INFORMATION TO USERS

While the most advanced technology has been used to photograph and reproduce this manuscript, the quality of the reproduction is heavily dependent upon the quality of the material submitted. For example:

- Manuscript pages may have indistinct print. In such cases, the best available copy has been filmed.

- Manuscripts may not always be complete. In such cases, a note will indicate that it is not possible to obtain missing pages.

- Copyrighted material may have been removed from the manuscript. In such cases, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, and charts) are photographed by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each oversize page is also filmed as one exposure and is available, for an additional charge, as a standard 35mm slide or as a 17”x 23” black and white photographic print.

Most photographs reproduce acceptably on positive microfilm or microfiche but lack the clarity on xerographic copies made from the microfilm. For an additional charge, 35mm slides of 6”x 9” black and white photographic prints are available for any photographs or illustrations that cannot be reproduced satisfactorily by xerography.
Development of a simulation model for freeway weaving sections

Zarean, Mohsen, Ph.D.
The Ohio State University, 1987
PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark √.

1. Glossy photographs or pages ______
2. Colored illustrations, paper or print ______
3. Photographs with dark background ______
4. Illustrations are poor copy ______
5. Pages with black marks, not original copy ______
6. Print shows through as there is text on both sides of page ______
7. Indistinct, broken or small print on several pages √
8. Print exceeds margin requirements ______
9. Tightly bound copy with print lost in spine ______
10. Computer printout pages with indistinct print ______
11. Page(s) _________ lacking when material received, and not available from school or author.
12. Page(s) _________ seem to be missing in numbering only as text follows.
13. Two pages numbered ______. Text follows.
14. Curling and wrinkled pages ______
15. Dissertation contains pages with print at a slant, filmed as received ______
16. Other ________________________________
   ________________________________
   ________________________________

University
Microfilms
International
DEVELOPMENT OF A SIMULATION MODEL
FOR
FREEWAY WEAVING SECTIONS

DISSERTATION

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

By
MOHSEN ZAREAN, B.S.C.E.,M.S.C.E

The Ohio State University
1987

Dissertation Committee:
Prof. Z.A. Nemeth
Prof. M. Mccord
Prof. Whitehurst
Prof. D. Fairly
Prof. B. Nelson

Approved by
Prof. Z.A. Nemeth
Department of Civil Engineering
ACKNOWLEDGMENTS

It is impossible to acknowledge, in an entirely appropriate fashion, the various contributions of those involved in this educational endeavor. Though they are too many to mention individually, a few deserving of higher and specific recognition are highlighted.

I wish to express my deepest gratitude to my advisor Professor Z. A. Nemeth. He has extensively influenced my academic life by his constructive direction, guidance, vital support, and criticism. His professional supervision, since the beginning of my graduate work at the Ohio State University, created a personal atmosphere conducive to research and learning. I will always remember his intellectually stimulating discussions and professional instructions which are all united in the body of this dissertation.

I also wish to express a special thanks to Professor J. Treitere and Dr. J. R. Mekemson who taught several graduate courses all of which found ready application in this work.

I gratefully acknowledge the numerous assistance received from Dr. D. Fairly. I am particularly grateful for the gem of ideas he contributed in the statistical part of my dissertation. A debt of gratitude is also owed to Dr. M. McCord and Dr. B. Nelson for their guidance, advise, and criticism of my research.
I would like to express my appreciation to the Department of Mathematics for the financial support and the staff of the Instructional and Research Computer Center for helping with the computer programing of this research. Indeed, without their sincere assistance, at crucial times, this dissertation would not have been possible.

It is most appropriate to acknowledge the role my parents have played in my education. My mother provided me with a desire to learn and to strive for excellence. My father has provided the zest, impetus, and encouragement that has brought about the successful completion of this work. To them, I dedicate this effort and accomplishment. To my wife, Arlene, I offer sincere thanks for her patience and willingness to endure with me the vicissitude of my endeavors. To my daughter, Sara, I thank her for understanding my frequent absences.

Last but by no means the least, my respect and appreciation goes to my friends who, in their several capacities, have given me moral and inspirational support throughout this very important phase of my formal education.
VITA

May 12 1957  Born, Shahreza, Iran

June 1975  University of Isfahan’s High School
High School Diploma
Isfahan, Iran

1976-1979  B.S. Civil Engineering
West Virginia Institute of Technology
Montgomery, West Virginia, U.S.A.

1977-1979  Deans Honor List
West Virginia Institute of Technology
Montgomery, West Virginia, U.S.A.

1979  Honor Society of Tau Beta Pi
Beta of West Virginia
Montgomery, West Virginia, U.S.A.

1981  M.S.C.E. (Transportation Engineering)
The Ohio State University
Columbus, Ohio, U.S.A.

1982-1983  Graduate Teaching Assistant
Department of Civil Engineering
The Ohio State University
Columbus, Ohio, U.S.A.

1982-Date  Graduate Teaching Assistant
Department of Mathematics
The Ohio State University
Columbus, Ohio, U.S.A.

1984  ENO Foundation Scholarship
Columbus, Ohio, U.S.A.

1985 (Fall)  Lecturer
Department of Civil Engineering
The Ohio State University
Columbus, Ohio, U.S.A.
TABLE OF CONTENTS

PAGE

ACKNOWLEDGMENTS ................................................................. ii

VITA ................................................................. iv

LIST OF TABLES ................................................................. viii

LIST OF FIGURES ................................................................. ix

Abstract ................................................................. x

CHAPTER

I. INTRODUCTION ................................................................. 1

1.1 OVERVIEW ................................................................. 1
1.2 PROBLEM STATEMENT ................................................................. 2
1.3 MOTIVATION ................................................................. 2
1.4 RESEARCH APPROACH AND OBJECTIVES ......................... 3

II. LITERATURE REVIEW ................................................................. 5

2.1 OBJECTIVES OF THE LITERATURE REVIEW ......................... 5
2.2 SIMULATION ................................................................. 5
  2.2.1 TRAFFIC SIMULATION ......................................................... 7
  2.2.2 FREEWAY SIMULATION MODELS ........................................ 8
  2.2.3 LIMITATIONS OF EXISTING MODELS ......................... 23
2.3 WEAVING SECTIONS ................................................................. 25
  2.3.1 OPERATIONAL FEATURES OF WEAVING SECTIONS ............. 30
  2.3.2 WEAVING SECTIONS ANALYSIS AND DESIGN ................. 33
    2.3.2.1 BACKGROUND ................................................................. 34
2.3.2.2 PINY METHOD ............................................................. 36
2.3.2.3 LEISCH METHOD ....................................................... 43
2.3.2.4 FAZIO METHOD .......................................................... 46
2.3.2.5 JHK METHOD ............................................................ 51
2.3.2.6 1985 HCM ............................................................... 51
2.3.3 CONCLUSIONS ........................................................... 54

III. DEVELOPMENT OF THE SIMULATION MODEL ............... 56

3.1 INTRODUCTION ................................................................. 56
3.2 INPUT ELEMENTS .............................................................. 56
3.2.1 VEHICLE ARRIVAL HEADWAYS .................................... 57
3.2.2 SPEED ........................................................................... 58
3.2.3 BRAKE REACTION TIME .............................................. 60
3.2.4 GAP ACCEPTANCE ....................................................... 61
3.2.5 ACCELERATION/DECELERATION CAPABILITIES .......... 64
3.2.6 LEVEL OF SERVICE ..................................................... 67
3.3 SIMULATION LANGUAGE ................................................... 68
3.4 DESCRIPTION OF THE MODEL ......................................... 71
3.4.1 ASSUMPTIONS AND LIMITATIONS ................................. 71
3.4.2 FUNCTIONAL STRUCTURE OF THE MODEL ..................... 72
3.4.3 SIMULATION INPUT ...................................................... 72
3.4.4 SIMULATION OUTPUT ................................................... 73
3.4.4.1 STANDARD OUTPUTS ............................................... 73
3.4.4.2 OPTIONAL OUTPUTS ................................................ 74
3.4.5 DESCRIPTION OF INDIVIDUAL ROUTINES ..................... 75
3.4.6 VEHICLE AND DRIVER ATTRIBUTES ............................. 82
3.4.7 CAR-FOLLOWING ALGORITHM ..................................... 84
3.4.8 LANE CHANGING DEVELOPMENT ................................. 91
3.4.8.1 INITIAL CHECK ....................................................... 95
3.4.8.2 FINAL CHECK .......................................................... 96
3.4.9 INITIALIZATION BIAS ................................................... 97

IV. MODEL CALIBRATION ......................................................... 101

4.1 DATA COLLECTION .......................................................... 101
4.2 DATA BASE .................................................................... 103
4.3 ARRIVAL HEADWAY CALIBRATION ................................. 105
4.4 LANE CHANGING CALIBRATION .................................... 107
4.4.1 LANE-CHANGING FACTOR ......................................... 109
4.4.2 PROBABILITY OF NON-ESSENTIAL LANE-CHANGING .... 112

V. SENSITIVITY ANALYSIS .................................................... 114

5.1 MAXIMUM EMERGENCY DECELERATION ....................... 115
5.2 PROBABILITY OF NON-ESSENTIAL LANE-CHANGING ....... 116

- vi -
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LEVEL OF SERVICE CRITERIA FOR WEAVING AREAS (HCM)</td>
<td>31</td>
</tr>
<tr>
<td>2. LANE SHIFT EQUATIONS (Fazio)</td>
<td>48</td>
</tr>
<tr>
<td>3. EQUATIONS FOR WEAVING AND NON-WEAVING SPEEDS (Fazio)</td>
<td>49</td>
</tr>
<tr>
<td>4. RECOMMENDED LEVEL OF SERVICE RANGES (Fazio)</td>
<td>50</td>
</tr>
<tr>
<td>5. CONFIGURATION TYPE VS. NUMBER OF REQUIRED LANE CHANGES (HCM)</td>
<td>52</td>
</tr>
<tr>
<td>6. CRITERIA FOR UNCONSTRAINED VS. CONSTRAINED OPERATION OF WEAVING AREAS (HCM)</td>
<td>53</td>
</tr>
<tr>
<td>7. CONSTANTS FOR PREDICTION OF WEAVING AND NON-WEAVING SPEEDS IN WEAVING AREAS (HCM)</td>
<td>54</td>
</tr>
<tr>
<td>8. COMPARISON OF SEVERAL SIMULATION LANGUAGES (Banks and Carson)</td>
<td>70</td>
</tr>
<tr>
<td>9. RESULTS OF THE SENSITIVITY ANALYSIS FOR BRAKE REACTION TIME</td>
<td>123</td>
</tr>
<tr>
<td>10. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)</td>
<td>137</td>
</tr>
<tr>
<td>11. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)</td>
<td>141</td>
</tr>
<tr>
<td>12. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)</td>
<td>146</td>
</tr>
<tr>
<td>13. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME)</td>
<td>150</td>
</tr>
<tr>
<td>14. COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)</td>
<td>155</td>
</tr>
</tbody>
</table>
15. COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME) .......... 158

16. COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME) .......... 161

17. COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME) ......................................................... 164

18. COMPARISON OF SIMULATED VS. OBSERVED MERGING POINT DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME) .......... 172

19. COMPARISON OF SIMULATED VS. OBSERVED MERGING POINT DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME) .......... 176

20. REGRESSION MODEL FOR WEAVING SPEED ......................... 198

21. REGRESSION MODEL FOR NON-WEAVING SPEED ................... 200

22. REGRESSION MODEL FOR WEAVING AND NON-WEAVING DELAYS ................................................................. 201
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TYPICAL EXAMPLES OF WEAVING SECTIONS</td>
<td>27</td>
</tr>
<tr>
<td>2. TYPICAL EXAMPLES OF TYPE A WEAVING SECTIONS</td>
<td>28</td>
</tr>
<tr>
<td>3. TYPICAL EXAMPLES OF TYPE B WEAVING SECTIONS</td>
<td>29</td>
</tr>
<tr>
<td>4. TYPICAL EXAMPLES OF TYPE C WEAVING SECTIONS</td>
<td>29</td>
</tr>
<tr>
<td>5. MEASUREMENT OF WEAVING AREA LENGTH</td>
<td>32</td>
</tr>
<tr>
<td>6. DIAGRAM OF VARIOUS CONFIGURATIONS OF WEAVING (NCHRP 212)</td>
<td>38</td>
</tr>
<tr>
<td>7. SPEED RELATIONSHIPS FOR WEAVING AREAS (NCHRP 212)</td>
<td>39</td>
</tr>
<tr>
<td>8. MAXIMUM NUMBER OF LANES IN MAJOR WEAVING SECTIONS (NCHRP 212)</td>
<td>40</td>
</tr>
<tr>
<td>9. SHARE OF ROADWAY RELATIONSHIP FOR WEAVING VEHICLES (NCHRP 212)</td>
<td>41</td>
</tr>
<tr>
<td>10. SPEED-FLOW RELATIONSHIP FOR NON-WEAVING VEHICLES (NCHRP 212)</td>
<td>42</td>
</tr>
<tr>
<td>11. NOMOGRAPH FOR DESIGN AND ANALYSIS OF ONE-SIDED WEAVING SECTIONS (Leisch)</td>
<td>44</td>
</tr>
<tr>
<td>12. NOMOGRAPH FOR DESIGN AND ANALYSIS OF TWO-SIDED WEAVING SECTIONS (Leisch)</td>
<td>45</td>
</tr>
<tr>
<td>13. EXAMPLES ON DETERMINING LANE SHIFT MULTIPLIERS (Fazio)</td>
<td>47</td>
</tr>
<tr>
<td>14. VARIOUS FORMS OF GAP ACCEPTANCE FUNCTIONS (Drew)</td>
<td>62</td>
</tr>
<tr>
<td>15. MAXIMUM RATE OF ACCELERATION VS. SPEED</td>
<td>66</td>
</tr>
<tr>
<td>16. A TYPICAL LANE-CHANGING ATTEMPT</td>
<td>94</td>
</tr>
<tr>
<td>17. AVERAGE DELAY AS A FUNCTION OF SIMULATION TIME</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>AVERAGE TRAVEL TIME AS A FUNCTION OF SIMULATION TIME</td>
</tr>
<tr>
<td>19</td>
<td>AVERAGE ARRIVAL SPEED AS A FUNCTION OF BUFFER LENGTH</td>
</tr>
<tr>
<td>20</td>
<td>BALTIMORE WASHINGTON PARKWAY WEAVING SECTION</td>
</tr>
<tr>
<td>21</td>
<td>SHIFTED NEGATIVE EXPONENTIAL DISTRIBUTION</td>
</tr>
<tr>
<td>22</td>
<td>GENERAL FORM OF THE LANE CHANGING FACTOR</td>
</tr>
<tr>
<td>23</td>
<td>NON ESSENTIAL LANE CHANGING FREQUENCY AS A FUNCTION OF VOLUME</td>
</tr>
<tr>
<td>24</td>
<td>AVERAGE WEAVING AND NON-WEAVING SPEEDS AS A FUNCTION OF SAFETY DISTANCE</td>
</tr>
<tr>
<td>25</td>
<td>AVERAGE WEAVING AND NON-WEAVING DELAYS AS A FUNCTION OF SAFETY DISTANCE</td>
</tr>
<tr>
<td>26</td>
<td>AVERAGE WEAVING AND NON-WEAVING SPEEDS AS A FUNCTION OF HEAVY VEHICLES</td>
</tr>
<tr>
<td>27</td>
<td>STANDARD DEVIATION OF RATE OF FLOW AT VARIOUS TIME INTERVALS</td>
</tr>
<tr>
<td>28</td>
<td>HARBOR FREEWAY WEAVING SECTION</td>
</tr>
<tr>
<td>29</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE HARBOR SITE (HIGH VOLUME)</td>
</tr>
<tr>
<td>30</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE HARBOR SITE (HIGH VOLUME)</td>
</tr>
<tr>
<td>31</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE HARBOR SITE (HIGH VOLUME)</td>
</tr>
<tr>
<td>32</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE BALTIMORE SITE (HIGH VOLUME)</td>
</tr>
<tr>
<td>33</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE BALTIMORE SITE (HIGH VOLUME)</td>
</tr>
<tr>
<td>34</td>
<td>COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE BALTIMORE SITE</td>
</tr>
</tbody>
</table>
35. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE HARBOR SITE (MEDIUM VOLUME) .......................................................... 147
36. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE HARBOR SITE (MEDIUM VOLUME) .................................................. 148
37. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE HARBOR SITE (MEDIUM VOLUME) .......................................................... 149
38. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE BALTIMORE SITE (MEDIUM VOLUME) .......................................................... 151
39. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE BALTIMORE SITE (MEDIUM VOLUME) .......................................................... 152
40. COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE BALTIMORE SITE (MEDIUM VOLUME) .......................................................... 153
41. COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME) .......................................................... 156
42. COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME) .......................................................... 157
43. COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME) .......................................................... 159
44. COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME) .......................................................... 160
45. COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME) .......................................................... 162
46. COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME) .......................................................... 163
47. COMPARISON OF SIMULATED VS. OBSERVED WEAVING
SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME) ......................................................... 165

48. COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME) .............................................................. 166

49. COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME) ................................................................. 168

50. COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME) ................................................................. 169

51. COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME) .............................................................. 170

52. COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME) .............................................................. 171

53. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (3 to 2) AT THE HARBOR SITE (HIGH VOLUME) .......................................... 173

54. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 3) AT THE HARBOR SITE (HIGH VOLUME) .......................................... 174

55. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 1) AT THE HARBOR SITE (HIGH VOLUME) .......................................... 175

56. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (3 to 2) AT THE BALTIMORE SITE (HIGH VOLUME) .......................................... 177

57. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 3) AT THE BALTIMORE SITE (HIGH VOLUME) .......................................... 178

58. COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 1) AT THE BALTIMORE SITE (HIGH VOLUME) .......................................... 179

59. VEHICLE TRAJECTORIES FOR LANE (1) OBTAINED FROM FIELD DATA ........................................... 181

60. VEHICLE TRAJECTORIES FOR LANE (1) OBTAINED FROM
CHAPTER 1
INTRODUCTION

1.1 OVERVIEW

In this era, construction of new freeways is coming to an end, due to right of way, environmental and construction cost problems. Strong emphasis has, instead, been placed on increasing the efficiency of the existing facilities. For example, attention has been devoted to development and implementation of incident detection strategies and integration of these with surveillance and control policies to alleviate traffic congestion on the nation's freeways. Much of this attention has been directed toward conducting systematic, well-designed research which provides an excellent basis for development of new concepts and designs in traffic management.

While some studies have been conducted dealing with related areas of ramp flow (Charles, 1971), merging capacity (Drew, 1968; Athan, 1969), priority lane (Cilliers, 1978), and lane closures (Rathi, 1983; Rouphail, 1980), not enough effort has been directed toward a detailed examination of the weaving sections.

"The potential exists for research to obtain a more detailed understanding of merging and weaving behavior".

(Bullen, 1982)
1.2 PROBLEM STATEMENT

Weaving sections represent the physical space along a freeway where two or more traffic streams, traveling in the same general direction, cross each other. Intensive lane-changing maneuvers are required in these sections as drivers must cross lanes appropriate to their desired destinations. Therefore, traffic in weaving areas is subjected to turbulence in excess of what is normally present on basic freeway sections. This turbulence imposes difficult operational conditions upon freeway and can result in traffic congestion deteriorating the overall efficiency of the highway. Consequently, weaving sections have been recognized as a special feature of the freeway requiring individual attention in design and operation. Therefore, a study of weaving sections is likely to provide benefit to the overall freeway operations.

Although the state-of-the-art in analysis and design of weaving sections provides some basic information regarding the relations between geometric features of weaving and some traffic characteristics, some basic questions about the mechanism of weaving are yet to be explored. For example, one might be interested in: the level of traffic at which weaving movements between lanes become hazardous; the effect of various length of weaving sections on traffic flow; or the impact of upstream conditions on operational conditions within weaving sections.

1.3 MOTIVATION

In recognition of the need for a more detailed understanding of the weaving behavior, a series of data sets on microscopic vehicular movements through weaving sections were collected for the Federal Highway Administration (Smith, 1985). The data is perhaps the richest source of its type that has been developed to date and is expected to be useful in enhancing freeway simulation models, as well as in direct empirical research.
The desire to study the traffic operational characteristics of freeway weaving sections complimented with the availability of the above mentioned data, has established the motivation for this research.

