBROUTINE GIVES VEHICLE TRAJECTORY EVERY ITRAJ SECONDS.
C USED FOR END-OF-RUN PROCESSING AND OUTPUT REPORTING
C ---------------------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,


     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C ---------------------------------------------------------------------------------
      WRITE (NPRNT, 10) TIME
   10 FORMAT(//, 20X,' VEHICLE TRAJECTORY AT TIME', F10.5,' SEC'/
     +         , 20X,' *************************************'//)
      JA = NNQ (1)
      JB = NNQ (2)
      IF (NNQ(1).EQ.0.AND.NNQ(2).EQ.0.) GO TO 40     ! BOTH FILES EMPTY
      IVEH_1 = MMFE (1)
      IVEH_2 = MMFE (2)
   15 IF (JA.EQ.0.) THEN                             ! FILE 1 IS EMPTY
      IVEHICLE = IVEH_2
      IFILE    = 2
```

```
      GO TO 20
      END IF
      IF (JB.EQ.0.) THEN                              ! FILE 2 IS EMPTY
      IVEHICLE = IVEH_1
      IFILE   = 1
      GO TO 20
      END IF
C BOTH FILES HAVE ENTITIES, LOCATE VEHICLE MOST DISTANT FROM ENTRANCE
      CALL COPY (-IVEH_1,1,ATRIB)
      DIST_1     = ATRIB (19)
      CALL COPY (-IVEH_2,2,ATRIB)
      DIST_2     = ATRIB (19)
      IF (DIST_1.GE.DIST_2) THEN
      IVEHICLE  = IVEH_1
      IFILE       = 1
      ELSE IF (DIST_1.LT.DIST_2) THEN
      IVEHICLE  = IVEH_2
      IFILE       = 2
      END IF
   20 CALL COPY (-IVEHICLE, IFILE, ATRIB)
      ID_NO      = ATRIB(24)
      ITYPE      = ATRIB(8)
      ORIG       = ATRIB(9)
      STATUS     = ATRIB(13)
      POSI       = ATRIB(19)
      SPEED      = ATRIB(21)
      ACCE       = ATRIB(22)
      C_LANE     = ATRIB(17)
      WRITE (NPRNT, 30) ID_NO, ITYPE, STATUS, ORIG, POSI,
     + SPEED, ACCE, C_LANE
   30 FORMAT (//4X, 'VEHICLE ID NO                    = ', I5,
     +        /4X, 'VEHICLE TYPE (1-PC, 2-SU, 3-TC)  = ', I5,
     +        /4X, 'VEHICLE STATUS (W-1, NW-2)       = ', F8.2,
     +        /4X, 'ORIGINAL APPROACH (A-1, B-2)     = ', F8.2,
     +        /4X, 'VEHICLE POSITION (FT)            = ', F8.2,
     +        /4X, 'SPEED  (MPH)                     = ', F8.2,
     +        /4X, 'ACCELERATION (MPH/S)             = ', F8.2,
     +        /4X, 'CURRENT LANE                     = ', F8.2)
      IF (IFILE.EQ.2) THEN
      JB         = JB - 1
        IF (JB.GT.0.) THEN
        IRANK_2  = NFIND(1,2,19,-2,DIST_2,0.0)
        IVEH_2   = LOCAT(IRANK_2,2)
        END IF
      ELSE IF (IFILE.EQ.1) THEN
      JA         = JA - 1
        IF (JA.GT.0.) THEN
        IRANK_1  = NFIND(1,1,19,-2,DIST_1,0.0)
        IVEH_1   = LOCAT(IRANK_1,1)
        END IF
      END IF
      IF (JA.EQ.0.AND.JB.EQ.0) GO TO 40
      GO TO 15                              ! BOTH FILES HAVE ENTITIES
   40 RETURN
      END
```