1.4 RESEARCH APPROACH AND OBJECTIVES

Computer simulation has been applied effectively in development of new concepts in traffic management. Simulation allows the traffic engineer to investigate traffic situations which are difficult to analyze directly. The great appeal of simulation modeling is that it can provide an indication as to the important variables that control the smooth and efficient movement of traffic, as well as the relationship between the variables, possibly leading to analytic solutions.

While several simulation models have been developed for study of ramp flow, merging capacity and lane closures, no attempt has yet been made to develop a model of the dynamics of traffic flow at weaving sections. Development of a systematic well designed simulation model is the most effective method of studying the time varying, complex, and stochastic process of traffic flow through weaving sections. It provides the highest level of detail and accuracy of available analysis techniques.

It is, therefore, the intent of this study to develop a realistic and reliable microscopic simulation model which provides the means for study of dynamics of traffic flow at weaving sections.
Development of this model, which will be called WEAVSIM, involves:

1. Deployment of an English-like, free-form, self-documenting simulation language, which enhances the simulation program documentation; and

2. Calibration and validation of the model, based on FHWA data; this greatly enhances the reliability and creditability of the model as an analysis tool.

The research is segmented into the following tasks:

1. A literature review of some relevant simulation models and state-of-the-art in weaving section analysis and design;

2. Formulation of a general model of a man-machine-environment interactions for traffic operations through the weaving section; this involves the formulation of the component models (car-following, lane changing, etc.), representing freeway traffic dynamics.

3. Simulation of the above model on a digital computer; WEAVSIM will be programmed using SIMSCRIPT II.5 Simulation Language. The model will be thoroughly debugged by exercising all logical paths.

4. Calibration of the model; this involves calibration of parameters imbedded in the model to represent the dynamics of freeway traffic flow.

5. Validation by means of uncontrolled field experiments; the model will be subjected to wide range of traffic demand to ascertain the overall performance of the model. Comparison of simulation output with field data will be performed for the following measures of effectiveness (MOE):
   a. Weaving and non-weaving speed for different constant volume.
   b. Headway distributions for various volumes.
   c. Merging point distributions.
   d. Accepted gaps distributions.

6. Demonstration of some simulation experiments.

In the following chapter a literature review of the freeway simulation models, along with, the state-of-the-art in weaving sections analysis and design will be presented.
CHAPTER II
LITERATURE REVIEW

2.1 OBJECTIVES OF THE LITERATURE REVIEW

Specific objectives of the literature review are three-fold:

1. To review relevant freeway simulation models and discuss their potential limitations;
2. To present operational features of weaving sections;
3. To trace the evolutions of weaving section analysis and design;

It is anticipated that as the result of this literature review some incisive conclusions could be drawn regarding the shortcomings of the methodology used in development of the current weaving analysis and design techniques.

Since the main objective of this research is development of a simulation model, a review of published freeway simulation models and a discussion of their deficiencies will also be presented. This would provide the means for identification of some features of the proposed simulation model to which more attention should be devoted.

2.2 SIMULATION

_Nature of Simulation:_ Simulation is an experiment performed on an artificial model of real system. It is a technique which permits the study of a complex system in the laboratory rather than in the field.
Simulation models allow traffic engineers to investigate traffic situations which are difficult to analyze either directly or analytically. The great appeal of simulation modeling is that it can provide an indication as to the important variables that control the smooth and efficient movement of traffic, as well as the relationship between the variables, possibly leading to analytic solutions. In the same vein, it can also be used to assess the accuracy of the proposed analytic solutions.

In comparison with experimental observation, simulation provides a cheaper and safer alternative. It provides the means to analyze the effect of traffic control measures on existing highways without having to institute the measures in the field and observing the consequences (i.e., traffic accidents). Finally simulation can be deployed to test alternative systems under identical conditions, and to test the behavior of a new system prior to its actual construction.

In performing any simulation a normal sequence of events evolves. Following is a brief description of these events: (Drew, 1968)

1. **DEFINITION** of the problem, specifically in familiar terms and symbols with placement of the necessary limitations.

2. **FORMULATION** of the model, including the statement of assumptions, choice of criteria for optimization, and the selection of operational procedures.

3. **CONSTRUCTION** of the block diagram establishing the functional relationships between the components of the system to be simulated.

4. **DETERMINATION** of the inputs for the simulation program.

5. **PREPARATION** of the complex simulation program.

6. **CONDUCTING EXPERIMENTAL RUNS** of the simulated system including experimental design to determine the number of runs and the parameters to be used and to establish confidence limits.

7. **EVALUATION** and testing of the simulated system.
2.2.1 TRAFFIC SIMULATION

Simulation of traffic flow started in the mid-1950's right after the digital computer became available to traffic researchers. Since then, it has attracted considerable interest in traffic related research. It began with the simulation of vehicles approaching and departing from isolated signal controlled intersections (Goode, 1965). It was not until mid-1960's that digital simulation was applied to freeway traffic and related features (Gerlough, 1959). New generation of computers in late 60's offered increased storage and faster computations. With these, computer simulation of freeway traffic at a microscopic level of detail became possible. Since then, a considerable number of computer models have been developed to aid the transportation engineers and planner in evaluating control strategies in freeway traffic.

Computer simulation application in traffic studies is especially appropriate because it allows a stochastic process, traffic flow, to be studied under controlled laboratory conditions. Traffic simulation is, at the present time, a very dynamic discipline. It is growing fast and changing rapidly because it is closely linked with the rapid and continuous advances of the digital computer.

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

1. The results of the simulation must fit the facts. Observations obtained as a result of any simulation must agree with similar results obtained from observations of actual traffic flow.

2. The results of the simulation must be accessible in a format that is meaningful to those using them. The actual simulation takes place within the computer and is, of course, unobservable to the user (in the absence of some type of on-line visual display device). Thus, it is necessary to devise some means of displaying simulation results in a form convenient to the users.
3. The time required to simulate a problem must be reasonable. The ratio of simulated time to real time must be such that the computer simulation of a freeway network is economically feasible.

2.2.2 FREEWAY SIMULATION MODELS

In the last decade a considerable number of traffic simulation models have been developed. However, despite the intense interest in traffic simulation, it is only recently that a very limited number of these models have been applied productively to solve real-world problems in traffic engineering. The reasons for this limitation are two-fold:

1. The complexity in programming the logic required to properly replicate the real world events;
2. Lack of reliability.

Complexities in programming are greatly amplified as the level of detail increases and as the scope of the problem enlarges from an isolated intersection to a network representation of freeway system. Therefore, an essential ingredient in a successful simulation model is a careful trade-off between level of detail and complexity of the model. Clearly the level of detail of any simulation model should be tailored to the nature of the process it is describing. This requires a good understanding of both the dynamic of the process and efficient simulation methodology.

One of the approaches for portraying traffic is to represent traffic in terms of overall parameters such as: traffic volume, average speed, and density; or handle the vehicles in groups. This approach is called macroscopic. Another approach, called microscopic, represents each vehicle by a set of variables such as: vehicle type, position, speed, acceleration, etc., and updates this set of variables at fixed or variable time intervals.
Macroscopic models, even though very economical, are unable to describe a complex process adequately, yielding inaccurate or misleading results which in some cases are wholly unacceptable. Microscopic models, on the other hand, are more costly and require a great deal of effort to program and debug; however, they provide greater resolution and potentially more accurate results.

The following pages describe briefly the existing microscopic freeway simulation models which are, in one way or another, similar to the one developed here. Specifically following features of each model will be examined:

1. **PURPOSE**: Primary application of the model.
2. **MODELING APPROACH**: Type of analytical approach used for representation of traffic flow.
3. **VEHICLE GENERATION AND PROCESSING**: Vehicle generation at the system entry point and their characteristics as they move through the section.
4. **GEOMETRIC CAPABILITIES**: Geometric features of the model.
5. **PROGRAM LANGUAGE**: The programming language of the software.
6. **PROGRAM STRUCTURE**: The structure of the model—either a single routine, modular (a series of programs), or structured (a master program with other subroutines used as required).
7. **VALIDATION**: Extent of validation based upon computational and/or field verification.
8. **EFFICIENCY**: Refers strictly to the ratio of the computer time to real time for the period modeled.

**FREESIM**: A MICROSCOPIC SIMULATION MODEL FOR FREEWAY LANE CLOSURES (Rathi, 1983)

**PURPOSE**: This model was developed to study traffic operations through lane closures.

**MODELING APPROACH**: FREESIM is a microscopic, stochastic, time scanning simulation model.
VEHICLE GENERATION AND PROCESSING: Vehicles enter the system based on a shifted negative-exponential function. Upon arrival in the system, each vehicle is assigned a set of attributes, which dictate its behavior in the system. Vehicles are advanced in the system using classical car-following approach. The car-following and lane-changing algorithms are similar to those used in INTRAS.

GEOMETRIC CAPABILITIES: FREESIM can simulate single lane closure of a freeway section with 2 or 3 unidirectional lanes. There are practically no restriction on the length of the simulated section.

PROGRAM LANGUAGE AND STRUCTURE: The program is written in SIMSCRIPT II.5 programming language using the event scheduling approach. Emphasis has been placed on structured programming and system modularity.

OUTPUTS:

- Summary statistics on measures of performance.
- Volume-Throughput data.
- lane-changing data.

VALIDATION: This model has been validated at both microscopic and macroscopic level, by comparison of simulated observations with empirical and available field data collected by the author. The validation results revealed that the model reproduces behavior of real-life system quite accurately.

EFFICIENCY: The ratio of the computer time to simulated real-time is approximately 1:70.

COMMENTS: The strength of this model is in its programming language (SIMSCRIPT II.5) and structure. SIMSCRIPT II.5 is an English-like, free-form, and self-documenting programming language. This has significantly improved the model's documentation. As part of simulation experimentation, some variance reduction concepts were introduced and tested for their efficiencies. These techniques could well be applied to future simulation models. Many applications of this model are yet to be exploited.

A MODEL OF TRAFFIC FLOW AT FREEWAY CONSTRUCTION (FREECON) LANE CLOSURE (Rouphail, 1981)

PURPOSE This model is developed for evaluating traffic control
systems at freeway lane closures.

**MODELING APPROACH**

FREECON is a microscopic, stochastic model with one second time scanning intervals.

**VEHICLE GENERATION AND PROCESSING:** Vehicle arrivals to the system are generated randomly from one of the nine available probability distribution functions (user specified). Upon arrival of vehicles, some tests are performed to satisfy car-following rules at the entry points. Individual vehicle status are described by a set of twenty attributes. Vehicles attributes are generated either stochastically or deterministically. The car following algorithm of this model is similar to that of INTRAS (Wisk, 1980). The car-following rules apply only to vehicles in 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.

**PROGRAM LANGUAGE AND STRUCTURE:** This model has been written in GASP IV simulation language and it consists of a main program and eighteen supporting subprograms and functions.

**OUTPUTS:**

- statistics on work zone interference with prevailing traffic flow conditions.
- statistics on delay in the construction and maintenance zone.
- statistics on speed.
- probability of disturbances in the open lane.
- lane-changing statistics.

**VALIDATION:** Validation of this model has been done using data collected at two contraction sites in the State of Ohio. Results of the statistical tests reveal that the model accurately predicted driver's car-following and merging behavior in moderate-to-high volume/density conditions.

**COMMENTS:** In development of this model much of the attention has been devoted to the simulation model itself, therefore, many of its applications were not fully exploited. Also the accuracy of the data base used for validation is in question since the lane changing data were collected manually.
INTEGRATED TRAFFIC SIMULATION (INTRAS) MODEL (Wicks, et al. 1980)

PURPOSE: INTRAS has been developed for studying freeway incident detection and control strategies.

MODELING APPROACH: This freeway model is microscopic, stochastic and employs a time stepping procedure for moving discrete vehicles through the section.

VEHICLE GENERATING AND PROCESSING: Vehicle generation is done according to a negative shifted exponential distribution function. The vehicles characteristics are randomly generated, i.e., drivers type, vehicle type, desired lane, and desired speed. Each time step all vehicles are processed in accordance with their desired speeds and destinations inhibited by the immediate traffic and control environment. The lane-changing, car-following, and vehicle generation algorithms are detailed and rather straightforward.

GEOMETRIC CAPABILITIES: INTRANS is capable of simulating a freeway section of practically unlimited length with up to five undirectional lanes. It allows simulation of intersections, freeway-freeway and freeway-ramp intersections, grade specification, and curvature.

PROGRAM LANGUAGE AND STRUCTURE: This model is written in standard FORTRAN for the IBM 360/370 computer series and has a modular structure.

OUTPUTS:

- The freeway link station data
- Fuel consumption and emission statistics
- Trajectories of all vehicles
- Traffic parameter values on a detector specific basis
- Comparison and statistical tests of MOE values from separate runs
- Warning and error messages

VALIDATION: The data bases used for validation of this model include the Ohio State Trajectory data, the Long Island Expressway data, and the PINY weaving data. Results of validation of this model reveal close agreement between simulated data and the field data.
Among the existing general-purpose models, INTRAS is the most detailed simulation model of freeway traffic. It has been completely validated. Users of this model have reported problems with some aspects of traffic behavior. These relate mainly to: vehicles that merge from acceleration lanes, vehicles behavior at exit ramps, and the method of assigning destinations (Bullen, 1982).

Sinha Freeway Simulation Model (Sinha, 1973)

**PURPOSE:**
This model was developed to be used as a general purpose tool for evaluation of traffic flow characteristics.

**MODELING APPROACH:** This model is a microscopic, stochastic, time scanning simulation model.

**VEHICLE GENERATION AND PROCESSING:** A shifted negative-exponential distribution is used to generate vehicles in the mainline. Ramp vehicles are generated from a Hyper-Erlange distribution. Vehicle mix is allowed. The mean desired speed of commercial vehicles is 90% of that for passenger vehicles. A set of reasonably complex logic is used for lane-changing, gap-acceptance, and car-following. However, the realism of the car-following algorithm has not been specifically tested.

**GEOMETRIC CAPABILITIES:** Freeway section of up to three and one half miles with five through lanes, four direct on-ramps, six direct off ramps with acceleration and deceleration lanes can be simulated.

**PROGRAM LANGUAGE AND STRUCTURE:** The model has been programmed in FORTRAN IV with a series of programs (Modular).

**OUTPUTS:** The primary outputs of this model are distributions of the following traffic flow parameters:

- Headway
- Speed
- Origin destination
- Lane speed
- Lane volume

**VALIDATION:** This model has been validated by comparison of the sim-
ulation outputs with the field data at both microscopic and macroscopic levels. The 1965 HCM and the data from the Eisenhower Expressway in Chicago and the Long Island Expressway in New York were used for validation. Results of the validation tests indicate reasonable agreement with field data, particularly at low volumes.

**COMMENTS:**

The strength of this model is in its provision of broad geometric capabilities and its program documentation which consists of a description of the main program and subroutines plus program listing. A distinguished feature of this model is the inclusion of a Hyper-Erlange ramp headway generation distribution.

**SYSTEM DEVELOPMENT CORPORATION (SDC) FREEWAY SIMULATION MODEL** (Warnshuis, 1972)

**PURPOSE:**

This model was developed to serve as a general purpose operations analysis tool for evaluation of freeway traffic flow characteristics.

**MODELING APPROACH:** It is a microscopic, stochastic simulation model with 1 second time scanning intervals.

**VEHICLE GENERATION AND PROCESSING:** Vehicles enter the system based on a shifted negative exponential distribution. Upon arrival vehicles are assigned a desired speed, a car-following factor, a preferred lane, and a preferred acceleration. Vehicles are processed through the section based on some car-following logics which are very condensed.

**GEOMETRIC CAPABILITIES:** The most distinguished feature of this model is the introduction of a "circular-track" roadway representation which allows simulation of any length roadway. All reasonable freeway configurations can be modeled.

**PROGRAM LANGUAGE AND STRUCTURE:** The model has been programmed in FORTRAN IV for IBM 360/67 and UNIVAC 1108. The model has a modular structure which allows direct simulation of vehicle detectors, traffic controls and control algorithms.

**OUTPUTS:** An interesting model output is a series of circular position-time plots which can be viewed sequentially to observe the overall behavior or trace individual vehicle movements. Other outputs include:
• Average speed, flow, and concentrations by lane
• Lane-changing counts and plots as a function of position in the system
• The status of every vehicle; position, speed, and lane at any given time

**VALIDATION:**
Validation of this model has been very limited (Diaz, 1982)

**EFFICIENCY:**
The ratio of computer time to real time is about 1:100.

**COMMENTS:**
This model is the most recent one of a series of general-purpose models developed by SDC. A unique feature of this model is that multiple highways are modeled by circular tracks. Consequently, unlimited length of freeway can be simulated; however, the core size for this model is only 65K. This limits the number of simulated vehicles to 2500. Like most of the existing models lack of validation seems to have limited its application as an analysis tool.

**MIDWEST RESEARCH INSTITUTE MOUNTAINOUS TERRAIN MODEL** (Kobett, et al. 1970)

**PURPOSE:**
This model was developed to study traffic characteristics on four lane divided highways in mountainous terrain.

**MODELING APPROACH:** This model is microscopic, stochastic, with time scanning interval of 1 second.

**VEHICLE GENERATION AND PROCESSING:** Vehicles enter the system with stochastically determined time headways consistent with a truncated negative exponential distribution and the input flow rate. Vehicles are placed on the road prior to employing the simulation model to move them. This process is called priming. Vehicles are assigned (under input controls) characteristics which basically determine their behavior in the system. Vehicles acceleration and deceleration capabilities are altered in accordance with the local road grade which is an input to the model. As time progresses and/or situation worsens lane-changing vehicles become willing to accept greater risk and use more severe deceleration. Two types of accidents are possible in this model. One type involves vehicles which may be forced to abandon a lane-change after they are committed to pass through the end of the lane occupied. The other type is ramming accidents which are rectified by using greater than possible deceleration.
GEOMETRIC CAPABILITIES: The model is able to simulate freeway section of up to 131,000 feet long with two continuous lanes and an intermittent lane and no provision for on or off ramps. Grade is defined at every point along the road.

PROGRAM LANGUAGE AND STRUCTURE: Except for one short assembly language, the program is written in FORTRAN IV. The program has three parts; Input and Priming program, Simulation Program, and Output Program.

OUTPUTS: The outputs of this model include:

- time headway
- spot speeds
- overall travel times and speeds
- lane-changing frequencies
- time spent at risk level greater than zero

VALIDATION: Validation of this model has been performed at both microscopic and macroscopic levels. At the macroscopic level, simulation results were compared with experimental results from Firey and Peterson (Firey, 1962).

EFFICIENCY: Efficiency of this model in terms of the ratio of computer time to real time is in the range of 20:1 to 10:1.

COMMENTS: A distinguished feature of this model is that the driver speed and acceleration capabilities are functions of grades and horizontal curvature. This model is not very efficient in terms of computer time; however, due to extensive validation and detailed logic, the model possesses sufficient realism for its purpose.

CONNECTICUT DEPARTMENT OF TRANSPORTATION FREeway SIMULATION MODEL (Leland, 1970)

PURPOSE: This model was developed as a freeway operation analysis tool for traffic performance evaluation.

MODELING APPROACH: The model is a microscopic, stochastic, time scanning simulation model.

VEHICLE GENERATION AND PROCESSING: Vehicles are generated from a negative-exponential distri-
bution and are assigned desired speeds according to a near-normal distribution based on field data. Each vehicle is assigned three gap acceptance figures and two minimum headways based on the relative speed of the vehicle. Other driver/vehicle characteristics are randomly assigned, except acceleration rates which are linearly proportional to the desired speeds. In comparison with other models the car-following and lane-changing logics are relatively simple. Vehicle mix is not allowed in the model.

**GEOMETRIC CAPABILITIES:**

Up to 5 miles of freeway with a maximum of 7 lanes, 10 on-ramps and 10 off-ramps can be simulated.

**PROGRAM LANGUAGE AND STRUCTURE:**

The program has been written in FORTRAN IV with a master program and other programs which are used as required (structured).

**OUTPUTS:**

- Lane, speed, and headway distributions.
- Average delay to vehicles
- Number of vehicles stopping on ramp
- Time spent queuing on ramp
- Average travel time for through and ramp vehicles

**VALIDATION:**

The Chi-square and Kolmogorov-Smirnov tests were applied to compare the simulation results with the speed and headway distribution figures given in the 1965 Highway Capacity Manual (HCM 1965). Data collected by the Connecticut Department of Transportation were used to validate the lane distribution obtained from the simulation model runs. The Chi-square test was used for cell-by-cell comparison of the two distributions, while the Kolmogorov-Smirnov test was deployed to test the maximum difference between two cumulative distributions.

**EFFICIENCY:**

The ratio of computer time to real time for this model is 2:1.

**COMMENTS:**

Even though good correlations were obtained in validation, the overall realism of the model is reported to be relatively poor (Diaz, Seckinger & Associates, Inc. 1982). This could be due to simplicity of car-following and lane-changing algorithms.
TEXAS TRANSPORTATION INSTITUTE FREEWAY MERGING MODEL (Buhr, 1970):

**PURPOSE:** The purpose of this model was to evaluate freeway operations under alternative ramp-control systems. The focus was on the on-ramp control techniques and hardware, as opposed to overall vehicular behavior.

**MODELING APPROACH:** As in most models, a microscopic, stochastic, time scanning approach has been used.

**VEHICLE GENERATION AND PROCESSING:** A poisson distribution is used in generating vehicular arrival headways, and a truncated normal distribution is used to assign desired speeds to vehicles. Other vehicles attributes such as: entry speed, length, and point of generation are also stochastically assigned. The gap-acceptance logic for ramp merging is very detailed but the car-following and lane-changing logic is simple.

**PROGRAM LANGUAGE AND STRUCTURE:** The simulation model has been programmed in FORTRAN IV for IBM 7094 and it has a modular structure with one monitor routine and 16 subroutines.

**GEOMETRIC CAPABILITIES:** The simulated section of freeway is limited to two exit ramps and maximum of six freeway lanes plus entrance ramps. There is no limit on freeway length; 6000 ft is the default value. The following ramp control alternatives can be simulated:

- no control
- Fixed-time metering
- Demand-capacity metering
- Gap acceptance control

**OUTPUTS:**

- A table of average values of travel times and volumes.
- A graphical display by means of a time-space diagram for each lane.

**VALIDATION:** A simple validation has been done by comparison of the
simulation outputs with the data collected by TTI at the Cullen entrance ramp on the Gulf Freeway in Houston. Validation results show that simulated drivers generally behave in a more uniform manner than real drivers. However, their speed-spacing relationships show close agreements with field data.

**EFFICIENCY:** The ratio of computer time to real time for this model is unknown.

**COMMENTS:** This model provides extensive ramp merging logic and, therefore, could be an excellent analysis tool for testing various ramp control strategies. Even though the model outputs were compared with real data, no statistical tests were conducted to indicate the level of confidence.

**NORTHWESTERN UNIVERSITY LANE CHANGING MODEL** (Worral and Bullen, 1969)

**PURPOSE:** This model was developed for evaluation of lane-changing behavior in freeways.

**MODELING APPROACH:** It is a microscopic, stochastic, time scanning simulation model. The scanning period is 1 second.

**VEHICLE GENERATION AND PROCESSING:** Vehicles are generated according to a shifted negative-exponential probability distribution. Desired speeds are assigned to vehicles from a normal distribution. Vehicles are processed through the section according to some complex car-following logics along with detailed lane changing rules which considers lane-changing desires and available gap structure. Vehicle mix is not considered, however, a study conducted for the Georgia State Highway (Widemuth et al., 1971) has expanded this model to allow a vehicle mix.

**GEOMETRIC CAPABILITIES:** The simulated section is limited to a four-lane tangential section several miles in length with no ramps.

**PROGRAM LANGUAGE AND STRUCTURE:** The program has been written in FORTRAN IV/SPURT simulation language. The structure of the model contains a series of programs (modular). It has been installed and successfully executed on CDC 6400 operating system.

**OUTPUTS:**
- Lane-changing frequencies for each five minute interval
- Statistics on lane-changing delay
- Distribution of accepted lags
- Average speeds of all vehicles in the system

**VALIDATION:**
Validation of the model indicated close agreements between the outputs of the model with the field data collected by Northwestern University at six Chicago area freeways.

**EFFICIENCY:**
The ratio of computer time to real time is in the range of 1:4 to 1:20.

**COMMENTS:**
Development of this model was based on a detailed examination of freeway lane-changing behavior (Worrall, 1969). The model could be used for a wide range of volumes (600,1800 vph). Its shortcomings are in its geometric capabilities (no ramp) and computer running efficiency.

**ARIZONA TRANSPORTATION AND TRAFFIC INSTITUTE TRAFFIC SIMULATION MODEL (Richard, Baker, and Sheldon, 1965)**

**PURPOSE:**
This model was developed to simulate traffic flow to establish interchange design in terms of:

- The distance between nose points of adjacent loops on an interchange; and
- The distance between adjacent interchanges; and
- The length of the acceleration lane.

**MODELING APPROACH:** This model is a microscopic, stochastic, variable time scanning, simulation model.

**VEHICLE GENERATION AND PROCESSING:** A negative exponential distribution is used to generate arrival headway for vehicles. Desired speeds are selected from a normal distribution but modified as required to reflect truck operations and freeway grades. Acceleration ratio for commercial vehicles are one-quarter, and deceleration rates are two-thirds of those of passenger vehicles. The percentage of commercial vehicles on the roadway is an input parameter. The logic for volume distributions among lanes, car following, and lane changing are extremely simple.
GEOMETRIC CAPABILITIES: The freeway geometry is limited to three through lanes and a ramp, an acceleration lane, or an auxiliary lane.

PROGRAM LANGUAGE AND STRUCTURE: The model has a modular structure and has been written in FORTRAN with some AUTOCODER statements for the IBM 7072-1401 computer system.

OUTPUTS:
- Average length of roadway needed to make specific maneuvers.
- Status review variables are output at specific points in the simulation run:
  - Assigned and observed speed of each vehicle.
  - Lane and position of each vehicle.

VALIDATION: No firm conclusions can be drawn as to the validity of this model.

COMMENTS: Although this model seems to be flexible enough to allow some simple additional capabilities as required by user, its validation and geometric capabilities are very limited. Also, due to the fact that the overall logic of the model is very simple, it is doubtful that the model realistically represents traffic flow in any detail.

MIDWEST RESEARCH INSTITUTE FREEWAY SIMULATION MODEL (Kobett and Leny, 1965)

PURPOSE: The purpose of this model was evaluation of freeway traffic operations, including ramp controls. The primary focus was to provide information which would be useful in the design of freeway interchanges. Special emphasis was placed on providing a method for assessing the effects of design variables on traffic capacity, safety, and level of service.

MODELING APPROACH: The model is a microscopic, stochastic, time scanning simulation model. The time scanning interval is 1 second.

VEHICLE GENERATION AND PROCESSING: Vehicles are generated based on a negative-exponential distribution. Three types of drivers have been defined for the model according to driver behaviors; conservative,
average, and aggressive. Each driver type is defined by
nineteen parameters. Deceleration capability is constant
for each vehicle type but acceleration capability is a
function of current speed. Upon arrival each vehicle is
assigned a vehicle type, a driver type, a desired speed
(from truncated normal distribution), and a cooperation
indicator which indicates the driver willingness to cooper­
ate with other motorists. The car-following and lane-
changing algorithms are sophisticated in comparison with
other models.

**GEOMETRIC CAPABILITIES:**
Up to 8000 ft. of freeway with 2 to 4 lanes and up to
6 right-hand and 6 left-hand ramps can be simulated. No
restriction is imposed on ramp lengths and acceleration/
deceleration lane lengths. Only one continuous pairing of
on- and off-ramps can be connected by an auxiliary lane.

**PROGRAM LANGUAGE AND STRUCTURE:**
The program has been written in FORTRAN IV for run­
ing under the IBM 360 Full Operating System. The pro­
gram is divided logically into a main program and three
subroutines which are called by the main program.

**OUTPUTS:**
Frequency distribution of:
- Traverse time
- Spot speeds by lane and checkpoint location
- Time headway
- Counts of stops
- Counts of "uncomfortable" deceleration
- Exiters who are unable to exit
- Lane changing statistics

**VALIDATION:**
No attempt has been made to validate this model.

**EFFICIENCY:**
Due to the complexity of the logic of the model the
simulation running time is high. One minute of simulated
time requires approximately 20 minutes of computer time.

**COMMENTS:**
This model seems to possess many desirable features, i.e.,
complete program documentation and excellent geometric
capabilities; however, since no comparison has been made
between the simulation results and field data, the model's
validity is in question. Also the bulkiness of the model prohibits its use for actual practice.

2.2.3 LIMITATIONS OF EXISTING MODELS

The literature review of the current simulation models reveals that most of these models suffer from lack of reliability which limits the credibility and, consequently, the applicability of the model as useful analysis tools. Reliability is established by verification and validation of the simulation program output. Validation of these models has usually been based on the comparison of the model's output with equivalent field data. Since collecting pertinent and reliable field data was very difficult, in most cases a small amount of data, collected by the researchers themselves, has been the only source for validation. Therefore, when discrepancies were found between the model predictions and the data, it was not known whether the flaw was in the model or data. A careful review of current simulation models reveals that, due to lack of pertinent data, little attention has been given to the validity of these models. In recent years, this has become the specific target of many of the comments and criticisms of users of these models.

Goodwin has published a detailed examination of nine microscopic simulation models (Goodwin, 1972). In this report he recommends:

"... further validation and analysis of these existing simulation models be performed and that the best models, or part of models, be utilized to develop a working simulation tool for the future analysis of traffic characteristics and design procedures."

(Goodwin, 1972)
Hsu and Munjal (Hsu, 1975) have published a critical review of 15 models associated with various aspects of freeway vehicular traffic. Their paper, after a careful examination of the existing models indicates, there was a lack of coordination in the development of models. They conclude:

"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 needs."

Another problem with current simulation models is that they require considerable human time in input preparation, output interpretation and bug detection when undetected errors in program prevented model use. It was found, in a study done by Radelat (1981), that human time involved in these tasks were substantially affected by the following factors:

1. Diversity in models and programs — Although diversity in the early stages of simulation resulted in desirable creativity, it later became a source of inefficiency and confusion;

2. Documentation — Most of the early simulation models were poorly documented because their developers were too busy trying to make the computer programs work and had little time for other things that were considered of secondary importance;

3. Programming Style — The program structure and coding style found in most of the early simulation programs and in the others more recently developed left much to be desired and were characterized by inadequate design, large and complex subroutines that often performed several unrelated functions, and disorganized and poorly annotated code; and

4. Maintenance and Support — Recognition of the importance of these activities has been very slow; therefore, most of the traffic simulation models have received inadequate maintenance and support — a deficiency that has resulted in sizable waste of user time in input preparation, output interpretation, and debugging.
Despite all these deficiencies, more programs were being developed as the need for proper model and program testing was becoming definite. In late 70's more vigorous validations were performed, program demonstration became the rule rather than the expectation, and model implementation efforts were initiated. As Radelot (1981) indicates, it was realized by this time that even a model that does not represent the real world system could be useful if it can give indications on the relative merits of traffic control alternatives.

What follows is a description of various types of weaving sections and a review of the state-of-the-art in weaving sections design and analysis procedures.

2.3 WEAVING SECTIONS

This section contains description of weaving sections and operational characteristics of different types of weaving sections.

Weaving is defined in the "Highway Capacity Manual" (HCM, 1985), as the crossing of two or more traffic streams traveling in the same general direction along a significant length of highway without aid of traffic control devices. A weaving section, therefore, may be described as a length of one-way roadway accommodating weaving, at one end of which two one-ways merge and at the other end they separate. Thus, weaving areas are formed when a merge area is closely followed by a diverge area, or when an on-ramp is joined by an auxiliary lane to an off-ramp.

Intensive lane-changing maneuvers are required in weaving sections as drivers must access lanes appropriate to their desired destinations. Therefore, traffic in weaving areas is subjected to turbulence in excess of what is normally present on basic freeway sections. This turbulence imposes upon the freeway difficult opera-
tional conditions and can result by various degrees in traffic congestion deteriorating the overall efficiency of the highway. Thus, weaving sections have been recognized as a special feature of the freeway requiring individual attention in design and operation.

There are several variations of weaving sections which perform with a degree of similarity even though somewhat different in form. There are four principal means of classifying weaving sections:

**SIMPLE WEAVING SECTION:** consists of two joining roadways followed by two separating roadways. It involves only one point of ingress and one point of egress.

**MULTIPLE WEAVING SECTION:** is a more complex weaving section consisting of two or more overlapping weaving sections. It is formed by several ramp junctions in sequence.

**ONE-SIDED WEAVING SECTION:** is a weaving section in which weaving maneuvers take place only on one side of the freeway. It is formed when both the entrance and the exit ramps are on the same side of the freeway.

**TWO-SIDED WEAVING SECTION:** Requires maneuvers on both sides; weaving across the roadway. It is formed when the entrance ramp and the exit ramp are on the opposite sides of the freeway. Typical examples of weaving sections are shown in figure (1).

The new Highway Capacity Manual (HCM, 1985) classifies weaving sections into three types: A, B, and C, based on the minimum number of lane changes which must be made by weaving vehicles as they travel through the section.

In type A weaving sections, each weaving vehicle is required to make one lane change. In type B weaving sections a through lane is provided for at least one of the weaving movements. Therefore, one weaving movement may be accomplished without making any lane changes. The other weaving movement requires at most one lane changes. Type C sections are similar to type B sections in that through
Figure 1: TYPICAL EXAMPLES OF WEAVING SECTIONS
lanes are provided for one of the weaving movements. However, in type C sections, the other weaving movement requires two or more lane changes.

Figures (2)(3), and (4) show different type of configurations.

Figure 2: TYPICAL EXAMPLES OF TYPE A WEAVING SECTIONS

In the following sections the operational features of freeway weaving sections will be examined. Also a brief description of the state-of-the-art in design and analysis of weaving sections along with some comments on their methodology will be presented.
Figure 3: TYPICAL EXAMPLES OF TYPE B WEAVING SECTIONS

Figure 4: TYPICAL EXAMPLES OF TYPE C WEAVING SECTIONS
2.3.1 OPERATIONAL FEATURES OF WEAVING SECTIONS

Weaving sections are characterized by vehicles entering a common road-way area from two or more entrance flows, and shortly afterward splitting into two or more exit flows within a relatively limited distance. A weaving section accommodates two classes of traffic; weaving and non-weaving. Traffic entering, passing through and leaving the section without crossing the normal path of other vehicles is called non-weaving traffic. Weaving traffic, on the other hand, is the traffic which must cross the path of other vehicles after entering the section. Intermixing of weaving and non-weaving traffic introduces a stream friction which has an adverse effect on the operational performance of the weaving sections along the freeway.

Level of service is a quantitative rating of the effectiveness of a highway describing the operational conditions, ranging from "A" for best operation (low volume, high speed) to "E" for poor operations at possible capacity load. Weaving and non-weaving traffic are each assigned a level of service based on their average running speeds. Since the weaving vehicles must undertake intense lane-changing maneuvers to access lanes appropriate to their desired destinations, their speed is expected to be somewhat lower than that of non-weaving vehicles. Therefore, the speed criteria for weaving vehicles, for any given level of service, are generally several mph lower than that of non-weaving vehicles. This is reflected in the criteria defined in the new Highway Capacity Manual (HCM, 1985), shown in table (1).

When designing a weaving section, to achieve a balanced design, attempt is made to keep average running weaving and non-weaving speeds as equal as possible, or at least keep the weaving and non-weaving level of service in the same level. This facilitates safe and efficient lane-changing of weaving vehicles and provides the least
Table 1

LEVEL OF SERVICE CRITERIA FOR WEAVING AREAS (HCM)

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>MIN. AVG. WEAVING SPEED, $S_w$ (MPH)</th>
<th>MIN. AVG. NON-WEAVING SPEED, $S_{nw}$ (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>54</td>
</tr>
<tr>
<td>C</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>D</td>
<td>40</td>
<td>42</td>
</tr>
<tr>
<td>E</td>
<td>35/30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35/30&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 35/30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>&lt; 35/30&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>The 35-mph boundary for LOS E/F is used when comparing to computed speeds using the equations of Table 4-3. The 30-mph boundary is used for comparison to field-measured speeds.

Disruption to non-weaving vehicles. As the difference between the two speeds increases, the operational performance of the facility is adversely affected and the weaving maneuvers performed by the weaving vehicles become more difficult to safely accomplish.

The time and space in which weaving process must take place is constrained by the length of the weaving section. The measurement of weaving area length is shown in figure (5). Weaving length is measured from the merge gore area at a point where the right edge of the freeway shoulder lane and the left edge of the merging lane are 2 feet apart to a point at the diverge gore area where 2 edges are 12 feet apart. Operational performance of weaving sections is fundamentally dependent upon the
length of the weaving section. As this length is increased, the effect of weaving is lessened, since the merging and diverging movements often segregate with lane changing tending to concentrate near merge and diverge gore area and operation is approximately the same as that experienced in a basic freeway section. Length of any weaving section should be long enough to provide an operating level compatible with the level of service in the highway facility of which the weaving section is a part.

![Diagram](image)

**Figure 5: MEASUREMENT OF WEAVING AREA LENGTH**

Since lane-changing is the critical operational feature of weaving sections, another critical geometric characteristic which drastically affects the performance of such sections is configuration. Configuration is the relative placement and number of entry lanes and exit lanes in a weaving section. It has a major impact on the number of lane-changing made by weaving vehicles and, therefore, carries a high priority in
weaving area design and analysis. In design of weaving sections, determination of N (No. of lanes) and L (Weaving length) is not sufficient, as a given pair may exist in many different configurations, all with differing operating characteristics.

Other geometric and operational features which have an effect on weaving section performance are: width of the weaving section, gradient, traffic composition, and potential speed of entering or exiting traffic as affected by ramp geometry and nearby traffic control devices.

2.3.2 WEAVING SECTIONS ANALYSIS AND DESIGN

Weaving sections are formed along a highway where a merge area is followed closely by a diverge area. The complexity of operation becomes evident where some of the traffic is required to pass through the section (non-weaving traffic), while the rest of the traffic is required to cross the path of other vehicles within the section (weaving traffic). Intermixing of weaving and non-weaving traffic introduces a stream friction which has an adverse effect on the overall operation of such sections along the freeway. Therefore, a knowledge of weaving process has become an important requirement in modern highway design and traffic operation, especially for freeway's channelized intersections and other designs where the crossing of two or more traffic streams is not controlled by traffic signals.

Design procedures for weaving sections involves determining the number of lanes and the minimum length which meets the prespecified level of service under prevailing traffic compositions. Operations analysis involves determination of an average running speed and a probable level of service for a known or projected situation. When designing weaving sections, to facilitate safe and efficient lane changing of
weaving traffic and to provide the least disruption to non-weaving traffic, engineers try to keep expected average running weaving and non-weaving speeds as equal as possible.

Currently several operational analysis and design procedures are available to the highway and traffic engineers. An evolution and brief description of these procedures are in order.

2.3.2.1 BACKGROUND

The original highway capacity manual, published in 1950, provides one of the earliest procedures for the operational analysis and design of weaving sections. These procedures were essentially based on empirical analysis of data collected prior to 1948. In many instances the available data base was quite sparse (Pignataro, 1975). Therefore, it could not be expected to serve adequately in the design of some complex weaving section situations. In 1953, a major effort was initiated by the U.S. Bureau of Public Road (BPR) to collect additional data for updating the 1950 procedures. As a result a new weaving design and analysis procedures was published in the 1965 HCM (HCM 1965). Evaluation procedures developed in 1950 HCM, as well as the modifications, extension, and new methodologies presented in the 1965 edition of HCM, exposed some problem areas such as:

- Instructions that may be subject to misinterpretation.
- Results that sometimes appear unreasonable.
- Procedures that are complex and difficult to apply.

This procedure was, therefore, the specific target of the comments and criticism of many of the users of the HCM.
In recognition of the need for the revision of the HCM procedure a study was initiated by the National Cooperative Highway Research Program (NCHRP) to develop a new procedure for design and analysis of weaving sections. In this study, which was conducted by Politechnic Institute of New York, after recognition of procedural flaws and lack of clarity in the HCM procedure, a new weaving procedure (PINY Method) was developed by means of analytical manipulations and some nomograph solutions.