```
C ******************************************************************************
      FUNCTION LOS1 (SW)
C ---------------------------------------------------------------------------
C THIS FUNCTION RETURNS LEVEL OF SERVICE BASED ON AVERAGE WEAVING (SW)
C SPEED
C LEVEL OF SERVICE FOR WEAVING VEHICLES
      IF (SW.GE.42.)                 LOS1 = 1
      IF (SW.LT.42.AND.SW.GE.38.)    LOS1 = 2
      IF (SW.LT.38.AND.SW.GE.33.)    LOS1 = 3
      IF (SW.LT.33.AND.SW.GE.30.)    LOS1 = 4
      IF (SW.LT.30.AND.SW.GE.25.)    LOS1 = 5
      IF (SW.LT.25.)                 LOS1 = 6
      RETURN
      END
C ******************************************************************************
      FUNCTION LOS2 (SNW)
C ---------------------------------------------------------------------------
C THIS FUNCTION RETURNS LEVEL OF SERVICE BASED ON AVERAGE NOW-WEAVING
C (SNW) SPEED
C ---------------------------------------------------------------------------
C LEVEL OF SERVICE FOR NON-WEAVING VEHICLES
      IF (SNW.GE.45.)                  LOS2 = 1
      IF (SNW.LT.45.AND.SNW.GE.40.) LOS2 = 2
      IF (SNW.LT.40.AND.SNW.GE.35.) LOS2 = 3
      IF (SNW.LT.35.AND.SNW.GE.30.) LOS2 = 4
      IF (SNW.LT.30.AND.SNW.GE.25.) LOS2 = 5
      IF (SNW.LT.25.)                  LOS2 = 6
      RETURN
      END
C ******************************************************************************
      SUBROUTINE OTPUT
C ---------------------------------------------------------------------------
C SUBROUTINE OTPUT IS CALLED AT THE END OF EACH SIMULATION RUN AND IS
C USED FOR:
C 1. END-OF-RUN PROCESSING AND OUTPUT REPORTING
C 2. COLLECTING STATISTICS OVER SIMULATION RUNS
C 3. COMPUTING LEVEL OF SERVICE BASED ON AVERAGE WEAVING &NON-WEAVING
C    SPEEDS
C ---------------------------------------------------------------------------
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/LENGTH, IWIDTH, L_UP, L_DN, GRADE, NLANE
      COMMON/UCOM2/LCAR, LTRUCK, LTRAILER, ACE_MAX, DEC_MAX
      COMMON/UCOM3/IVOL_A,IVOL_B,TRUCK_PR,TRAILER_PR,VOL_PR_AD,VOL_PR_BC
      COMMON/UCOM4/AV_ACE, AV_DEC, DEC_MIN, SPEED_MAX, AV_BR_TIME,
     +BR_TIME_MIN,BR_TIME_MAX,SIGMA_BR_TIME
      COMMON/UCOM5/ISCAN, ITRAJ, WARM_TIME, ISEED
      COMMON/UCOM6/AR_HDWY_MIN,AR_HDWY_MAX,AV_AR_HDWY,SIGMA_AR_HDWY
      COMMON/UCOM7/AR_SPEED_MIN,AR_SPEED_MAX,SIGMA_AR_SPEED,AV_AR_SPEED
      COMMON/UCOM8/ID_NO_A, ID_NO_B, TIME_FIRST (2), N_VEH_A, N_VEH_B,
     +SAVE (26), FS
C ---------------------------------------------------------------------------
      DIMENSION A(5,15), B(4)
      CALL PRNTP (-1)                ! PRINTS ALL PLOST/TABLES
      CALL SUMRY                     ! PRINTS SLAM II SUMMARY REPORT
```