In an independent effort, in early 80's, a different technique for design of weaving sections was developed and introduced by Jack E. Leisch & Associates (Leisch Method). This method is basically a design oriented tool which allows for relatively easy solution of length and number of lane of any weaving section.

By this time engineers were faced with a decision as to which of the two available methods; Jack Leisch & Associates or PINY method, should be used to analyze weaving sections on freeway. Since these methods gave two different answers to the same problem, in 1983 a research project was initiated by Federal Highway Administration to determine which, if either, of these methods was more applicable to planning, design, and operational analysis of weaving sections. In this project, which was conducted by JHK & Associates (Smith, 1985), a complete review of both PINY and Leisch Methods were made and both procedures were applied to a series of 76 example problems. It was found, as the result of this study, that some of the variables used in both methods generated little or no sensitivity in the output, and therefore, neither the Leisch nor the PINY Method was very accurate and reliable for predicting speeds and determining level of service. A series of recommendations were made regarding the new material to be included in the new HCM. During this research a third method (JHK method) was developed for analyzing weaving sections.
In early 1985, the PINY Method was revised and eventually adopted as the weaving procedures for the new Highway Capacity Manual (HCM, 1985).

Since 1983, the Leisch method has also undergone further revision to readjust nomographs and expand validity of the technique by enlargement of the calibration data set.

These revised methods, which constitute the current state-of-the-art in design and analysis of weaving sections, are so new that they have not yet been tested by engineers. A new study has recently been conducted (Fazio, 1985) to review and evaluate these methods. In this study the JHK weaving procedure was revised by enlargement of calibration data and inclusion of a lane shift variable. This study resulted in yet another method for analysis and design of weaving sections. This new method was then compared with the PINY, the Leisch, and the JHK method in predicting average running weaving and non-weaving speed. Statistical testing of this comparison indicated that the new method gives better results than the others. This model is also yet to be scrutinized in the field.

A brief description of the current state-of-the-art in weaving analysis and design techniques is in order.

2.3.2.2 PINY METHOD

This procedure was evolved from an interactive evaluation of macroscopic and microscopic data collected at 17 northeastern sites. The model is basically for operational analysis, that is, the estimation of level of service for both weaving and non-weaving vehicles for a given set of geometry and traffic compositions. If the user wishes to apply the PINY Method for design, an iterative process should be performed.
The first step in PINY method is conversion of the volumes to passenger car units during the peak period. One of the four configuration types shown in figure (6) is then selected and an arbitrary speed (typically 55 mph) is assumed for non-weaving vehicles in order to begin the process. From figure (8) the speed of weaving vehicles is determined and the value for maximum number of lanes, \( N_{w(\text{max})} \), for weaving vehicles is read from figure (7). The ratio of \( N_{w(\text{max})} \) divided by \( N \) (number of lanes in weaving section) is then determined from figure (9). Speed relationships for weaving and non-weaving traffic could be determined graphically from figure (9) and (10) respectively. Finally, the level of service is determined using a standard look-up table.

A concept which was introduced by PINY and is part of the computational procedures is the \( N_{w(\text{max})} \). Although this is part of the calculation, typical users do not have a clear understanding of what this means nor is it clear as to the calibration and validation efforts made for this factor (Reilly, 1984). Level of service in this method is based strictly on the difference between the weaving and non-weaving speed. The validity of this is questionable since it is possible to estimate low levels of service for weaving vehicles even though their speed may be on the order of 50 to 60 mph.
Figure 6: DIAGRAM OF VARIOUS CONFIGURATIONS OF WEAVING (NCHRP 212)
(a) RAMP-WEAVES  
(All Cases)

(b) TYPE I MAJOR WEAVES  
(Unconstrained Cases Only)

(c) TYPE II MAJOR WEAVES  
(Unconstrained Cases Only)

EXAMPLE

Ramp-weave  
$S_{NW} = 42$ mph  
$L = 1000$ ft.  
Thus, $S_{W} = 38$ mph

Figure 7:  SPEED RELATIONSHIPS FOR WEAVING AREAS (NCHRP 212)
EQUATIONS

\[ \log N_{w, \text{max.}} = 0.719 + 0.480 \log R \]  
(TYPE I)

\[ \log N_{w, \text{max.}} = 0.896 + 0.189 \log R - 0.402 \log L_{w} \]  
(TYPE II)

**Example**

TYPE II SECTION

\( \frac{R}{L} = 0.4 \)

\( L = 1500 \text{ ft.} \)

Thus, \( K_{w, \text{max.}} = 2.2 \)

---

*Data base for Type I curve limited to lengths in the order of 400 to 750 feet. For other lengths, multiply the value from the Type II curve of appropriate length by 0.85 as a rough estimate.*

**Note:** 1 ft. = 0.3048 m.

Figure 8: MAXIMUM NUMBER OF LANES IN MAJOR WEAVING SECTIONS  
(NCHRP 212)
EXAMPLE

$S_w = 37$ mph,
$L = 1000$ ft.,
$VR = 0.18$

Ramp-weave

Thus, $N_w/N = 0.30$

Figure 9: SHARE OF ROADWAY RELATIONSHIP FOR WEAVING VEHICLES (NCHRP 212)
Figure 10: SPEED-FLOW RELATIONSHIP FOR NON-WEAVING VEHICLES (NCHRP 212)
2.3.2.3 LEISCH METHOD

This method has as its base the 1965 Highway Capacity Manual (HCM 1965). It is a design-oriented tool which allows for relatively easy solution of weaving length and total number of lanes within the weaving section.

The basic steps are carried out on one of the two nomographs; one-sided or two-sided; shown in figure (11) and (12). The inputs to the nomographs are the total weaving volume in passenger car per hour, level of service, the approach freeway volume and number of lanes, and the weaving ratio which is the smaller of the two weaving volumes divided by the sum of the two. Following a set of paths, shown in the nomograph, the minimum required weaving length and total number of lanes required for a balanced design could be obtained. A new report provided by Leisch (Leisch 1983) contains additional material which allows the user to estimate speed of weaving and non-weaving traffic.

The principle on which development of the Leisch Method was based is that weaving volume, weaving length, and weaving speed are interrelated. The concept used by Leisch to select one of the two nomographs (one-sided or two-sided) is not totally clear (Reilly, 1984), since some weaving sections may be classified as either one-sided or two-sided.
Figure 11: NOMOGRAPH FOR DESIGN AND ANALYSIS OF ONE-SIDED WEAVING SECTIONS (Leisch)
TRANSPORTATION RESEARCH CIRCULAR 212, INTERIM MATERIALS ON HIGHWAY CAPACITY. FIGURES 1 AND 2 FOR A NEW TECHNIQUE FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS ON FREEWAYS (SEE PAGE 267).

**Figure 12: Nomograph for Design and Analysis of Two-Sided Weaving Sections (Lanes)**

<table>
<thead>
<tr>
<th>N = 2</th>
<th>N = 3</th>
<th>N = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Service</td>
<td>Level of Service</td>
<td>Level of Service</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>J</td>
<td>J</td>
<td>J</td>
</tr>
<tr>
<td>K</td>
<td>K</td>
<td>K</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

**Legend:**
- L = LENGTH OF WEAVING SECTION - FEET
- W = TOTAL WEAVING VOLUME - VEHICLES PER HOUR
- R = RATIO: W₁: W₂
- W₁ = SMALLER WEAVING VOLUME - NON-CIRCULAR
- W₂ = CIRCULAR

**Note:**
- LANE-BALANCED WEAVING SECTIONS
- LANE-IMBALANCED WEAVING SECTIONS
- AVERAGE RUNNING SPEED: WEAVING TRAFFIC

**Analysis Nomograph:**
- For design and operation of two-sided weaving sections.

**Table Data:**
- Length of weaving section, number of lanes, and weaving volume relationships.
2.3.2.4 FAZIO METHOD

In this method, which was developed in late 1985, configuration of the weaving sections were accounted for by inclusion of a lane shift variable which represents the average amount of lane shifts occurring under a given geometric configuration and prevailing traffic compositions.

First step in this procedure is determination of the lane shift multiplier which is the minimum amount of lane shifts a vehicle, in a particular lane, must make in order to complete the weaving maneuver, see figure (13). All volumes are then converted to the peak flow rate by applying appropriate adjustments. The lane shift variables LS and LS3 as determined using equations in table (2) and the average running weaving and non-weaving speeds are calculated using equation in table (3). Finally, level of service could be obtained from table (4). Statistical testing of this procedure, carried out by its author, indicate that in most cases a better prediction of observed average running weaving and non-weaving speeds, when compared with the other methods, are obtained.
Lane Shift Multipliers (LS/veh):
A = 0, B = 1, C = 2, D = 3

Lane Shift Multipliers (LS/veh):
A = 1, B = 1, C = 2, D = 3

Figure 13: EXAMPLES ON DETERMINING LANE SHIFT MULTIPLIERS (Fazio)
Table 2

*LANE SHIFT EQUATIONS (Fazio)*

<table>
<thead>
<tr>
<th>$N_D$</th>
<th>$LS_2$</th>
<th>$LS_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$V_B^2 / (PHF \times f_{HV} \times f_W \times f_P)$</td>
<td>$V_{3A} / (PHF \times f_{HV} \times f_W \times f_P)$</td>
</tr>
<tr>
<td>2</td>
<td>$(0.934V_B^2 + 0.66V_C^2) / (PHF \times f_{HV} \times f_W \times f_P)$</td>
<td></td>
</tr>
<tr>
<td>$\geq 3$</td>
<td>$(0.905V_B^2 + 0.085V_C^2 + 0.010V_D^2) / (PHF \times f_{HV} \times f_W \times f_P)$</td>
<td></td>
</tr>
</tbody>
</table>

$LS = LS_2 + LS_3$
Table 3

EQUATIONS FOR WEAVING AND NON-WEAVING SPEEDS (Fazio)

\[
S_W = 15 + \frac{50}{(1 + (V_3 + V_4)/V)^3.045(V/N)^{0.605}} \times (LS/L)^{0.902}/(75.959(1 + LS_3/V)^{3.395})
\]

\[
S_{NW} = 15 + \frac{50}{(1 + (V_4/V)^{5.080}(1 + V_W/V)^{2.019}} \times (V/N)^{1.523}/(60.995(1 + LS_3/LS)^{0.916}(L)^{1.070})
\]

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S_W)</td>
<td>predicted average running weaving speed, mph</td>
<td>(&gt;15)</td>
</tr>
<tr>
<td>(S_{NW})</td>
<td>predicted average running non-weaving speed, mph</td>
<td>(&gt;15)</td>
</tr>
<tr>
<td>(V)</td>
<td>total volume, pcph</td>
<td>(&gt;0)</td>
</tr>
<tr>
<td>(V_W)</td>
<td>total weaving volume, pcph</td>
<td>(0)</td>
</tr>
<tr>
<td>(V_3)</td>
<td>movement 3 volume, pcph</td>
<td>(0)</td>
</tr>
<tr>
<td>(V_4)</td>
<td>movement 4 volume, pcph</td>
<td>(0)</td>
</tr>
<tr>
<td>(N)</td>
<td>total number of lanes in weaving section</td>
<td>2</td>
</tr>
<tr>
<td>(L)</td>
<td>length of weaving section, feet</td>
<td>(&gt;0)</td>
</tr>
<tr>
<td>(LS)</td>
<td>number of lane shifts by weaving vehicles, pcLSph</td>
<td>(&gt;0)</td>
</tr>
<tr>
<td>(LS_3)</td>
<td>number of lane shifts by movement 3 vehicles, pcLSph</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4

*RECOMMENDED LEVEL OF SERVICE RANGES (Fazio)*

<table>
<thead>
<tr>
<th>LOS&lt;sub&gt;W&lt;/sub&gt;</th>
<th>average running weaving speed S&lt;sub&gt;W&lt;/sub&gt; (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≥ 50</td>
</tr>
<tr>
<td>B</td>
<td>≥ 45</td>
</tr>
<tr>
<td>C</td>
<td>≥ 40</td>
</tr>
<tr>
<td>D</td>
<td>≥ 35</td>
</tr>
<tr>
<td>E</td>
<td>≥ 25</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOS&lt;sub&gt;NW&lt;/sub&gt;</th>
<th>average running weaving speed S&lt;sub&gt;NW&lt;/sub&gt; (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≥ 55</td>
</tr>
<tr>
<td>B</td>
<td>≥ 50</td>
</tr>
<tr>
<td>C</td>
<td>≥ 45</td>
</tr>
<tr>
<td>D</td>
<td>≥ 40</td>
</tr>
<tr>
<td>E</td>
<td>≥ 30</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 30</td>
</tr>
</tbody>
</table>
2.3.2.5 JHK METHOD

In this method, hourly volumes are adjusted to passenger car equivalents by applying the heavy vehicle factor (Q). Then the following two equations are utilized to obtain the average running weaving and non-weaving speeds.

\[
S_{\text{w}} = 15 + \frac{50}{(1 + (2000 / V) \frac{1 + V}{V} \frac{V}{V/Q/N} / L)}
\]

\[
S_{\text{nw}} = 15 + \frac{50}{1 + (100 / V) \frac{1 + V}{V} \frac{V}{V/Q/N} / L}
\]

Once the average running speeds are calculated, weaving and non-weaving level of services are determined from appropriate tables.

One of the disadvantages of this method is that the effect of configuration on the design and analysis of weaving sections has not been considered.

2.3.2.6 1985 HCM

In the 1985 HCM, weaving sections are categorized into three different types; A, B, and C, based on the minimum number of lane changes which must be made by weaving vehicles as they travel through the section, table (5).

A key step in applying the HCM procedures is determination of type of operation; constrained or unconstrained. This is done based on comparison of two variables; \( N_w \) and \( N_w(\text{max}) \). Table (6) reflects the criteria for unconstrained versus constrained operation of weaving areas. Once the type of operation is determined, weaving and non-weaving speeds are calculated from:
Table 5

*CONFIGURATION TYPE VS. NUMBER OF REQUIRED LANE CHANGES (HCM)*

<table>
<thead>
<tr>
<th>NUMBER OF REQ'D LANE CHANGES FOR WEAVING MVT. a</th>
<th>NUMBER OF REQ'D LANE CHANGES FOR WEAVING MVT. b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>≥ 2</td>
<td>≥ 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type B</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type B</td>
<td>Type A</td>
<td>—</td>
</tr>
<tr>
<td>Type C</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\[ S \text{ or } S = \frac{15+50}{1+a(1+VR) \left( \frac{V}{N} \right) /L} \]

Where \(a, b, c\) and \(d\) are calibration constraints based on type of operation and configuration table (7). Finally the level of service for weaving and non-weaving traffic is read out from table (1).
### Table 6

**CRITERIA FOR UNCONSTRAINED VS. CONSTRAINED OPERATION OF WEAVING AREAS (HCM)**

<table>
<thead>
<tr>
<th>TYPE OF CONFIGURATION</th>
<th>NO. OF Lanes Req'd FOR UNCONSTRAINED OPERATION, $N_\ast$</th>
<th>MAX. NO. OF WEAVING LANES, $N_\ast$ (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>$2.19 N VR^{0.311} L_w^{0.134}/S_w^{0.044}$</td>
<td>1.4</td>
</tr>
<tr>
<td>Type B</td>
<td>$N [0.085 + 0.703 VR + (234.8/L) - 0.018(S_{uv} - S_w)]$</td>
<td>3.5</td>
</tr>
<tr>
<td>Type C</td>
<td>$N [0.761 - 0.011 L_w - 0.005(S_{uv} - S_w) + 0.047 VR]$</td>
<td>3.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> All variables are as defined in Table 4-2.

<sup>b</sup> For 2-sided weaving areas, all freeway lanes may be used as weaving lanes.

**NOTE:**
- When $N_\ast \leq N_\ast$ (max), operation is unconstrained.
- When $N_\ast > N_\ast$ (max), operation is constrained.
Table 7

CONSTANTS FOR PREDICTION OF WEAVING AND NON-WEAVING SPEEDS IN WEAVING AREAS (HCM)

GENERAL FORM:

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

<table>
<thead>
<tr>
<th>TYPE OF CONFIGURATION</th>
<th>CONSTANTS FOR WEAVING SPEED, ( S_w )</th>
<th>CONSTANTS FOR NONWEAVING SPEED, ( S_{nw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( a )</td>
<td>( b )</td>
</tr>
<tr>
<td>TYPE A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconstrained</td>
<td>0.226</td>
<td>2.2</td>
</tr>
<tr>
<td>Constrained</td>
<td>0.280</td>
<td>2.2</td>
</tr>
<tr>
<td>TYPE B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconstrained</td>
<td>0.100</td>
<td>1.2</td>
</tr>
<tr>
<td>Constrained</td>
<td>0.160</td>
<td>1.2</td>
</tr>
<tr>
<td>TYPE C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconstrained</td>
<td>0.100</td>
<td>1.8</td>
</tr>
<tr>
<td>Constrained</td>
<td>0.100</td>
<td>2.0</td>
</tr>
</tbody>
</table>

2.3.3 CONCLUSIONS

The literature review revealed that, in development of the current methods for weaving analysis and design, one of the most critical problems researchers had to deal with was availability of pertinent and reliable data. Perhaps the best articulation of this problem was found in a study by Bullen (1982):

"The amount of field data available is much less than that required to fully calibrate and validate the macro methods in more detail."

(Bullen, 1982)

Therefore, in most cases the models were calibrated on limited data collected prior to 1970. Such models may not reflect 1980's traffic compositions and driver characteristics.
Another persistent problem with the available models is that they are macroscopic and, therefore, not containing enough detail, which limits the level of analysis. These models basically reflect an established relationship between several variables and represent the overall operational conditions of the section via a single measure of performance (speed). When the problem involves unique or unusual geometric and traffic operation characteristics, additional level of analysis may be required. In such cases a microscopic model, such as WEAVSIM, could provide the necessary capability. Microscopic models reflect the effect of geometric and human factors influencing the operation of traffic flow. They provide the means to study different problem areas by providing detailed information (second-by-second, lane-by-lane) about the system performance.

Therefore, development of a well designed microscopic simulation model is an effective method of studying the time varying, complex, and stochastic process of traffic flow through weaving sections. It provides the highest level of detail and accuracy of available analysis techniques.

In the following chapter the modeling process of WEAVSIM, as well as a full description of its features and individual components are presented.
CHAPTER III
DEVELOPMENT OF THE SIMULATION MODEL

3.1 INTRODUCTION

The modeling process of WEAVSIM involved selection of a set of input elements and development of the logic which controls the generation and movement of vehicles through the weaving area, as well as selection of an appropriate simulation language for programming the model. In this chapter an investigation of some studies that have direct bearing on the modeling process of WEAVSIM will be presented along with the final decisions for selection of elements and the simulation language used in this model. Full description of the model including its features and individual components are also presented in this chapter.

3.2 INPUT ELEMENTS

In the following sections, an extensive overview of existing information concerning elements involved in the modeling process of WEAVSIM will be presented. The purpose of this overview is to reveal the application of various elements in current simulation models, and therefore, select appropriate input parameters for the proposed model.
3.2.1 VEHICLE ARRIVAL HEADWAYS

Vehicle interarrival time distribution is directly related to the input volume. Numerous attempts have been made by researchers to fit some of the well known statistical distributions to observed data. Following is a brief review of some of the arrival headway distributions commonly used in current freeway simulation models.

An investigation of arrival headways on shoulder and median lanes of the Eisenhower expressway was conducted by May (1965). As the result of this study, May proposed a composite normal-poisson distribution, a normal distribution for restrained vehicles (in platoon) and a Poisson distribution for free flow vehicles.

A Hyper-Erlang probability distribution for headways was proposed by Dawson and Chimini (1968). The negative exponential and Erlang distributions are considered special cases of this model.

Based on an investigation of the Ohio State University data by Tolle and Treiterer (1969-1976), a lognormal distribution was suggested for interarrival time headways. This result was based on a comparison of the lognormal, exponential, shifted exponential and composite exponential distributions.

Pignataro (1973) suggests that vehicle spacing at a point will follow a random distribution, which can be described mathematically by the Poisson distribution.

A composite model was suggested by Cowan (1975). This model consists of two components: one for free flow and one for vehicles in platoon.

Leland (1970) used a negative exponential distribution to determine interarrival time of vehicles for the Connecticut simulation model. The shortcoming of the expo-
nential distribution is prediction of too many short headways. To treat this situation some researchers have introduced the shifted negative exponential distribution by provision of a minimum allowable headway. Most current freeway simulation models; CARSIM (Benekohal, 1986), FREESIM (Rathi, 1985), INTRIS (Wicks, 1980), Northwestern model (Worrall, 1969) have applied shifted negative distribution models to represent interarrivals of vehicles.

In general, the multi-region models such as: Hyper-Erlang, Composite Exponential, and Shifted Lognormal, give better fits to observed data than the simpler models. However, their pitfall is in their number of parameters which require considerable amount of data for calibration.

Selection of a suitable interarrival headway distribution for this model was based on analysis of the FHWA data. Statistical analysis of this data resulted in a selection of a shifted negative exponential distribution with a minimum headway of one (1) second.

3.2.2 SPEED
Speed distribution is influenced by various factors such as: traffic volumes, traffic density, roadway and vehicle conditions, and environmental conditions, as well as the restraints of speed and regulations. At the system entry point where the conditions are such that drivers can select whatever speed they desire — i.e., a free flowing condition — there is always a wide range of speeds in which the various individuals operate their vehicles.

Numerous researchers have used normal distribution to represent speeds at freeway lanes. An excellent example of this is contained in the work of Leong (1968).
He reports speed measurements of free-flow speeds at several rural locations in New South Wales (Austria). The speed distributions are found to be normal. Pignataro (1973) also suggests a normal distribution for vehicular speeds on rural freeway sections. Breiman's investigation of the Long Island Expressway data (Breiman et al, 1977) also shows that the time sequence of speeds as well as the space speeds are normally distributed. Several simulation models; SINHA (Sinha, 1973), Connecticut (Leland, 1970), Northwestern (Worral and Bullen, 1969), and Arizona (Richard, et al, 1965); have used normal distribution of speeds in their simulation of freeway segments.

Some researchers, however, have found speed distributions to be quite skewed when a fit of normal distribution is attempted, and therefore, have suggested other distributions for speed. Ashworth (1976) for example, suggests that Erlang distribution gives a better representation of observed speeds than normal distribution. Haight and Mosher (1961) have also proposed use of lognormal distribution for speed models. Some investigators have suggested use of truncated normal distributions to represent speeds. For example; the Texas Transportation Institute Simulation model (Buher et al, 1968) generates desired speeds from a normal distribution with truncation at a set maximum speed, mean of 85% of the maximum speed and a standard deviation which is 1.375 more than 7% of the mean. FREESIM (Rathi, 1983), INTRAS (Wicks, 1980), Mikhalkin (Mikhalkin, 1970), and Midwestern Research Institute (Kobett and leny, 1965) freeway simulation models have also used truncated normal distribution to generate desired speeds.

In WEA VSIM, desired speeds are generated from a truncated normal distribution obtained from analysis of the FHWA data.
3.2.3 BRAKE REACTION TIME

Brake reaction times were first measured under simulated conditions in the laboratories. Greenshields (1936) conducted an experiment which included 1461 samples and resulted in mean reaction time of .496 second. In another study, Normann (1953) found values ranging from .4 seconds to a high of 1.7 seconds for alerted drivers. Forbes and Katz (1957) obtained a mean reaction time of .641 from a sample size of 907. These results are now considered too short.

Recent measurements of reaction times, which are results of field driver responses, are considered more reliable. The time measured in these experiments is the sum of the time to perceive the need for braking and the time to move the foot from the accelerator to the brake pedal. Drew (1968) conducted an experiment consisting of 1000 men and women drivers. The mean reaction time for men was 0.57 and for women was 0.62 second. Norman (1953) obtained a mean reaction time of .73 sec. under alerted condition from a sample of 53 drivers. Johansson and Rumar (1971) measured the brake-reaction times of 321 drivers under an anticipated condition and a much smaller sample of 5 drivers under surprise conditions. It was concluded as the result of this study that on 10 percent of the occasions, mean brake reaction time was estimated to be 1.5 seconds, the mean reaction time for surprised drivers was .89 seconds, and for anticipated conditions the mean was .75 seconds.

Hooper and McGee (1983) after their review of the current specification values for perception reaction-time, recommended a brake reaction time of 2 seconds for intersection sight distance where there is a stop sign on the minor street.

Olson and Cleveland (1984) have recently conducted a study to investigate perception-response time for young (age 40 or less) and older (age of 60 or more)
drivers under surprised and alerted conditions. Under alerted conditions the 20th and 90th percentile values for both young and old drivers was in the range of .42 to .70 seconds. Under surprised conditions the 20th and 90th percentile values were (.57, .95) and (.63, 1.00) for young and older drivers respectively.

In WEAVSIM, vehicles brake reaction times are generated stochastically from a gamma distribution based on the results of the Johansson and Rumar study. The mean and variance of the gamma distribution are 0.745, and 0.073 seconds, respectively. To prevent generation of unreasonable brake reaction times, the generated values are truncated at 0.25 and 1.50 seconds. Furthermore, for vehicles with short arrival headway, the generated brake reaction time is adjusted to a smaller value such that the vehicle can at least maintain the minimum lane speed while maintaining a safe-following distance. This prevents excessive rejection of vehicles at high volume levels.

3.2.4 GAP ACCEPTANCE

Drew (1968), in a study of gap acceptance, evaluated the effect of relative speed on the critical gap for merging ramp vehicles at the Dumble entrance ramp of the Gulf Freeway. Drew, as a result of his study, suggests that the critical gap is directly related to the speed. The critical gap for moving vehicles (based on the first gap evaluated) is about 20% less than that of stopped vehicles. A set of gap acceptance functions, illustrated in figure (14), and a merging delay model were developed by Drew.

Tsongos and Wiener (1969), in their investigation of gap acceptance, have found different distribution of acceptance and rejection for night than for day.
Figure 14: VARIOUS FORMS OF GAP ACCEPTANCE FUNCTIONS (Drew)
Worral and Bullen (1970) conducted a statistical analysis of the data collected at thirty freeway locations in Chicago area. The study results indicates that there is a tendency for the intensity of lane changing to increase in the vicinity of ramp area. Furthermore, gap acceptance behavior displays only a very weak, and as yet largely undefined, relationship to traffic flow. As a result of this study, a gap acceptance function based on lane density was formulated for lane changing vehicles.

In another study of gap acceptance Mosher (1970) applied the critical gap concept by using a distribution of angular velocities at merges. The drivers' critical gaps were then evaluated based on the 50th percentile value of the angular velocity.

In an analysis of aerial data, Paul (1972) investigated gap acceptance characteristics for exiting vehicles close to their intended off ramps and for through vehicles as a function of distance from the off ramp. In this study Paul has shown that the mean and median gap that was accepted decreases as drivers move closer to the exit ramp. Paul supports these findings by referring to the fact that as the driver felt more psychological pressure to move toward the exit lane, he was willing to change the threshold requirements of the gap size that was needed. This result, which tends to agree with Worral and Bullen findings, has some implication in development of the lane-changing algorithm of WEAVSIM. In fact, development of the lane-changing factor (discussed in section 4.4.1) is based on the fact that as drivers move closer to the diverge gore area, they become willing to accept greater risk and use more severe deceleration. Paul also shows that the size of the accepted gap decreases as flow levels increase.

Miller (1980), in his study of drivers gap estimation capabilities, explored the threshold gap acceptance functions under both static and dynamic conditions. One
major finding of this study was that when gaps of equal length were compared, the lead gaps were shorter than the lag gaps.

The gap acceptance logic deployed in WEAVSIM is explained in section 3.4.8 where the lane-changing algorithm is discussed.

3.2.5 ACCELERATION/DECELERATION CAPABILITIES

Acceleration/deceleration rates are influenced by speed as well as by grade and vehicle type. Several attempts have been made to investigate the acceleration/deceleration capabilities of different vehicle types at various speeds. For example, Loutzenheiser (1938), in his study of speed change rates for passenger vehicles, found that pickup under the normal or unhurried control of typical drivers decreases as the speed increases and is about 60 percent of the full rates of acceleration found by Bureau of Public Road Study. In another study, conducted by Beakey (1938), the distance traveled during acceleration for vehicles ultimately reaching a running speed of 40 to 50 mph compares favorably with those of the study done by Loutzenheiser. The transportation and Traffic Engineering Handbook (1982) provides some data on acceleration/deceleration capabilities for different vehicle types at various speeds (table 9).

Some of the current freeway simulation models (Buhr, 1968) assume constant values for both acceleration and deceleration rates. Those values are provided as input information and are held constant throughout the simulation process. Some others; (Bullen, 1976; Rathi, 1983) assume a discrete or step function relationship between acceleration/deceleration rates and speed. Finally some use mathematical formulation of acceleration/deceleration rates as a continuous function of operating speed.
In WEAVSIM, the maximum rate of acceleration is expressed as an inverse linear function of speed for different vehicle types. This was done by regression analysis of the data presented in the 1982 Traffic Engineering Handbook. Figure(15) illustrates the relationship between maximum rate of acceleration and speed for different vehicle type. The normal deceleration rates are, on the other hand, obtained from a discrete step function relationship developed from information provided in the 1982 Transportation and Traffic Engineering Handbook. The maximum rate of deceleration is computed as follows:

The equation for the stopping sight distance is:

\[ S = \frac{\frac{2}{V}}{30(f+g)} \]  

(1)

Where:  
V = speed of the vehicle before braking (mph.)  
S = stopping distance (ft.)  
f = friction coefficient  
g = gradient

Transportation and Traffic Engineering Handbook (1982) contains skidding friction coefficients for various pavement and tire conditions. Using a mean value of .58 for friction coefficient and assuming a zero grade, equation (1) will be reduced to:

\[ S = \frac{\frac{2}{V}}{17.4} \]  

(2)

From the laws of dynamic, using the constant deceleration model, the stopping distance is:

\[ S = \frac{\frac{2}{(1.47V)}}{2d} \]  

(3)
Figure 15: Maximum Rate of Acceleration vs. Speed
Equating equations (1) and (2) makes possible calculation of the maximum deceleration rate:

\[
\frac{2}{V} = \frac{2}{1.47V}
\]

\[
17.4 = 2d
\]

\[d = 18.71 \text{ fps/s}\]

This value is imbedded in WEAVSIM as the maximum deceleration rate.

3.2.6 LEVEL OF SERVICE

Level of service is, as described in the new Highway Capacity Manual (1985), a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists. It generally describes the operating conditions in terms of such factors as speed, travel time, traffic interruptions, freedom to maneuver and comfort and safety. Level of service ranges from A to F, with level of service A representing the best operating conditions and level of service F the worst.

In weaving sections, level of service is directly related to the average weaving and non-weaving speeds. The new Highway Capacity Manual provides speed criteria for various level of services. Due to additional turbulence in weaving sections, created by weaving vehicles, the speed criteria for any given level of service are generally several mph lower than similar criteria for a basic freeway section.

In WEAVSIM the level of service, for weaving and non-weaving traffic, is determined in accordance with the criteria provided in the Highway Capacity Manual, table (1).
3.3 SIMULATION LANGUAGE

Now that all aspects of the model to be simulated have been decided on, the model must be translated into a form suitable for the computer. That is, the model must be coded using a simulation language.

The range of available simulation programming languages that have been used in simulation covers the entire spectrum, from the low-level, machine-oriented assembly languages to the specialized simulation-oriented languages such as SIMSCRIPT and GPSS. The following factors influence the choice of a language (Graybeal 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 the simulation is to be done.

Multipurpose languages such as FORTRAN, ALGOL, and PL/I are more commonly used due to the ease with which the language is learned and their widespread availability. Even a very small computer installation probably has these compilers. Nevertheless, the main drawback of these languages is that the entire model must be coded by the programmer and they provide very few simulation-oriented functions and little debugging assistance other than pointing out syntactic errors.
Because many simulation projects needed similar functions across various applications, special-purpose simulation languages were developed in the late 1950's. Although several such languages were developed, only a few have gained some degree of popularity. More commonly used special-purpose languages are SIMSCRIPT II.5, GPSS, GASP, and SLAM. Table (8) provides a comparison of several simulation languages based on the work of Banks and Carson (1984). A detailed discussion of choosing a simulation language and the criteria for making that choice is provided by Shannon (1975).

Based on evaluation of the factors influencing the choice of a simulation language, SIMSCRIPT II.5 was chosen to program WEAVSIM.

SIMSCRIPT II.5 is a high-level programming language which has the full power and flexibility of a complete programming language for both discrete event and continuous simulation. It is a free-format, english-like language which makes the simulation programs more readable and understandable even for a nonprogrammer.

SIMSCRIPT II.5 is a compiler-type language in which the system is described in terms of permanent and temporary entities, attributes, sets, and events. Permanent entities are objects in the system that will remain in the system for the whole duration of the simulation. Temporary entities, on the contrary, are objects which arrive to the system, remain for a while, and then leave the system. Entities may have attributes and may belong to sets. Sets are collections of individual entities with common properties. An event represents one or more actions that takes place instantaneously at a given time. Events are usually handled by FORTRAN-like subroutines. The state of the system at any given time is described by the current list of individual entities, their attributes, and set memberships. In SIMSCRIPT II.5 the
<table>
<thead>
<tr>
<th>Criteria</th>
<th>FORTRAN</th>
<th>GASP</th>
<th>SIMSCRIPT II.3</th>
<th>GPSS V</th>
<th>SLAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of learning</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Ease of conceptualizing a problem</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Systems oriented toward</td>
<td>None</td>
<td>All</td>
<td>All</td>
<td>Queueing</td>
<td>All</td>
</tr>
<tr>
<td>Modeling approach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event-scheduling</td>
<td>No*</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Continuous</td>
<td>No*</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random sampling built in</td>
<td>No*</td>
<td>Yes</td>
<td>Yes</td>
<td>No*</td>
<td>Yes</td>
</tr>
<tr>
<td>Statistics-gathering capability</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>List-processing capability</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Ease of getting standard report</td>
<td>Poor</td>
<td>Excellent</td>
<td>Fair</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Ease of designing special report</td>
<td>Fair</td>
<td>Good</td>
<td>Excellent</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Debugging aids</td>
<td>Excellent*</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Computer runtime</td>
<td>Excellent*</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Documentation for learning language and</td>
<td>Very good</td>
<td>Very good</td>
<td>Fair</td>
<td>Very good</td>
<td>Very good</td>
</tr>
<tr>
<td>for reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-documenting code</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*For queueing models, the block diagram (network) conceptualization is excellent.
*FORTRAN is not oriented toward system simulation. The programmer develops any desired orientation and takes any desired modeling approach.
*Several scientific subroutine libraries (e.g., IMSL) have FORTRAN routines for random variate generation.
*GPSS H is much improved over GPSS V in these respects.
*FORTRAN will be fast assuming that the model is programmed in the most efficient manner.
*Usually available at most computer installations.
time advance routine, random variate generation routines, and statistics gathering routines are provided automatically. Capabilities of SIMSCRIPT II.5 is described briefly by Russel (1976) and Law and Kelton (1982) and in more detail by Russel (1983).

In WEAVSIM, vehicles constitute the temporary entities and lanes represent the permanent entities. Attributes of each vehicle would include type, origin, destination, speed, position, etc. Sets would include all vehicles in lane 1, 2, or 3 at any given time.

3.4 DESCRIPTION OF THE MODEL

The following sections contain assumptions and limitations of WEAVSIM, as well as its structure, input, and output.

3.4.1 ASSUMPTIONS AND LIMITATIONS

Prior to programming the WEAVSIM, certain restrictions and assumptions were made. These assumptions and limitations were carefully tailored so as not to interfere with the expected applications of the model.

The geometry of the simulated weaving section is restricted as to maximum allowable lanes of three lanes, while the length of the weaving section is conceptually unlimited. The model could easily be modified to extend the number of lanes. A maximum of three vehicle types, passenger car, trucks, and trailers, are defined.

The model assumes a straight level roadway alignment. However, the effect of vertical grade could be accounted for by adjustments in vehicle acceleration and deceleration capabilities.
3.4.2 FUNCTIONAL STRUCTURE OF THE MODEL

This section contains a full description of individual components of the model as well as the methodology incorporated into the model.

WEAVSIM simulation model moves discrete vehicles through the simulated traffic network by updating their positions and speeds at each 1-second time interval. All vehicles are processed in accordance with their desired speeds and destinations inhibited by the immediate traffic and control environment.

3.4.3 SIMULATION INPUT

Input parameters required in WEAVSIM are all free format. Following is a list of the inputs:

1. SIMULATION RUN PARAMETERS:
   . Total simulation time
   . Warm-up period
   . Random number seeds

2. WEAVING SECTION PARAMETERS:
   . Simulated weaving section
   . Downstream buffer length
   . Upstream buffer length

3. TRAFFIC PARAMETERS:
   . Traffic volume for each lane
   . Proportion of weaving vehicles for each lane
   . Mean and standard deviation of maximum speed
   . Mean and standard deviation of arrival speed
   . Probability of lane-changing for non-weaving vehicles
4. VEHICLE AND DRIVER CHARACTERISTICS:

- Average length of a passenger car
- Average length of a truck
- Average length of a trailer
- Maximum emergency deceleration rate
- Mean brake reaction time
- Brake reaction time parameter for gamma distribution

5. LIST OF DESIRED OUTPUTS: A simple yes (no) answer to any of the following questions would provide (eliminate) the desired (undesired) set of outputs.

- Are intermediate outputs desired? If yes;
  - At what intervals?
- Are merging point distributions desired?
- Are graphs of C.D.F of merging points desired?
- Are distributions of accepted gaps desired?
- Are graphs of C.D.F of accepted gaps desired?
- Are lane speed distributions required?
- Are distributions of weaving and non-weaving speed desired?
- Are graphs of C.D.F of weaving and non-weaving speed desired?
- Are headway distributions desired?
- Are graphs of C.D.F of headways desired?
- Are vehicle trajectories desired? If yes;
  - At what intervals?

3.4.4 SIMULATION OUTPUT

The WEAVSIM model produces various standard and optional outputs. The following section describes these outputs.

3.4.4.1 STANDARD OUTPUTS

1. TITLE PAGE: This page contains information about the scanning intervals, data collection intervals, and the warm-up period. It also marks the beginning of the simulation output.
2. **ECHO OF INPUT PARAMETERS**: A list of all input parameters are provided for each simulation run. This list fully identifies the geometric, control, and traffic input descriptors which characterize the weaving section under study.

3. **STATISTICS ON MEASURES OF PERFORMANCE**:  
   - Delay for weaving and non-weaving vehicles  
   - Travel time  
   - Arrival speed for each lane

4. **VOLUME DATA**  
   - Actual input volume for each lane  
   - Exiting volume for each lane

5. **LANE-CHANGING DATA**  
   - Total number of lane changing for each lane  
   - Number of lane-changing from/to each lane

6. **MISCELLNEOUS DATA**  
   - Number of rescheduled arrivals for each lane  
   - Number of rejected gaps for each lane

3.4.4.2 **OPTIONAL OUTPUTS**

1. **INTERMEDIATE OUTPUTS**: Summary statistics (ave., max., and std.dev) on measures of performance for each lane are provided at user specified time intervals. The measures of performance include:
   - Lane speed  
   - Lane density  
   - Lane headway  
   - Delay for weaving and non-weaving vehicles  
   - Total delay  
   - Travel time  
   - Weaving and non-weaving speeds  
   - Level of service for weaving and non-weaving traffic
2. DISTRIBUTIONS: Frequency distributions, as well as cumulative distribution functions, are provided for the following parameters:

- Merging points for each lane
- Accepted gaps for each lane
- Weaving and non-weaving speeds
- Lane speed
- Headway for each lane

3. GRAPHICS: Vehicle trajectories are provided at user specified time intervals. Graphs of cumulative distribution functions are provided for the following measures of performance:

- Merging points for each lane
- Accepted gaps for each lane
- Weaving and non-weaving speeds
- Lane headway

3.4.5 DESCRIPTION OF INDIVIDUAL ROUTINES

WEAVSIM is composed of a Preamble, a Main routine, eight Event routines, and thirty four subroutines.

PREAMBLE: The preamble is purely declarative in nature and does not contain any executable statement. It gives a static description of the system by defining all entities, their attributes, and the sets to which they may belong. The computational modes and global variables are defined along with a list of the statistics which are to be collected on certain variables.