```
      CALL PRNTF (1)              ! PRINTS STATISTICS ON FILE 1
      CALL PRNTF (2)              ! PRINTS STATISTICS ON FILE 2
      CALL PRNTC (-1)             ! PRINTS STATISTICS FOR ALL
                                  ! COLCT VARIABLES
      CALL PRNTH (-1)             ! PRINTS HISTOGRAMS FOR ALL
                                  ! COLCT VARIABLES
      CALL PRNTB (-1)             ! PRINTS ALL HISTOGRAMS FOR
                                  ! TIME-PERSISTENT VARIABLES
     CALL PRNTT (-1)              ! PRINTS STATISTICS FOR TIME-
                                  ! PERSISTENT VARIABLES
C OBTAIN STATISTICS OVER SIMULATION RUNS
      DO 1 I = 1, 15
C OBTAIN STATISTICS OF VARIABLE I
         A(1,I)  = CCAVG (I)      ! AVERAGE OF VARIABLE I
         A(2,I)  = CCSTD (I)      ! STANDARD DEVIATION OF VARIABLE I
         A(3,I)  = CCMAX (I)      ! MAXIMUM OF VARIABLE I
         A(4,I)  = CCMIN (I)      ! MINIMUM OF VARIABLE I
         A(5,I)  = CCNUM (I)      ! NUMBER OF OBSERVATION OF I
    1 CONTINUE
      WRITE (NPRNT,  2) (A(J,1 ), J=1,5)
      WRITE (NPRNT,  3) (A(J,2 ), J=1,5)
      WRITE (NPRNT,  4) (A(J,3 ), J=1,5)
      WRITE (NPRNT,  5) (A(J,4 ), J=1,5)
      WRITE (NPRNT,  6) (A(J,5 ), J=1,5)
      WRITE (NPRNT,  7) (A(J,6 ), J=1,5)
      WRITE (NPRNT,  8) (A(J,7 ), J=1,5)
      WRITE (NPRNT,  9) (A(J,8 ), J=1,5)
      WRITE (NPRNT, 10) (A(J,9 ), J=1,5)
      WRITE (NPRNT, 11) (A(J,10), J=1,5)
      WRITE (NPRNT, 12) (A(J,11), J=1,5)
      WRITE (NPRNT, 13) (A(J,12), J=1,5)
      WRITE (NPRNT, 14) (A(J,13), J=1,5)
      WRITE (NPRNT, 15) (A(J,14), J=1,5)
      WRITE (NPRNT, 16) (A(J,15), J=1,5)
    2 FORMAT( /15X,'** STATISTICS OF VARIABLES OVER SIMULATION RUNS **',
     +  /15X,'==================================================',
     +  //24X,'MEAN      STANDARD    MAXIMUM    MINIMUM     NO. OF',
     +  /24X,'VALUE     DEVIATION    VALUE      VALUE       OBS' ,//
     +2X,'REACTION TIME_A',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    3 FORMAT(/2X,
     +'ARRIVAL SPEED_A',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    4 FORMAT(/2X,
     +'ACCEPTED GAP_A ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    5 FORMAT(/2X,
     +'ARR HEADWAY_A  ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    6 FORMAT(/2X,
     +'REACTION TIME_B',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    7 FORMAT(/2X,
     +'ARRIVAL SPEED_B',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    8 FORMAT(/2X,
     +'ACCEPTED GAP_B ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
    9 FORMAT(/2X,
     +'ARR HEADWAY_B  ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
   10 FORMAT(/2X,
     +'WEAVING SPEED  ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
```

```
  11 FORMAT(/2X,
   +'WEAVING ACCELRA',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
  12 FORMAT(/2X,
   +'SPEED NONWEAVIN',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
  13 FORMAT(/2X,
   +'ACCEL NONWEAVIN',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
  14 FORMAT(/2X,
   +'SPACE HEADWAY  ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
  15 FORMAT(/2X,
   +'TIME IN SYSTEM ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0)
  16 FORMAT(/2X,
   +'MERGING POINT  ',3X,E9.2,3X,E9.2,3X,E9.2,3X,E9.2,3X,F8.0/)
    DO 20 IFILE = 1, 3
C COLLECT STATISTICS OF ENTITIES IN FILE IFILE
      B(IFILE)= FFAVG (IFILE)            ! AVERAGE # OF ENTITIES IN FILE IFILE
  20 CONTINUE
C GET LEVEL OF SERVICE
    SW  =  A(1, 9)                       ! AVERAGE WEAVING SPEED
    SNW =  A(1,11)                       ! AVERAGE NON-WEAVING SPEED
    L1   = LOS1 (SW)
    L2   = LOS2 (SNW)
C PRINT COMPUTED LEVEL OF SERVICE FOR WEAVING VEHICLES
    IF (L1.EQ.1) WRITE (NPRNT,30)
    IF (L1.EQ.2) WRITE (NPRNT,40)
    IF (L1.EQ.3) WRITE (NPRNT,50)
    IF (L1.EQ.4) WRITE (NPRNT,60)
    IF (L1.EQ.5) WRITE (NPRNT,70)
    IF (L1.EQ.6) WRITE (NPRNT,80)
C PRINT COMPUTED LEVEL OF SERVICE FOR NON-WEAVING VEHICLES
    IF (L2.EQ.1) WRITE (NPRNT,35)
    IF (L2.EQ.2) WRITE (NPRNT,45)
    IF (L2.EQ.3) WRITE (NPRNT,55)
    IF (L2.EQ.4) WRITE (NPRNT,65)
    IF (L2.EQ.5) WRITE (NPRNT,75)
    IF (L2.EQ.6) WRITE (NPRNT,85)
  30 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = A')
  35 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = A')
  40 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = B')
  45 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = B')
  50 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = C')
  55 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = C')
  60 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = D')
  65 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = D')
  70 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = E')
  75 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = E')
  80 FORMAT(/10X,'LEVEL OF SERVICE FOR WEAVING VEHICLES       = F')
  85 FORMAT(/10X,'LEVEL OF SERVICE FOR NON-WEAVING VEHICLES   = F')
    RETURN
    END
```

SAMPLE DATA FILE

```
60., 7, 1,60, 100, 200
302, 24, 0., 2
1100, 1150, .03, .01, 0.52, 1.
35., 7.5, 30., 7., 15., 50.
2.3, 2., .6, 12.
.39,.25,1.6,.5,4.,7.,3.
19, 40, 52, 13.2,7.
1.
```

SAMPLE CONTROL FILE

```
GEN,SHAHID IQBAL,WEAVING,11/29/1992;
LIMITS,3,23,1100;
INITIALIZE,0.,3600.;
;
MONTR,CLEAR,120;                        WARMUP PERIOD = 120 SEC.
MONTR,TRACE,120,420;                    ANALYSE FOR FIVE MINUTES
MONTR,FILES,420,400;
MONTR,SUMRY,420,400;
RECORD,TNOW,CURRENT TIME,0,B,1.;
STAT,1,REACTION TIME_A,20/0.0/0.2;
STAT,2,ARRIVAL SPEED_A,20/0.0/5.0;
STAT,3,DEST POINT_A,10/0.0/0.1;
STAT,4,VEH STATUS_A,10/0.0/0.1;
STAT,5,ACCEPTED GAP_A,20/50/10;
STAT,6,DISC TIME_A,10/0/2;
STAT,7,ARR HEADWAY_A,20/0.0/.5;
STAT,11,REACTION TIME_B,20/0.0/0.2;
STAT,12,ARRIVAL SPEED_B,20/0.0/5.0;
STAT,13,DEST POINT_B,10/0.0/0.1;
STAT,14,VEH STATUS_B,10/0.0/0.1;
STAT,15,ACCEPTED GAP_B,20/50/10;
STAT,16,DISC TIME_B,10/0/2;
STAT,17,ARR HEADWAY_B,20/0.0/.5;
TIMST,NNQ(1),NUMBER IN QI,10/0/1;
TIMST,NNQ(2),NUMBER IN Q2,10/0/1;
EQUIVALENCE/ATRIB(1),  VEH ID NO;
EQUIVALENCE/ATRIB(2),  ENTRY TIME;
EQUIVALENCE/ATRIB(3),  REAC TIME;
EQUIVALENCE/ATRIB(4),  ARR SPEED;
EQUIVALENCE/ATRIB(5),  VEH LENGTH;
EQUIVALENCE/ATRIB(6),  VEH WIDTH;
EQUIVALENCE/ATRIB(7),  VEH HIGHT;
EQUIVALENCE/ATRIB(8),  VEH TYPE
EQUIVALENCE/ATRIB(9),  ORIGIN;
EQUIVALENCE/ATRIB(10), OR LANE;
EQUIVALENCE/ATRIB(11), DESTINATION;
EQUIVALENCE/ATRIB(12), DEST LANE;
EQUIVALENCE/ATRIB(13), VEH STATUS;
EQUIVALENCE/ATRIB(14), CRIT GAP;
EQUIVALENCE/ATRIB(15), EXIT TIME;
FIN;
```

SAMPLE ECHO REPORT