MAIN: The main program of the WEAVSIM provides instructions to control the simulation, reads the value of input parameters, and allocates computer memory to arrays. It also starts simulation by scheduling some initial events.

Following is a brief description of the EVENTS used in WEAVSIM:

ARRIVAL: Creates vehicles in the system at interarrival times. By calling routine SPEED.BR a desired speed and brake reaction time is assigned to each vehicle. If the brake reaction time is unacceptable (<.25 or >1.5 sec.) the vehicle is destroyed
and the number of rejected arrivals is incremented. To insure safe entrance to the system necessary adjustments are made to the speed of the vehicle upon arrival to the system. Arrival time of each vehicle is recorded and other attributes such as ID, type, origin, and destination are also assigned to each vehicle. Total volume and lane volume are both incremented and finally the vehicle is filed in one of the three sets (lanes) depending on its origin. Event arrival is rescheduled at interval times generated by routine HDWY.ARRIVAL.

**PRE PROCESS:**

This event schedules event PROCESS for lane 1, 2, and 3 respectively. It also schedules the L.CHANG event after all vehicles have been processed by event PROCESS. This event is scheduled in every 1-second interval.

**PROCESS:**

This event is also scheduled at each 1-second time interval. Through a complete scan of the system, it updates speed and position of all vehicles through the simulated section. This is done in accordance with vehicle's desired speed and destination inhibited by the surrounding traffic and control environment. All vehicles in lane 1, 2, and 3 are processed respectively, starting with the vehicle most distant from the system entry point. Based on updated speed and position, a current space headway is computed and assigned to each vehicle. At user specified time intervals, routines SPD.HDWY.DATA and VEH.ATTRIBUTE are called upon to collect vehicle attributes for each lane and for the system as a whole. If the vehicle has just entered/exit the weaving section, its exact entrance/exit time is computed and assigned to the vehicle. By calling routine LN.CHANGE, a new lane is determined and assigned to all changing vehicles. At each time interval the updated position of each vehicle will be compared with the position of its leader to determine whether or not the vehicle is involved in a collision. In case of collision the counter for number of accidents is incremented and appropriate routine will be called upon to provide information as to the reason for the collision and at user specified time intervals vehicle trajectories are collected and plotted for each lane. Finally, for all vehicles which have passed the system exit point, data on measures of performance are collected and in case of any unsuccessful weaving, appropriate counter is incremented. Exiting vehicles are removed from the system.

**L.CHANGE:**

This event is scheduled right after all vehicles are updated by event PROCESS. A complete scan of the system is made and vehicles will go through either one of the following two checks:
1. Vehicles which have not changed lane during past 2 seconds will be checked to see whether or not a need for lane changing has been established. If yes, routine INITIAL.CHECK will be called upon to search for possibility of such lane-changing. If the search is successful then the vehicle is scheduled to go through the final check at the next time interval.

2. Vehicles which have successfully passed the initial check will now go through the final check for lane-changing. Routine FINAL.CHECK performs this check. If successful the vehicle will be removed from its current lane and placed in its new lane. Otherwise the vehicle will remain in its original lane.

Statistics on the number of lane-changing and merging points are collected. Finally, appropriate attributes of the changing vehicles are updated.

STAT.COLLECT: This event is scheduled at user specified intervals. It collects intermediate statistical data on lane-changing, speed, delay, headway, and density for each interval. It reschedules itself for the next interval.

LIST.INPUT: Prints the title page and lists all the input parameters including summary description of the simulated weaving section.

RESULT: This event prints simulation results at the end of simulation period by calling routines: L.ATTRIBUTE, INT.OUTPUT, MRG.DIST, DIST.HEADWAY, SPD.DIST, and GAP.DIST. It also graphs speed, headway, and accepted gap distributions by calling appropriate subroutines. The user has complete control over the type of output he desires. A simple "no" answer to any of the questions asked during the input process, would eliminate the undesired set of outputs.

Following is a brief description of the subroutines deployed in this model.

SNAP.R: This subroutine is called upon in case of any collision or error in the program. It prints the current simulation time and lists the attributes of all vehicles in each lane as well as the those in any of the two dummy lanes.

DESIRED.LANE: It determines the lane-changing need for weaving and non-
essential lane changing need for non-weaving vehicles. It assigns new lanes to all changing vehicles based on their current lane and destination.

**SPEED.BRT:**
This subprogram is activated upon entrance of a new vehicle in the system. It determines the brake reaction time and adjusted speed for each vehicle. Brake reaction times and speeds are generated from truncated gamma and normal distributions respectively. Based on the safe-following distance criteria the speed and brake reaction times are adjusted prior to the vehicle's entrance to the system.

**NON.ESSENTIAL.LC:**
Determines the lane-changing desire for non-weaving vehicles in the through lane. The lane-changing desire is generated randomly from a binomial probability (PLC) for vehicles traveling below their desired speed and accelerating by less than 1.00 ft./sec./sec. during the last update interval.

**CRITICAL.GAP:**
This subroutine computes a critical gap for all changing vehicles based on their type and speed.

**INITIAL.CHECK:**
This check is performed, for those vehicles flagged for lane-changing, to determine whether such a lane-change is possible or not. If the vehicle is a weaving vehicle a lane-changing factor is computed based on the current position of the vehicle with respect to the weaving section exit gore. Then following three checks are performed:

1. Lead Headway Check
2. Lag Headway Check
3. Critical gap check

If all three checks are positive the subprogram returns a "1" and a "0" otherwise. If either the lead or the lag headway check is unsuccessful, appropriate subroutine is called upon to adjust vehicle speed to make the lane-changing possible. Information on size and number of accepted gaps are collected and when needed, number of rejected gaps are incremented.

**LD.CHECK:**
Performs all the necessary checks for a successful Lead-Headway check. If the check is positive, it returns a '1' and a '0' otherwise.
LD.SPD.ADJ: This subroutine is activated when the lead check has been unsuccessful. A type of speed adjustment is determined for the changer vehicle. This is done based on an evaluation of the current position and speed of the changer and its potential leader in the new lane. If the changer is to speed up and pass the current leader (in the new lane), the leader's headway (new gap) is evaluated. If this gap is smaller than the current gap the vehicle will slow down rather than speeding up.

LG.CHECK: Performs all the necessary checks for a successful Lag-Headway check. If the check is positive a '1' is returned and a '0' otherwise.

LG.SPD.ADJ: This subroutine determines the speed adjustment for the changing vehicle when the lag check has failed. The speed adjustment is determined based on an evaluation of the current and updated position and speed of the changer and the potential follower in the new lane.

SAFE: This subroutine is called upon by subroutines LD.CHECK and LG.CHECK as part of their check for a successful lane-changing maneuver. It computes the acceleration that a lane-changing vehicle must undergo so that it will be safely behind the new leader or the acceleration that the potential follower in the new lane must undergo in order for the lane-changing vehicle to move in front of it safely. This acceleration is then compared with the vehicle's acceptable deceleration rate. When the computed acceleration is greater than the acceptable deceleration, indicating the merging is safe, the subprogram returns a "1", otherwise, a "0" will be returned indicating denial of merging due to unsafe positioning of the vehicles.

FINAL.CHECK: This subprogram is activated at time (t+2) by those vehicles which have successfully passed the initial check at time (t). If current positions of the changer and its potential leader and follower in the new lane allow a safe lane-changing maneuver, then the vehicle will change lanes, (subprogram returns a "1").

COMF.DECEL: For a given speed and vehicle type, this subprogram yields a comfortable deceleration rate.

CAR.FOLLOWING: Speed and position of each vehicle is updated by computing
the maximum possible rate of acceleration. This acceleration is computed based on safe-following distance criteria. The car-following algorithm is discussed in detail in section (3.4.7).

**ADJ.CAR.FOLLOW:** This subroutine computes the acceleration/deceleration rate for those vehicles flagged for speed adjustment. This is done in accordance with the vehicles' type of speed adjustment inhibited by the surrounding traffic and control environment.

**HDWY.ARRIVAL:** Using a shifted negative exponential distribution function, it computes the interarrival time for vehicles in each lane. The only input to this subprogram is the volume of each lane.

**MAX.ACCEL:** For a given speed and vehicle type it returns a maximum rate of acceleration.

**COAST.DECEL:** This subroutine yields a freeway coastal deceleration rate for a given speed and vehicle type.

**SPD.HDWY.DATA:** It is activated at each 1-second time interval by each vehicle. It collects and stores speed and headway data for each vehicle in each lane.

**INTERMEDIATE. OUTPUT:** Prints statistics on measures of performance for each lane and level of service for weaving and non-weaving traffic at user specified time intervals.

**L.O.S.:** Based on average running weaving and non-weaving speed, it returns a level of service (A through E) for weaving and non-weaving traffic.

**MERGE.DIST:** This subroutine prints merging points for weaving vehicles in each lane and merging point frequency distributions. It also prints average and standard deviation of the distance from beginning of the weaving section to the merging point.

**MOE:** Prints statistics on some measures of effectiveness as well as number of rejected gaps and rejected arrivals.
DIST.HEADWAY: Prints headway frequency distribution, standard deviation, minimum headway, average headway for each lane within the weaving section.

HDWY.GRAPH: This subroutine graphs the cumulative distribution function of headways for each lane.

COLLECT: It collects speed, position, and acceleration data at each user specified time interval.

VEH.ATTRIBUTE: This subroutine prints vehicle attributes for each lane at user specified time intervals.

SPD.DIST: It generates and prints speed distributions for weaving and non-weaving traffic. It also prints the cumulative distribution function, minimum, maximum, average, and standard deviation of weaving and non-weaving speeds.

SPD.WV.GRAPH: This subroutine graphs cumulative distribution function of speed for weaving and non-weaving traffic.

SPD.L.DIST: It generates and prints speed distributions for each lane. It also prints statistics on lane speed.

SPD_GRAPH: This subroutine graphs cumulative distribution function of speed for each lane.

GAP.DIST: It generates and prints frequency distribution function, as well as the standard deviation, minimum and average of accepted gaps in each lane.

GAP_GRAPH: It graphs the cumulative distribution function of accepted gaps for each lane.
3.4.6 VEHICLE AND DRIVER ATTRIBUTES

In WEAVSIM, individual vehicles and drivers are assigned a set of permanent attributes which remain constant throughout the simulation run, and a set of temporary attributes which are updated periodically. A summary description of these follows:

PERMANENT ATTRIBUTES:

ARR.TIME  Arrival time of the vehicle to the system
BRAKT    Vehicle brake reaction time
DESTINATION  Destination (exit lane) of the vehicle
MAX.SPD  Desired speed of the vehicle
ID  Integer vehicle index assigned sequentially to each vehicle upon arrival to the system
LENGTH  Length of the vehicle
ORIGIN  Origin (entry lane) of the vehicle
STATUS  Status of the vehicle either "weaving" or "non-weaving"
TYPE  Type of the vehicle either "PASGR", "TRUCK", or "TRAILER"
W.ARR.T  Time at which the vehicle has entered the weaving section
W.EXT.T  Time at which the vehicle has exited the weaving section

TEMPORARY ATTRIBUTES:

ACCELERATION  Current acceleration of the vehicle, computed from the car-following model
ADJUST  "FASTER" if upward speed adjustment is required
         "SLOWER" if downward speed adjustment is required
         "NULL" if no speed adjustment is required
CURRENT.LANE  The current lane of the vehicle
HEAD.WY  Current space headway of the vehicle
MOV.STATUS  "1" if the leader has changed lane during last 2 seconds
            "0" otherwise
NEW.LANE: New lane of the lane-changing vehicle
NO.LCH: Number of lane-changing accomplished by the vehicle
P.AFTER: Updated position of the vehicle
P.BEFORE: Current position of the vehicle
S.AFTER: Updated speed of the vehicle
S.BEFORE: Current speed of the vehicle
T.L.C: "1" if the vehicle has initiated lane-changing during the last second
"2" if the vehicle has initiated lane-changing during the last two seconds
"0" if the vehicle has not initiated a lane-changing yet

The following is a description of the methodology deployed in assignments of some of the vehicle permanent attributes:

**ORIGIN-DESTINATION**: The origin of each vehicle is the same as its entry lane. Vehicle's destination is determined stochastically by comparing a randomly generated uniform number, in the domain of (0,1), with the proportion of weaving volume for each lane. If the vehicle's destination is same as its origin, the vehicle is a non-weaving vehicle; otherwise, it is a weaving vehicle.

**MAX.SPD**: This is the vehicle's free flow speed and is sampled from a truncated normal distribution. The mean and standard deviation for this distribution are input variables and reflect the overall speed condition of the weaving section.

**TYPE**: Vehicle type is assigned by comparing a uniform random number with the cumulative distribution for three different vehicle types; Passenger, Truck, and Trailer.
**LENGTH:** vehicle length is assigned deterministically based on vehicle type; 16 ft. for passenger cars, 32 ft. for trucks, and 40 ft. for trailers.

**BRAKE REACTION TIME** Vehicle's brake reaction time is generated stochastically from a gamma distribution based on the results of the Johansson and Rumar (1936) study. The mean and variance of the gamma distribution are 0.745, and 0.073 seconds, respectively. To prevent generation of unreasonable brake reaction times, the generated values are truncated at 0.25 and 1.50 seconds. Furthermore, for vehicles with short arrival headway, the generated brake reaction time is adjusted to a smaller value such that the vehicle can at least maintain the minimum lane speed while maintaining a safe-following distance. This prevents excessive rejection of vehicles at high volume levels.

After assignment of the attributes, the vehicle will be filed in any of the three available sets (lanes) depending on its origin. Vehicle operating characteristics (i.e. max. acceleration) are generated internally in the model.

### 3.4.7 CAR-FOLLOWING ALGORITHM

The car-following algorithm in WEAVSIM prescribes the behavioral response mechanism of individual vehicles. It determines the distance a vehicle will advance during any time interval.

Car-following has been the subject of numerous modeling efforts in the past (Chander et al. 1958; Gazis et al., 1961; Edie, 1961; Lee, 1966; Bender and Fenton, 1972; Tole, 1973; Gipps, 1980; and Benekohal, 1986) to name just a few. Most current models are a variation of:
\[
\begin{align*}
\dot{X}(t+T) &= a \frac{k}{n+1} \frac{(X(t)-X_{n+1}(t))}{m} \\
X(t+T) &= a \frac{(X(t)-X_{n+1}(t))}{n+1}
\end{align*}
\]

Where vehicle \( n \) is followed immediately by vehicle \( n+1 \) and

\[
\begin{align*}
T &= \text{Reaction time} \\
X_n(t) &= \text{Location of vehicle } n \text{ at time } t. \\
\dot{X}_n(t) &= \text{Speed of vehicle } n \text{ at time } t. \\
\dot{X}_{n+1}(t) &= \text{Speed of vehicle } n+1 \text{ at time } t. \\
\ddot{X}(t+T) &= \text{Acceleration of vehicle } n+1 \text{ at time } t+T \\
a, k, m &= \text{Parameters that need to be estimated.}
\end{align*}
\]

Although these models have been useful in many situations, as Seddon (1972) pointed out, it is desirable for the interval between successive recalculation of acceleration, speed, and location to be a fraction of reaction time. This will indeed necessitate the storage of a considerable quantity of historical data if the model is to be used in a simulation program. Furthermore, Gipps (1980) indicates that the parameters \( a, k, \) and \( m \) have no obvious connection with identifiable characteristics of driver or vehicle, and as Wicks (1980) mentions, no single model of this form is appropriate to all traffic conditions. Consequently, the car-following model of WEAVSIM will be based on the so called fail-safe approach developed for INTRAS (Wicks, et al., 1980). This approach is based on combination of the following two concepts:
1. Following vehicles will always seek a desired headway which will be a function of vehicle speed, relative speed, 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.

Using these two concepts the acceleration of each vehicle is determined given that the speed and position of its leader has already been calculated.

In order to describe the car-following component of this model the following symbols are defined:

- \( T \) = time scanning interval (sec.)
- \( LL \) = length of the leading vehicle (ft.)
- \( PLT \) = position of the leader at time \( t \) (ft.)
- \( VLT \) = velocity of the leader at time \( t \) (ft/ps)
- \( PFT \) = position of the follower at time \( t \) (ft.)
- \( VFT \) = velocity of the follower at time \( t \) (ft/ps)
- \( PFD \) = position of the follower at time \( t+T \) (ft.)
- \( VFD \) = velocity of the follower at time \( t+T \) (ft/ps)
- \( AFD \) = acceleration of the follower at time \( t+T \) (ftpss)
- \( PLD \) = position of the leader at time \( t+T \) (ft.)
- \( VLD \) = velocity of the leader at time \( t+T \) (ft/ps)
- \( ALD \) = acceleration of the leader at time \( t+T \) (ftpss)
- \( MED \) = maximum emergency deceleration rate (ftpss)
- \( BRT \) = brake reaction time of the following vehicle (sec.)
- \( S.D \) = safety distance (ft.)

Three possible conditions can arise in the car-following model:
1. Condition when the leader vehicle has come to a complete stop. The follower should also come to stop while maintaining a space headway of at least equal to the length of the leader plus a safety distance (S.D). This relationship can be written as:

\[ PLD - PFD \geq LL + S.D \] .............................................................................................. (1)

The updated position of the follower is:

\[ PFD = PFT + \frac{VFT}{2*AFD} \] ...................................................................................................(2)

Substituting in equation (1)

\[ PLD - (PFT + \frac{VFT}{2*AFD}) \geq LL + S.D \] ........................................................................ (3)

Solving for the acceleration of the follower

\[ AFD \leq -\frac{VFT}{2(PLD-PFT-LL-S.D)} \] .................................................................................. (4)

2. Condition when the updated speed of the leader is greater than zero but less than current speed of the follower. The follower should, therefore, decelerate to avoid collision. The space headway relationship for this case is:

\[ PLD-PFD \geq LL+S.D+\frac{BRT*VFD}{2*MED}-\frac{VL}{2*MED} \] ................................................................................ (5)

This headway relationship satisfies the non-collision constraint. The basic concept here is that the follower should be able to maintain a space headway of (LL+S.D) when its leader undertakes its maximum emergency deceleration rate.

The updated position of the follower is:

\[ PFD = PFT + \frac{VFT*^2 + AFD*^2}{2} \] .................................................................................. (6)

And the updated speed of the follower is:

\[ VFD = VFT + AFD*^2 \] .................................................................................. (7)
Substituting equations (6) and (7) in equation (4), then

\[ PLD - (PFT + VFT^2T + AFD^2T / 2) \geq LL + S.D. + BRT(VFT + AFD^2T) + (VFT + AFD^2T) / 2^*MED - VLD / 2^*MED \]

Simplifying and multiplying both sides by \(-2^*MED/T\) then

\[ AFD + AFD^2 * (VFT/T + MED) + AFD^2 * MED * BRT/T - 2^*MED/T (PLD - PFT - VFT^2T - LL - S.D. - BRT * VFT - (VFT - VLD) / 2^*MED) \leq 0.0 \]

Or

\[ AFD + AFD^2 * (2 * VFT + MED * T - 2 * BRT * MED) / T - 2^*MED/T (PLD - PFT - VFT^2T - LL - S.D. - BRT * VFT - (VFT - VLD) / 2^*MED) \leq 0.0 \]

If we let:

\[ B = (2 * VFT + MED * T + 2 * BRT * MED) / T \]

\[ C = -2^*MED/T (PLD - PFT - VFT^2T - LL - S.D. - BRT * VFT - (VFT - VLD) / 2^*MED) \]

Then expression (8) can be written as a quadratic inequality of the following form:

\[ AFD + B^*AFD + C \leq 0.0 \]

Solving for AFD, then

\[ AFD \leq \left( -B + (B - 4^*C) \right) / 2 \]

To compute the maximum allowable acceleration only the positive value has been used.
3. Condition when the updated speed of the leader is greater than the current speed of the follower. The space headway for this case can be expressed as:

\[
PLD - PFD \geq LL + S.D. + BRT \cdot VFD 
\] .......................... (13)

Substituting equations (6) and (7) for PFD and VFD in equation (12)

\[
PLD - (PFT + VFT \cdot T + AFD \cdot T/2) \geq LL + S.D. + BRT \cdot VFT + AFD \cdot T 
\] .......................... (14)

Solving for AFD, then

\[
AFD \leq \frac{2(PLD - PFT - LL - S.D. - VFT(T + BRT))}{(2 \cdot BRT \cdot T + T^2)} 
\] .......................... (15)

For this condition the non-collision constraint should also be satisfied. This means that the updated acceleration rate is the smaller one of the two computed from equations (12) and (15).