```
GEN,SHAHID IQBAL,WEAVING,11/29/1992,1,,,,,Y/1,132;
LIMITS,2,26,800;
INIT,0,360;
MONTR,CLEAR,120;                    WARMUP PERIOD = 120 SEC.
PRIORITY/1,FIFO/2,FIFO;
STAT,1, REACTION TIME_A,    20/0.0/0.2;
STAT,2, ARRIVAL SPEED_A,    20/0.0/5.0;
STAT,3, ACCEPTED GAP_A,     20/50 /10.;
STAT,4, ARR HEADWAY_A,      20/0.0/.5 ;
STAT,5, REACTION TIME_B,    20/0.0/0.2;
STAT,6, ARRIVAL SPEED_B,    20/0.0/5.0;
STAT,7, ACCEPTED GAP_B,     20/50 /10.;
STAT,8, ARR HEADWAY_B,      20/0.0/.5 ;
STAT,9, WEAVE SPEED,        20/0.0/5.0;
STAT,10,WEAVE ACCEL,        20/-15./2.;
STAT,11,SPEED NW,           20/0.0/5.0;
STAT,12,ACCEL NW,           20/-15./2.;
STAT,13,SPACE HEADWAY,      20/0.0/30.;
STAT,14,TIME IN SYSTEM,     10/0.0/4. ;
STAT,15,MERGING POINT,      20/0.0/5.0;
FIN;
```

ARRAY STORAGE REPORT

DIMENSION OF NSET/QSET(NNSET):	32000
WORDS ALLOCATED TO FILING SYSTEM:	24000
WORDS ALLOCATED TO VARIABLES:	774
WORDS AVAILABLE FOR PLOTS/TABLES:	7226

SAMPLE INTERMEDIATE REPORT

INTERMEDIATE RESULTS

VEHICLE TRAJECTORY AT TIME 120.00000 SEC
****

VEHICLE ID NO	=	80
VEHICLE TYPE (1-PC, 2-SU, 3-TC)	=	1
VEHICLE STATUS (W-1, NW-2)	=	1.00
ORIGINAL APPROACH (A-1, B-2)	=	2.00
VEHICLE POSITION (FT)	=	522.63
SPEED (MPH)	=	51.98
ACCELERATOIN (MPH/S)	=	2.80
CURRENT LANE	=	1.00

VEHICLE ID NO	=	61
VEHICLE TYPE (1-PC, 2-SU, 3-TC)	=	1
VEHICLE STATUS (W-1, NW-2)	=	1.00
ORIGINAL APPROACH (A-1, B-2)	=	2.00
VEHICLE POSITION (FT)	=	445.10
SPEED (MPH)	=	35.79
ACCELERATOIN (MPH/S)	=	7.00
CURRENT LANE	=	1.00

VEHICLE ID NO	=	83
VEHICLE TYPE (1-PC, 2-SU, 3-TC)	=	1
VEHICLE STATUS (W-1, NW-2)	=	1.00
ORIGINAL APPROACH (A-1, B-2)	=	2.00
VEHICLE POSITION (FT)	=	391.68
SPEED (MPH)	=	56.36
ACCELERATOIN (MPH/S)	=	1.90
CURRENT LANE	=	2.00

VEHICLE ID NO	=	69
VEHICLE TYPE (1-PC, 2-SU, 3-TC)	=	1
VEHICLE STATUS (W-1, NW-2)	=	2.00
ORIGINAL APPROACH (A-1, B-2)	=	1.00
VEHICLE POSITION (FT)	=	377.41
SPEED (MPH)	=	33.37
ACCELERATOIN (MPH/S)	=	7.00
CURRENT LANE	=	1.00

PRINTOUT OF FILE NUMBER 1

TNOW	=	.3600E+03
QQTIM	=	.3600E+03

TIME PERIOD FOR STATISTICS	.3000E+03
AVERAGE NUMBER IN FILE	8.2433
STANDARD DEVIATION	1.2319
MAXIMUM NUMBER IN FILE	11

FILE CONTENTS

ENTRY 1 =	.124E+03	.328E+03	.356E+00	.114E+02
	.190E+02	.700E+01	.425E+01	.100E+01
	.200E+01	.000E+00	.300E+01	.000E+00
	.100E+01	.723E+02	.000E+00	.000E+00
	.100E+01	.430E+03	.452E+03	.367E+02
	.404E+02	.367E+01	.153E+03	.243E+03
	.181E+03	.962E+01	.200E+01	.100E+01
ENTRY 2 =	.119E+03	.327E+03	.250E+00	.917E+01
	.190E+02	.700E+01	.425E+01	.100E+01
	.100E+01	.000E+00	.300E+01	.000E+00
	.200E+01	.000E+00	.000E+00	.000E+00
	.100E+01	.347E+03	.365E+03	.366E+02
	.436E+02	.700E+01	.862E+02	.242E+03
	.121E+03	.685E+01	.200E+01	.100E+01
ENTRY 3 =	.121E+03	.331E+03	.250E+00	.184E+02
	.190E+02	.700E+01	.425E+01	.100E+01
	.100E+01	.000E+00	.400E+01	-.400E+01
	.100E+01	.884E+02	.000E+00	.000E+00
	.100E+01	.269E+03	.281E+03	.266E+02
	.296E+02	.300E+01	.849E+02	.246E+03
	.571E+03	.681E+01	.200E+01	.100E+01
ENTRY 4 =	.125E+03	.338E+03	.250E+00	.198E+02
	.190E+02	.700E+01	.425E+01	.100E+01
	.100E+01	.000E+00	.300E+01	.000E+00
	.200E+01	.000E+00	.000E+00	.000E+00
	.100E+01	.201E+03	.214E+03	.263E+02
	.309E+02	.455E+01	.662E+02	.254E+03
	.421E+03	.745E+01	.200E+01	.100E+01
ENTRY 5 =	.128E+03	.345E+03	.130E+01	.173E+02
	.190E+02	.700E+01	.425E+01	.100E+01
	.100E+01	.000E+00	.400E+01	.000E+00
	.100E+01	.112E+03	.000E+00	.000E+00
	.100E+01	.168E+03	.178E+03	.476E+01
	.608E+01	.131E+01	.360E+02	.262E+03
	.910E+02	.103E+02	.200E+01	.100E+01
ENTRY 6 =	.129E+03	.346E+03	.250E+00	.867E+01
	.190E+02	.700E+01	.425E+01	.100E+01
	.100E+01	.000E+00	.300E+01	.000E+00
	.200E+01	.000E+00	.000E+00	.000E+00
	.100E+01	.792E+02	.871E+02	.200E+02
	.208E+02	.799E+00	.913E+02	.264E+03
	.151E+03	.851E+01	.200E+01	.100E+01

** STATISTICS OF VARIABLES OVER SIMULATION RUNS **

==

	MEAN VALUE	STANDARD DEVIATION	MAXIMUM VALUE	MINIMUM VALUE	NO. OF OBS
REACTION TIME_A	.53E+00	.42E+00	.16E+01	.25E+00	108.
ARRIVAL SPEED_A	.19E+02	.77E+01	.36E+02	.45E+01	45.
ACCEPTED GAP_A	.10E+03	.18E+02	.13E+03	.44E+02	23.
ARR HEADWAY_A	.27E+01	.23E+01	.12E+02	.60E+00	108.
REACTION TIME_B	.49E+00	.43E+00	.16E+01	.25E+00	111.
ARRIVAL SPEED_B	.26E+02	.86E+01	.49E+02	.11E+02	49.
ACCEPTED GAP_B	.93E+02	.16E+02	.14E+03	.54E+02	49.
ARR HEADWAY_B	.27E+01	.24E+01	.12E+02	.60E+00	111.
WEAVING SPEED	.32E+02	.14E+02	.69E+02	.00E+00	1546.
WEAVING ACCELRA	.60E+00	.47E+01	.70E+01	-.13E+02	1546.
SPEED NONWEAVIN	.22E+02	.94E+01	.54E+02	.00E+00	687.
ACCEL NONWEAVIN	.29E+00	.53E+01	.70E+01	-.13E+02	687.
SPACE HEADWAY	.88E+02	.46E+02	.44E+03	.18E+02	2233.
TIME IN SYSTEM	.44E+02	.10E+02	.67E+02	.25E+02	96.
MERGING POINT	.23E+03	.11E+03	.44E+03	.63E+01	59.

LEVEL OF SERVICE FOR WEAVING VEHICLES = D

LEVEL OF SERVICE FOR NON-WEAVING VEHICLES = F

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT WEAVING   BY SHAHID IQBAL

DATE 11/29/1992   RUN NUMBER   1 OF   1

CURRENT TIME   .3600E+03
STATISTICAL ARRAYS CLEARED AT TIME   .6000E+02

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
REACTION TIME_A	.529E+00	.417E+00	.790E+00	.250E+00	.160E+01	108
ARRIVAL SPEED_A	.190E+02	.769E+01	.405E+00	.452E+01	.356E+02	45
ACCEPTED GAP_A	.997E+02	.182E+02	.183E+00	.440E+02	.133E+03	23
ARR HEADWAY_A	.272E+01	.226E+01	.829E+00	.600E+00	.120E+02	108
REACTION TIME_B	.489E+00	.428E+00	.874E+00	.250E+00	.160E+01	111
ARRIVAL SPEED_B	.261E+02	.861E+01	.330E+00	.107E+02	.492E+02	49