To insure that the safe-following distance is not the same for all cars with the same speed, a safety distance (s.d) has been added to the space headway computed in equations (1), (5), and (13). The safety distance is inversely proportional to the driver's maximum speed. This means that a driver with high maximum speed will maintain a smaller lead-headway than a driver with low maximum speed, assuming both travelling at the same speed. The desired correlation is obtained by standardizing the randomly generated maximum speed in the domain (0,1) using the truncation points of the distribution of the maximum speed. If we let:

\[
UP.SPD = \text{Upper limit of the maximum speed distribution function} \\
LOW.SPD = \text{Lower limit of the maximum speed distribution function} \\
MX.SPD = \text{Randomly generated maximum speed of the vehicle}
\]
Then \( R = \frac{\text{UP.SPD} - \text{MX.SPD}}{\text{UP.SPD} - \text{LOW.SPD}} \) is in the domain \((0,1)\). Now let \( S.D = F(R) \).

Assuming a minimum and maximum value of 5, and 15 for \( S.D \) and a linear relationship between \( S.D \) and \( R \), then the \( S.D \) can be computed as:

\[
S.D = 10^*R + 5 
\]

The acceleration obtained from any one of the three conditions is inhibited by the following conditions:

1. It can not be less than the Maximum Emergency Deceleration (MED) rate. If it is, the MED (-18.0 ftpss) will be used instead.
2. It can not exceed the maximum possible rate of acceleration for a given vehicle type at a given speed.
3. It can not exceed the acceleration required for a vehicle to reach its desired speed \((\text{des.speed-VFT})/t\).

The above rules apply to all non-weaving vehicles and those weaving vehicles either not within the weaving section or having already reached their intended destination. Those vehicles which satisfy the following criteria will be updated by the \text{ADJ.CAR.FOLLOWING} subroutine:

1. The vehicle is a weaving vehicle;
2. In order to complete the lane-changing maneuvers, speed adjustment is required for this vehicle;
3. The vehicle is not currently decelerating 2.0 ftpss below its comfortable deceleration rate;
4. The vehicle is not the follower of a vehicle which has just changed lane; and
5. The vehicle has not changed lane during last two intervals.
In the ADJ.CAR.FOLLOWING subroutine if the vehicle is required to slow down or speed up to make the lane-changing possible, its speed will be adjusted accordingly. The non-collision constraint is not applied to these vehicles. This is due to the fact that, in the real world, vehicles assume somewhat unsafe positions for a short period of time when engaged in lane-changing process.

Having obtained the acceleration of the follower vehicle from either one of the above rules, the updated position and speed are then determined using following equations:

\[ V_{FD} = V_{FT} + A_{FD}T \]  \hspace{1cm} (17)

\[ P_{FD} = P_{FT} + V_{FT}T + \frac{A_{FD}T^2}{2} \]  \hspace{1cm} (18)

3.4.8 LANE CHANGING DEVELOPMENT

Weaving areas experience a higher frequency of lane changing than an open section of freeway, as weaving vehicles must access lanes appropriate to their desired destinations. To provide safe and efficient maneuvering of the weaving traffic, it is essential that the model satisfactorily performs lane-changing when engaged in the weaving process at high volumes. It is also imperative that the lane changing algorithm be fully integrated with the car-following algorithm. Therefore, lane-changing has been recognized as the most critical component of this simulation model.

In a normal section of highway there may be a variety of reasons for which a driver changes lanes: drivers lane preference, local traffic concentration, and average speed; to name just a few. However, in a weaving section, drivers change lanes primarily to access lanes appropriate to their desired exit points. Therefore, the lane changing behavior in weaving areas is somewhat different from that in a normal
section of freeway. The algorithm developed for WEAVSIM has been carefully tai­
lored to represent the lane-changing behavior of traffic in weaving areas.

It is assumed, in WEAVSIM, that neither the size of the gap immediately avail­
able to a driver in an adjacent lane, nor any other traffic parameters (e.g. relative
speeds between adjacent lanes), influences the initial desire of weaving vehicles to
change lanes. In another words, the lane changing probability for weaving vehicles
remains constant and has been determined prior to their entrance to the weaving sec­
tion. For non-weaving vehicles lane changing is desired if a vehicle catches up to a
slower vehicle in front of it, in the same lane, and wishes to change lanes to main­
tain its speed. This, in WEAVSIM, has been referred to as non-essential lane chang­
ing and the motivation for this lane changing is generated randomly according to a
binomial probability, known as the probability of lane-changing (PLC). The value
for PLC has been calibrated from FHWA data for non-weaving vehicles. This cali­
bration is discussed in section 4.4.2.

Upon arrival to the system each vehicle is assigned an origin and a destination.
This is done randomly based on the percentage of weaving, which is an input to the
model. Those vehicles for which the origin and destination are the same will be
referred to as non-weaving and those with different origin than destination are called
weaving vehicles.

In WEAVSIM, lane changing attempts, for weaving vehicles, are initiated two
seconds prior to the time at which the entrance gore is reached. This is to account
for the fact that, in the real world, the weaving traffic at a distance in advance of
weaving section can see the traffic on the other approach and start evaluating the
available gaps. This, in literature, has been referred to in discussion of effective
length of weaving sections (HCM, 1965). For non-weaving vehicles the non-essential lane-changing attempts are initiated if the vehicle is within the weaving section. Once the lane changing desire is initiated the vehicle will undertake a process to determine the possibility of lane-changing. Figure (16) illustrates a typical lane-changing attempt.

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

1. Check if the vehicle is a weaving or non-weaving vehicle. This is simply done by checking the status of the vehicle.

2. If weaving, has it reached its destination? If not, flag for lane changing. If non-weaving, has it initiated a non-essential lane changing? If yes, flag for lane changing.

3. Find a desired new lane for vehicles flagged for lane changing. This is done by comparison of the current lane, destination, and the adjacent lane.

4. For weaving vehicles compute the lane-changing factor (LCHF) discussed in section (4.4.1).

5. Perform an Initial Check to establish whether or not the change is currently possible. If yes;

6. Two seconds later perform a FINAL CHECK for possibility of any drastic changes in the system status on which the Initial Check relied.

When the vehicle has successfully passed the FINAL CHECK it will be moved to its new lane and its current lane will be updated accordingly. In case of violation of any of the above rules, 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 successful merge is completed.

It has been shown by Worrall and Bullen (Worrall, 1969), that the actual lane changing time is a function of vehicle speed. This relationship, however, is not a strong one and a constant lane changing time is a reasonable time as the variation is
Figure 16: A TYPICAL LANE-CHANGING ATTEMPT
very small compared to the normal scanning interval (Wicks, 1980). In WEAVSIM, a lane changing maneuver is considered complete three seconds after its initiation.

In the following sections a brief description of the procedures involved in the INITIAL and FINAL CHECK will be discussed.

3.4.8.1 INITIAL CHECK

Lane changing vehicles are checked to determine the possibility of such a maneuver. The first step is to locate the follower and leader of the vehicle in the desired lane. Then the lead headway will be examined to see whether it satisfies the car-following rule, or in another words is the lead-headway, in the new lane, safe for merging. Since the actual lane changing maneuver takes place one second after performance of the INITIAL.CHECK, the speed and position of the leader, as well as the lane changing vehicle is predicted for the next interval. This is done with the assumptions that the current acceleration rate of both vehicles remains constant during the next interval. If the predicted speed of the changer is less than the predicted speed of the leader and the distance between them is at least 10 feet, the lead-headway is acceptable. Otherwise the acceleration that the changer must undergo in order to safely move behind the new leader is predicted. If the changer is a non-weaving vehicle, the lead headway is considered safe when the predicted acceleration exceeds the comfortable deceleration (based on vehicle type and speed) of the changer vehicle. If the changer is a weaving vehicle, the Lane changing factor, discussed in section 4.4.1, will first be applied to the predicted acceleration and then if it exceeds the maximum emergency deceleration, the lead headway is acceptable.

If the lead headway is acceptable then a lag-headway check is carried out. In a similar manner, if the predicted speed of the lane changing vehicle is greater than
that of the follower and the distance between them is more than 15 feet, then the lag-headway is considered acceptable. Otherwise the acceleration that the following vehicle must undergo so that the changing vehicle can safely pull over ahead is predicted for the next interval. Same comparison will again be made for weaving and non-weaving changers.

If the lag headway check is also acceptable, a critical gap for the changer is deterministically generated. For non-essential lane changing (non-weaving vehicle) if the available gap is greater than the changer's critical gap then the lane changing maneuver is initiated in the current time scan. If the vehicle is making an essential lane changing (weaving vehicle), the LCHF will be applied to the available gap and then if it exceeds the changer's critical gap, the INITIAL CHECK is considered successful. If, because of violation of any one of the above rules, the INITIAL CHECK is unsuccessful, the lane changing attempt is aborted and at each successive interval an INITIAL CHECK will be carried out until a successful merge is completed.

3.4.8.2 FINAL CHECK

This check will be carried out for lane changing vehicles one second after they had successfully passed the INITIAL CHECK. This check is performed primarily to detect any drastic changes in position and speed of the new leader and follower of the changer. If current positions of the leader and follower still guarantee a safe maneuvering of the lane-changing vehicle, then the changing process is considered complete and the vehicle will be moved to its new lane. In case of a failure in FINAL CHECK an INITIAL CHECK will be initiated during the next time interval.
3.4.9 INITIALIZATION BIAS

In WEAVSIM, the system starts empty and idle. Thus, it contends with an initialization bias prior to the steady state conditions. The rule of thumb for eliminating the initialization bias is to drop all observations up to a certain point. Various suggestions have been made regarding the amount of original observations which are to be discarded. Conway (1963) suggests: discard initial observations until the first one left is neither the maximum nor the minimum of the remaining observations.

In order to determine when the system is no longer in the transient phase and has reached the steady state conditions, average delay and travel time were plotted as a function of simulation time, Figure (17) and (18). It can be seen from this figure that at approximately 200 sec. the system reaches the steady state conditions. A "warm-up" period of 200 seconds was, subsequently, selected to be used in WEAVSIM. Behavior of the system is totally discarded during the "warm-up" period.

To eliminate transient generated at the geometric boundaries of the system, buffer lengths have been provided at each end of the simulated weaving section. Figure (19) illustrates average arrival speed as a function of downstream buffer length. It is clearly seen, from this figure, that at about 400 feet the arrival speeds become relatively stable. Therefore, at the upstream end, 400 feet of the simulated weaving section is treated as "warm-up" zone. Also at the downstream end, 500 feet of the simulated weaving section is used as the "cool-off" zone. This buffer length is sufficient to eliminate transient effects carried over up to the fifth vehicle, where the effect of change in speed of the leader of the platoon normally disappears. Simulation results do not include behavior of vehicles in the warm-up and cool-off zones.
Figure 17: AVERAGE DELAY AS A FUNCTION OF SIMULATION TIME
Figure 18: AVERAGE TRAVEL TIME AS A FUNCTION OF SIMULATION TIME
Figure 19: AVERAGE ARRIVAL SPEED AS A FUNCTION OF BUFFER LENGTH
CHAPTER IV
MODEL CALIBRATION

The primary objective of the calibration is to specify parameters for applied distributions, as well as modifications of the car-following and lane-changing algorithms in order to represent the real world traffic behavior.

In this chapter a general description of the data base used for calibration, as well as the calibration procedure for various components of the model is presented.

4.1 DATA COLLECTION

A series of data sets on microscopic vehicular traffic flow were developed in a Federal Highway Administration Research Study entitled "Freeway Data Collection for Studying Vehicle Interactions" (Smith, 1985) The data is perhaps the richest source of its type that has been developed to date and is expected to be useful in enhancing freeway simulation models, as well as in direct empirical research.

The data acquisition involved an aerial photographic approach in conjunction with a microcomputer-based digitizing system. The aerial photography involved the use of a full-frame 35 mm motion picture camera operating in time-lapse mode mounted in a fixed-wing short-take-off-and landing aircraft. The aircraft was flying clockwise at a slow speed around each site at altitudes ranging between 2500 and 4500 feet. The study sites were filmed at one second intervals for over a one hour period. The
study sites were in range of 1200 and 3200 feet in length. The data reduction technique involved a microcomputer digitizing system. The most important component of this system was the method of vehicle matching which yielded complete vehicle trajectories for all vehicles.

A set of targets, (Squares of day glow orange plastics) which would be visible in the film, were set out on the right shoulder of each direction of travel on the freeway section being filmed. Through a ground survey the relative position of these targets were established and, therefore, served as control points. This was done to establish a known ground coordinate system for the data reduction process.

Some site and traffic flow requirements were to be met in the site selection process.

- The level of service for traffic should be in the C-E range. An effort was made to include, when possible, the transition period from uncongested flow to congested flow.
- Traffic flow congestion must not be influenced by conditions downstream of the site.
- There should be no bridge structures passing over the site so as to obscure vehicles from view in the film.
- Since film quality significantly deteriorates with low sun angles, the peak traffic time must occur at a time when light conditions for filming are favorable.

Each data set is contained in a single file consisting of two basic parts; the Geometric data followed by Vehicle Data. The Vehicle data includes: Vehicle Identification number, vehicle type (six categories), vehicle length (ft), vehicle speed (mph), lateral and longitudinal distances (ft.), vehicle color, and lane number.
A detailed description of the data collection procedures is given in appendix B.

4.2 DATA BASE

The Data Base used for calibration of WEAVSIM is the data provided by FHWA representing flow conditions on the following two sites:

- Baltimore-Washington Parkway Northbound at I-95 (Capital Beltway) in Prince George's County, Maryland. This site is a three (3) lane Cloverleaf-type weaving section, 1606 Feet long with a weaving section of 695 feet; (Figure 10 is a sketch of this site).

- Route 11 (Harbor Freeway) Northbound between I-10 (Santa Monica Freeway) and 6th Street, Los Angeles, California. This site is a 5-lane weaving section of 1450 feet. There are three lanes on the main line merging with two ramp lanes.

Data sets were analyzed to provide the required parameters for the proposed simulation model. A summary of these activities is described in the following sections.
SECTION LENGTH = 1606
3 12-FOOT LANES
CURVE RADIUS = 5730'
(1 DEGREE)
SUPERELEVATION .03
GRADE = +2%

Figure 20: BALTIMORE WASHINGTON PARKWAY WEAVING SECTION
4.3 ARRIVAL HEADWAY CALIBRATION

The time headways between the arrival of vehicles for both data sets were computed. The probability density function of these headways were determined. In all cases an exponential fit was observed.

The probability density of intervals (headways) for the exponential distribution is:

\[ p(t) = \frac{1}{h} e^{-\frac{t}{h}} \]  

Where: \( h \) is the average headway measured from hourly volume (3600/vol).

A critical shortcoming of the exponential distribution, as discussed in chapter 3, is its prediction of too many short headways. One approach to treating this situation is introduction of minimum allowable headway. This could be done by shifting the distribution to the right by an amount \( m \) (minimum headway). This is illustrated in figure (21).

When shifting, it is essential to make appropriate adjustments to the probability density functions:

\[ P(t) = \frac{1}{h-m} e^{-\frac{(t-m)}{(h-m)}} \]  

The main objective for calibration of vehicle generation is determination of the minimum allowable time headway from available data base. Based on an evaluation of the frequency distribution function of arrival headways obtained from field data, a minimum headway of one (1) second was selected to be used in WEAVSIM.
Figure 21: SHIFTED NEGATIVE EXPONENTIAL DISTRIBUTION
4.4 LANE CHANGING CALIBRATION

In development of lane changing algorithm for WEAVSIM the model logic was strictly based on satisfaction of lead and lag gap by car-following rules and the critical gap size. However, after a few simulation runs were made, it became clear that vehicles are too conservative in accepting gaps. As the result, too many vehicles are unable to complete weaving maneuvers and, consequently, not being able to reach their desired destinations. After a careful review of the actual lane changing process (from the field data) the following modifications were made in the lane-changing algorithm:

1. In determining a safe lead and lag headway the non-collision constraint equations are to be satisfied rather than car-following equations. This facilitates finer tolerances and lane-changing in heavy flow conditions.

2. If during the last lane-changing attempt the lead headway check has failed, the changer will try to adjust its speed in order to improve its position with respect to the available gap. The following steps will be carried out to determined the type of speed adjustment required:

   • Based on current position of the changer and leader a current space headway is computed.
   • The updated position of the changer and leader is computed. This is done with the assumption that the changer decelerates at its comfortable rate of deceleration.
   • The updated space headway is then computed as the difference between the updated positions.
   • If the updated space headway is less than the current headway (downward speed adjustment worsens the situation) and the headway of the leader is at least 100.0 ft, then the changer is flagged for upward speed adjustment. Otherwise the changer is flagged for downward speed adjustment.
The above steps are repeated until the changer can successfully pass the initial check of the lane-changing process.

It needs to be mentioned here that speed adjustments are not directly applied in the lane-changing algorithm. As discussed earlier, these adjustments are made in the car-following algorithm.

3. If the lag-headway was not successful during the last lane changing attempt, speed adjustment is applied to the changer vehicle in the following manner:

- A current space headway is computed as the difference between the current positions of the changer and the leader.
- With the assumption that the changer will accelerate at its maximum acceleration rate, the updated position of the changer and the follower is computed.
- Based on updated positions of the changer and follower, an updated space headway is computed.
- If the updated headway is greater than the current headway (upward speed adjustment improves the possibility of lane-changing) and the speed of changer is greater than the follower, then changing vehicle is flagged for upward speed adjustment. Otherwise, the changer is flagged for downward speed adjustment.

4. To enable the representation of forced lane changing, as vehicles reach the end of the weaving section, a lane-changing factor is introduced in the lane-changing logic. The lane-changing factor (LCHF) is discussed in the next section.

5. In case of multiple-lane changing, 2 seconds must elapse before initiation of the second lane changing attempt. This ensures smooth maneuvering of vehicles, present in the actual lane changing process.
Prior to calibration, the simulation logic would not allow acceptance of one gap by more than one vehicle. However, during the analysis of the field data it was observed that, in some instances, a gap is accepted by more than one vehicle.

1. When a gap in the middle lane (lane 2) is accepted by two vehicles, one in the left lane (lane 1) and the other in the right lane (lane 3).

2. When a gap is big enough to be accepted by two following vehicles in an adjacent lane.

The lane-changing logic of WEAVSIM was, therefore, modified to incorporate this feature. During the FINAL CHECK of the lane-changing process, the leader and the follower of the changer are both checked to see whether or not they have also flagged for the FINAL CHECK. If so, an INITIAL CHECK will be carried out immediately. Depending on the outcome of this check, the changing process is either completed or aborted.