ACCEPTED GAP_B	.926E+02	.160E+02	.173E+00	.536E+02	.139E+03	49
ARR HEADWAY_B	.267E+01	.242E+01	.904E+00	.600E+00	.120E+02	111
WEAVE SPEED	.317E+02	.136E+02	.427E+00	.000E+00	.685E+02	1546
WEAVE ACCEL	.599E+00	.466E+01	.778E+01	-.132E+02	.700E+01	1546
SPEED NW	.225E+02	.937E+01	.417E+00	.000E+00	.542E+02	687
ACCEL NW	.293E+00	.530E+01	.181E+02	-.132E+02	.700E+01	687
SPACE HEADWAY	.878E+02	.458E+02	.521E+00	.182E+02	.444E+03	2233
TIME IN SYSTEM	.436E+02	.995E+01	.228E+00	.250E+02	.670E+02	96
MERGING POINT	.233E+03	.114E+03	.488E+00	.630E+01	.445E+03	59

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1		8.243	1.232	11	6	.472
2		5.580	1.091	8	5	.460
3	CALENDAR	3.000	.000	3	3	1.721

****HISTOGRAM NUMBER 2****

ARRIVAL SPEED_A

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0        20        40        60        80       100

                    +    +    +    +    +    +    +    +    +    +    +
  0  .000  .000E+00 +                                                 +
  1  .022  .500E+01 +*                                                +
  6  .133  .100E+02 +*******C                                         +
  6  .133  .150E+02 +*******      C                                   +
 15  .333  .200E+02 +*****************             C                  +
  6  .133  .250E+02 +*******                              C           +
  5  .111  .300E+02 +******                                    C      +
  5  .111  .350E+02 +******                                          C+
  1  .022  .400E+02 +*                                                C
  0  .000  .450E+02 +                                                 C
  0  .000  .500E+02 +                                                 C
  0  .000  .550E+02 +                                                 C
  0  .000  .600E+02 +                                                 C
  0  .000  .650E+02 +                                                 C
  0  .000  .700E+02 +                                                 C
  0  .000  .750E+02 +                                                 C
  0  .000  .800E+02 +                                                 C
  0  .000  .850E+02 +                                                 C
  0  .000  .900E+02 +                                                 C
  0  .000  .950E+02 +                                                 C
  0  .000  .100E+03 +                                                 C
  0  .000    INF    +                                                 C

---                 +    +    +    +    +    +    +    +    +    +    +
 45                 0        20        40        60        80       100
```

****STATISTICS FOR VARIABLES BASED ON OBSERVATION****

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
ARRIVAL SPEED_A	.190E+02	.769E+01	.405E+00	.452E+01	.356E+02	45

HISTOGRAM NUMBER 9

WEAVE SPEED

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0        20        40        60        80       100

                    +    +    +    +    +    +    +    +    +    +    +
  2  .001  .000E+00 +                                                 +
  5  .003  .500E+01 +                                                 +
 73  .047  .100E+02 +**C                                              +
114  .074  .150E+02 +**** C                                           +
134  .087  .200E+02 +****      C                                      +
194  .125  .250E+02 +*******         C                                +
199  .129  .300E+02 +*******               C                          +
195  .126  .350E+02 +*******                      C                   +
190  .123  .400E+02 +*******                            C             +
139  .090  .450E+02 +****                                   C         +
 96  .062  .500E+02 +***                                       C      +
154  .100  .550E+02 +*****                                          C +
 37  .024  .600E+02 +*                                                C
 10  .006  .650E+02 +                                                 C
  4  .003  .700E+02 +                                                 C
  0  .000  .750E+02 +                                                 C
  0  .000  .800E+02 +                                                 C
  0  .000  .850E+02 +                                                 C
  0  .000  .900E+02 +                                                 C
  0  .000  .950E+02 +                                                 C
  0  .000  .100E+03 +                                                 C
  0  .000    INF    +                                                 C

---                 +    +    +    +    +    +    +    +    +    +    +
1546                0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
WEAVE SPEED	.317E+02	.136E+02	.427E+00	.000E+00	.685E+02	1546

HISTOGRAM NUMBER 11

SPEED NW

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80      100

                    +    +    +    +    +    +    +    +    +    +    +
   4 .006  .000E+00 +                                                 +
   9 .013  .500E+01 +*                                                +
  50 .073  .100E+02 +****C                                            +
  90 .131  .150E+02 +********  C                                      +
 119 .173  .200E+02 +**********         C                             +
 150 .218  .250E+02 +************                  C                  +
 140 .204  .300E+02 +***********                              C       +
  71 .103  .350E+02 +*****                                         C  +
  23 .033  .400E+02 +**                                             C +
  13 .019  .450E+02 +*                                               C+
  11 .016  .500E+02 +*                                               C+
   7 .010  .550E+02 +*                                                C
   0 .000  .600E+02 +                                                 C
   0 .000  .650E+02 +                                                 C
   0 .000  .700E+02 +                                                 C
   0 .000  .750E+02 +                                                 C
   0 .000  .800E+02 +                                                 C
   0 .000  .850E+02 +                                                 C
   0 .000  .900E+02 +                                                 C
   0 .000  .950E+02 +                                                 C
   0 .000  .100E+03 +                                                 C
   0 .000    INF    +                                                 C

---                 +    +    +    +    +    +    +    +    +    +    +
687                 0         20        40        60        80      100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
SPEED NW	.225E+02	.937E+01	.417E+00	.000E+00	.542E+02	687

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