4.4.1 LANE-CHANGING FACTOR

The primary motivation behind development of this factor was the fact that as weaving vehicles move closer to the exit gore they become more willing to accept higher risk when engaged in lane-changing process. The LCHF is assumed to have an exponential form of:

\[ LCHF = A + e^{B \times X} \]

Where: \( X = \) the distance from the entrance gore of the weaving section

A,B = constant values
Figure(22) shows the general form of the lane-changing factor. The LCHF could be thought of as the intensity of lane changing. As the distance from the entrance gore (X) increases the intensity of the lane-changing desire increases. Therefore, the LCHF should have its maximum value near the exit gore. Also, the LCHF should increase as the ratio of the lane-weaving volume (weaving volume entering each lane) to the total weaving volume increases. Consequently the following two initial conditions are set:

i) \[ \text{LCHF} = 1.0 \quad \text{when} \quad X = 0.0 \]

ii) \[ \text{LCHF} = 1 + \frac{\text{L.WV}}{\text{TOT.WV}} \quad \text{when} \quad X = L \]

Where:

\( L \) = length of the weaving section

\( \text{L.WV} \) = volume of traffic weaving into the lane

\( \text{TOT.WV} \) = total weaving volume

Substituting first condition in equation (1)

\[ B(0.0) \]

\[ 1.00 = A + e \]

\[ \Rightarrow A = 0.0 \]

Equation (1) now has the form:

\[ \text{B}^X \]

\[ \text{LCHF} = e \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2) \]

Substituting the second condition in equation (2)
Figure 22: GENERAL FORM OF THE LANE CHANGING FACTOR
\[ B^*L \]

\[ 1 + \frac{L.WV}{TOT.WV} = e \] .......................................................... (3)

Taking Natural Logarithm of both side and solving for B:

\[ \ln(1+\frac{L.WV}{TOT.WV}) = B^*L \]

Or

\[ B = \frac{\ln(1+\frac{L.WV}{TOT.WV})}{L} \] .................................................. (4)

Substituting in equation (2), then

\[ \frac{\ln(1+\frac{L.WV}{TOT.WV})}{L} \]

\[ \text{LCHF} = e \] .................................................. (5)

**4.4.2 PROBABILITY OF NON-ESSENTIAL LANE-CHANGING**

Another lane-changing parameter which needed to be calibrated is the probability of lane changing (PLC) for non-weaving vehicles. Again, a trial and error procedure was deployed. WEAVSIM was operated for a range of values for PLC. For various volumes a number of non-essential lane changing were obtained from simulation outputs. From the data base also number of lane-changing for non-weaving vehicles, at various volumes, were obtained. This comparison is shown in Figure (23). As a result an appropriate probability of lane changing of .04 was selected to be used in WEAVSIM.
Figure 23: NON ESSENTIAL LANE CHANGING FREQUENCY AS A FUNCTION OF VOLUME
CHAPTER V

SENSITIVITY ANALYSIS

Sensitivity analysis involves varying the input values on a range of interest and examining the effect on the model output. The objective of sensitivity analysis is to identify the particularly sensitive input parameters so that special care can then be taken in estimating them more closely. Sensitivity analysis can also be used to ascertain the realism of the simulation results by varying those input variables whose effects on the model output is known.

The following input variables are targeted for sensitivity analysis of WEAVSIM:

- Maximum Emergency Deceleration (MED)
- Safety Distance (SD)
- Brake Reaction Time (BRKT)
- Probability of Non-essential Lane-changing (PLC)
- Traffic Composition

The response variables used in sensitivity analysis include: lane mean headway, average running weaving and non-weaving speeds, and average weaving and non-weaving delays. Simulation runs were made for various levels of the input variables. To reduce the output variance for each level of input variable five replications were made. In order to provide similar operating environment for all simulation runs, the following characteristics were used:
Simulation Time 1200 sec.
Warmup Period 200 sec.
Length of Freeway section 2300 ft.
Length of Weaving section 1400 ft.
Buffer Length 500 ft.
Lane 1 Volume (through lane) 1700 vph 20% Weaving
Lane 2 Volume (through lane) 1700 vph 65% Weaving
Lane 3 Volume (ramp lane) 1400 vph 85% Weaving

Results of the sensitivity analysis are discussed in the following sections.

5.1 MAXIMUM EMERGENCY DECELERATION

As discussed in section 3.4.7, one of the major parameters in the overriding collision prevention model of the car-following algorithm is the maximum emergency deceleration rate (MED). In WEVSIM, MED has been computed from the stopping sight distance equation with assumption of .58 for friction coefficient between the tire and the road surface. The computed value is -18 ftps.

To ascertain the sensitivity of the response variables to MED, simulation runs were made with various values of MED in the range of (-13.5 to -22.5) ftps. The response variables selected were the mean lane headway and weaving and non-weaving speeds. It was expected that as the maximum emergency deceleration rate increases (decreases) the mean lane headway decreases (increases) and the average weaving and non-weaving speeds increase (decrease). This was indeed verified by the results of simulation runs. Nevertheless, the change in weaving and non-weaving speeds was about 3% and for mean lane headway it was 4.5%, when MED was changed by 25%. This indicates that response variables are not significantly affected by changes in MED. Therefore, the computed value of -18.0 ftps can be used as the maximum emergency deceleration rate without significantly affecting the performance measures of the system.
5.2 PROBABILITY OF NON-ESSENTIAL LANE-CHANGING

As discussed in section 3.4.8 the motivation for non-essential lane-changing for non-weaving vehicles is generated randomly according to a binomial probability distribution known as PLC. The value of PLC has been calibrated from the FHWA data (discussed in section 4.4.2).

To determine the sensitivity of the system's performance to the probability of non-essential lane-changing, simulation runs were made for various values of PLC in the range of (.02 - .10). The weaving and non-weaving speeds and delays were selected as response variables. When PLC was increased from .02 to .10, the maximum changes in weaving and non-weaving delays were .65 (2%) and .77 (4.5%) seconds respectively, and the maximum changes in weaving and non-weaving speeds were .22 (0.6%) and .29 (0.7%) mph respectively. This indicates that changes in the value of PLC has practically no influence on the delay and speeds. Therefore, it is reasonable to use the calibrated value of (.04) for PLC without affecting the system’s performance.

5.3 SAFETY DISTANCE

To insure that the safe-following distance is not the same for all vehicles travelling at the same speed, a safety distance was introduced in computation of the vehicles' space headway in the car-following algorithm. As discussed in section 3.4.7, the safety distance is inversely correlated with the driver's randomly generated maximum speed. In WEAVERS, safety distance is a random value in the domain of (5,15) feet.

Since safety distance is part of the space headway, computed in the car-following algorithm, it is expected that lane mean headway increases (decreases) and speed
decreases (increases) as the safety distance increases (decreases). To determine the sensitivity of this parameter on the system's performance, simulation runs were made with various domains for safety distance. The selected domains were (0,10), (5,15), and (10,20). The response variables selected for the sensitivity analysis were mean lane headway and weaving and non-weaving speeds.

Simulation runs show that as the domain of the safety distance is changed the expected logical pattern is followed. The results of the sensitivity analysis are shown in figure (25).

As the domain was increased from (0,10) to (10,20), the weaving and non-weaving speeds decreased by 11% and 6% respectively and average lane headway increased by about 6%. This indicates that the response variables are somewhat sensitive to the value of the safety distance. Special care should, therefore, be taken in estimating a reasonable value for this parameter.

To develop a reasonable domain for the safety distance, a calibration process was carried out. Speeds and headways obtained from the simulation runs were compared with those obtained from the field data. The domain of (5,15) was, as the result, selected to be used in WEAVSIM. The midpoint of this domain (10) has been used, as a constant safety distance, in previous freeway simulation models (Rathi 1982, Bene-kohal 1986).
Figure 24: AVERAGE WEAVING AND NON-WEAVING SPEEDS AS A FUNCTION OF SAFETY DISTANCE
Figure 25: AVERAGE WEAVING AND NON-WEAVING DELAYS AS A FUNCTION OF SAFETY DISTANCE
5.4 TRAFFIC COMPOSITION

There is a considerable variation in the characteristics and performance capabilities of various vehicle types. Heavy vehicles are larger than passenger cars and, therefore, occupy more roadway space than passenger cars. Also, they have poorer acceleration and deceleration capabilities and, therefore, cannot keep up with passenger cars, originating large gaps in the traffic stream. This creates inefficiencies in the use of roadway space. Therefore, the relative proportion of the heavy vehicles has a significant effect on the operating characteristics of the traffic stream, specially at downgrades/upgrades where the effect of operating capabilities is most pronounced.

To determine the sensitivity of the response variables to proportion of the heavy vehicles, simulation runs were made with different values for percentages of heavy vehicles (trucks and trailers). The percentage of heavy vehicles were increased, by increment of 4%, from 0% to 20%. The mean headway and weaving and non-weaving speeds were selected as response variables. The maximum change in mean headway was .46 sec., and the maximum change in weaving and non-waving speeds were 10.1, 7.3 mph respectively. This indicates that the changes in the percentage of heavy vehicles does appreciably affect the system performance as was expected. Figure (26) illustrates sensitivity of weaving and non-weaving speeds to proportion of heavy vehicles.
Figure 26: AVERAGE WEAVING AND NON-WEAVING SPEEDS AS A FUNCTION OF HEAVY VEHICLES
5.5 BRAKE REACTION TIME

One of the major parameters in computing space headway in the car-following and lane-changing algorithms is the vehicle's brake reaction time. As discussed in section 4.2.3 brake reaction times are generated stochastically from a gamma distribution with mean and variance of .745, .073 respectively. The parameter for the gamma distribution is 7.60. These values have been used in other freeway simulation models (Rathi 1983; Benekohal 1986).

Simulation runs were made with various values of the mean. The mean brake reaction time in the range of (.558 - 931) seconds. For each case the parameter for the gamma distribution was adjusted accordingly. The mean lane headway and weaving and non-weaving speeds were selected as the response variable for the sensitivity analysis.

Table (9) summarizes results of the simulation runs. Since the space headway computed in the car-following algorithm is directly proportional to the brake reaction time, it was expected that as brake reaction time increases the speed will decrease and headway will increase. This trend was indeed verified by the results of the simulation runs. When the mean brake reaction time was increased from .558 to .931 sec. the average weaving and non-weaving speeds decreased by 14% and 6% respectively. The average weaving speed is more sensitive, to changes in the brake reaction time, than the non-weaving speed. This reflects the effect of brake reaction time on the lane-changing logic of the model. The change in average headway was about 8.5%

The results of the sensitivity analysis indicate that the performance measures of the system are particularly sensitive to the changes in the mean brake reaction time.
To develop a reasonable value for the mean brake reaction time several values in the range of (.558 - .931) for this parameter were subjected to a calibration process. The value of .745 sec. provided the most consistent performance when compared to the field data.

Table 9

RESULTS OF THE SENSITIVITY ANALYSIS FOR BRAKE REACTION TIME

<table>
<thead>
<tr>
<th>BRAKE REACTION TIME</th>
<th>SPEED WEAVING</th>
<th>NON-WEAV</th>
<th>HEADWAY lane 1</th>
<th>lane 2</th>
<th>lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.558</td>
<td>38.16</td>
<td>43.91</td>
<td>2.58</td>
<td>2.10</td>
<td>2.51</td>
</tr>
<tr>
<td>0.596</td>
<td>37.96</td>
<td>43.83</td>
<td>2.59</td>
<td>2.10</td>
<td>2.56</td>
</tr>
<tr>
<td>0.633</td>
<td>37.80</td>
<td>43.23</td>
<td>2.64</td>
<td>2.14</td>
<td>2.57</td>
</tr>
<tr>
<td>0.670</td>
<td>37.66</td>
<td>42.92</td>
<td>2.60</td>
<td>2.14</td>
<td>2.56</td>
</tr>
<tr>
<td>0.707</td>
<td>37.14</td>
<td>42.82</td>
<td>2.61</td>
<td>2.15</td>
<td>2.61</td>
</tr>
<tr>
<td>0.745</td>
<td>36.53</td>
<td>42.53</td>
<td>2.66</td>
<td>2.17</td>
<td>2.68</td>
</tr>
<tr>
<td>0.782</td>
<td>36.29</td>
<td>43.03</td>
<td>2.64</td>
<td>2.18</td>
<td>2.70</td>
</tr>
<tr>
<td>0.819</td>
<td>34.90</td>
<td>42.93</td>
<td>2.70</td>
<td>2.21</td>
<td>2.67</td>
</tr>
<tr>
<td>0.856</td>
<td>33.36</td>
<td>40.90</td>
<td>2.71</td>
<td>2.18</td>
<td>2.70</td>
</tr>
<tr>
<td>0.894</td>
<td>32.98</td>
<td>40.45</td>
<td>2.75</td>
<td>2.21</td>
<td>2.72</td>
</tr>
<tr>
<td>0.931</td>
<td>32.66</td>
<td>40.35</td>
<td>2.78</td>
<td>2.29</td>
<td>2.75</td>
</tr>
</tbody>
</table>
CHAPTER VI

VALIDATION

A typical traffic simulation model consists of large number of elements, rules, and logical linkages. Therefore, even when the individual components have been carefully tested, numerous small approximations can still accumulate into gross distortions in the outputs of the model. Consequently, after writing and debugging the computer program, it is imperative to test the validity of the model for reasonable predicting of the behavior of the system being simulated.


"...computer simulation is more likely to be utilized when the degree of validation is indicated".

The goal of validation of simulation models is twofold:

1. To increase the creditibility of the model and, consequently, expand its applicability as a useful tool;
2. To produce a model that represents true system behavior closely enough to be used as a substitute for the actual system for the purpose of experimentation.

Validation, as Bank and Carson (1984) indicate, should not be seen as an isolated set of procedures that follows model development, but rather as an integral part of model development.
Many reports and papers have been written on methods of assessing the validity of a model. A three-stage approach for validation is suggested by most of the literature on validation of computer simulation models (Torres et al., 1983). First the face validity of the model should be established. This could be achieved by sensitivity analysis to see if the model behaves in the expected way when one or more input variables are changed. The second stage is an attempt to verify model assumptions. This stage is more of characteristics of the model building process. The third and most critical stage in validation is comparison of the input-output transformation of the model to those of the real world system.

In the simplest sense a computer is an input-output transformation device. Therefore, one of the best approaches for validation of simulation models is to compare the output of the model with the output of the real world system, using identical inputs.

Using appropriate two sample test statistics, it could then be determined whether the two samples are actually from different populations or practically from the same population. Statistical tests commonly used for this comparison are:

1. Test of means by: t-Test, nonparametric Mann-Whitney, or Sign Test, Torres et al. (1983) used standard paired t-Test in validation of NETSIM. Roupail (1981) and Rathi (1983) also applied t-Test to test the hypothesis that the simulated and the field data were drawn from population having equal means. The Sign test was applied in validation of INTRAS (Goldblatt, 1980).

2. Test of variance, using F-test, or test for goodness of fit using Chi-Square or Kolmogorov-Smirnov test. These tests have also been widely used in past traffic simulation models; Rathi, 1983; Goldblatt, 1980; Leland, 1968; etc.
6.1 ANALYSIS OF THE DATA BASE

As discussed in section 4.1, the available data sets were collected over one-hour period. These data sets have been carefully isolated to obtain time periods in which the average flow levels remain constant. Figure (27) shows the standard deviation of rate of flow at various time intervals.

From this figure it is clearly seen that at time intervals of five (5) minutes and greater the average flow level remains relatively constant. Therefore, a time interval of five (5) minutes was chosen to be used for analysis of the data.

The objective of the analysis of the field data is twofold:

1. To provide some input parameters for the simulation model such as: weaving and non-weaving volume, composition, vehicle type, etc.
2. To compare traffic characteristics in the field with that predicted by the model.

To achieve the above objectives, a SIMSCRIPT program was developed. This program reads the field data as if they were created by WEAVSIM. To manipulate and analyze the data, the program was properly linked to Statistical Analysis System package (SAS). This program produces outputs which are the same as those produced by WEAVSIM. This facilitated an easy comparison of the two outputs. This algorithm, based on evaluation of origin-destination of each vehicle, determines the number of weaving vehicles for each lane. In addition, it tracks vehicles' path through the weaving section and records all the lane-changing maneuvers. The size of the accepted gaps are computed as the ratio of the difference between position of the leader and the follower and speed of the follower. In WEAVSIM, gaps are evaluated one second before they are actually accepted. Therefore, to achieve maximum consistency in the
Figure 27: STANDARD DEVIATION OF RATE OF FLOW AT VARIOUS TIME INTERVALS
validation process, gap sizes in the field data were computed one second prior to their actual acceptance. The output of this program includes frequency and cumulative distribution function of headway, accepted gap, merging points, and weaving and non-weaving speed as well as vehicle trajectories for each lane.

6.2 MODEL VALIDATION

The following traffic description parameters were targeted for comparison:

- headway distributions
- distributions of accepted gaps
- merging point distributions
- weaving and non-weaving speed distributions
- vehicle trajectories

In each case, intervals of five minutes were chosen from the data base for comparison. The data sets were then run through the developed SIMSCRIPT program in order to transform the raw data into vehicular speeds and headways. The input volume and traffic compositions were also obtained from the data for each time interval. These were used as input parameters for the simulation model. The geometries of the model were also adjusted to represent that of the site at which the field-data were collected. Although five minute intervals of data were used, to eliminate randomness effect, the simulation model was run for a period of 30 minutes plus a 5 minutes warm-up time. The outputs were then compared with those obtained from the field-data.
Considering the fact that the data sets have been collected at medium to high level of traffic flow, validation of WEAVSIM is carried out at these two volume levels.

Following sections contain a description of the two sites chosen for comparison as well as the results of the comparison.

### 6.2.1 SITE DESCRIPTION

Two weaving sections were selected for validation of WEAVSIM:

- The Baltimore-Washington Parkway northbound at I-95 in Washington D.C. area
- The Harbour freeway northbound between Santa Monica freeway (I-10) and 6th street in Los Angeles California

**BALTIMORE-WASHINGTON FREEWAY** weaving section is a clover-leaf type weaving section. The following characteristics were obtained from the field-data and used as input for the simulation model:

<table>
<thead>
<tr>
<th>Weaving Section Length</th>
<th>700 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH VOLUME</strong></td>
<td></td>
</tr>
<tr>
<td>lane 1 volume</td>
<td>1968 vph</td>
</tr>
<tr>
<td>lane 2 volume</td>
<td>2316 vph</td>
</tr>
<tr>
<td>lane 3 volume</td>
<td>840 vph</td>
</tr>
<tr>
<td>percent truck</td>
<td>3.0%</td>
</tr>
<tr>
<td>percent trailer</td>
<td>1.0%</td>
</tr>
<tr>
<td>percent weaving from lane 1</td>
<td>8.0%</td>
</tr>
<tr>
<td>percent weaving from lane 2</td>
<td>45.0%</td>
</tr>
<tr>
<td>percent weaving from lane 3</td>
<td>88.0%</td>
</tr>
</tbody>
</table>
MEDIUM VOLUME

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>lane 1 volume</td>
<td>1644 vph</td>
</tr>
<tr>
<td>lane 2 volume</td>
<td>1632 vph</td>
</tr>
<tr>
<td>lane 3 volume</td>
<td>600 vph</td>
</tr>
<tr>
<td>percent truck</td>
<td>5.0%</td>
</tr>
<tr>
<td>percent trailer</td>
<td>1.0%</td>
</tr>
<tr>
<td>percent weaving from lane 1</td>
<td>9.0%</td>
</tr>
<tr>
<td>percent weaving from lane 2</td>
<td>30.0%</td>
</tr>
<tr>
<td>percent weaving from lane 3</td>
<td>70.0%</td>
</tr>
</tbody>
</table>

During analysis of the data at this site, it was noticed that when computing the accepted gaps for the ramp lane, the leader or the follower were often missing. This is due to the fact that the data for ramp lane is deleted at both ends of the study area, mainly from 0 to 600 ft. and from 1400 ft. to the end of the study area. This problem is also addressed in another study of this data set carried out by Watanabe (1986). An accurate count of the number and size of the accepted gaps in the ramp lane were, therefore, impossible. For the purpose of this validation only those gaps with both leader and follower were counted. These gaps were often very small.

HARBOR FREEWAY weaving section is formed where route 11 northbound merges with two ramp lanes from the Santa Monica freeway, as shown in Figure(28). This weaving section has five lanes, three on the mainline with two ramp lanes. For validation of WEAVSIM only the middle three lanes (two on the mainline and one ramp lane) were used. This was based on the results of the study done recently by Fazio (1985) on analysis of these data sets. As a
result of his study, he concludes that 99 percent of the weaving movements from the mainlines are from the first two lines closest to the ramp lane. He also concludes that only 1 percent of the weaving movement is from the lane furthest from the ramp lane.

The following characteristics were obtained from this data set and used as input to the simulation model:

<table>
<thead>
<tr>
<th>Weaving Section Length</th>
<th>1450 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH VOLUME</strong></td>
<td></td>
</tr>
<tr>
<td>lane 1 volume</td>
<td>1812 vph</td>
</tr>
<tr>
<td>lane 2 volume</td>
<td>1716 vph</td>
</tr>
<tr>
<td>lane 3 volume</td>
<td>1752 vph</td>
</tr>
<tr>
<td>percent truck</td>
<td>10.0%</td>
</tr>
<tr>
<td>percent trailer</td>
<td>1.0%</td>
</tr>
<tr>
<td>percent weaving from lane 1</td>
<td>19.0%</td>
</tr>
<tr>
<td>percent weaving from lane 2</td>
<td>64.0%</td>
</tr>
<tr>
<td>percent weaving from lane 3</td>
<td>75.0%</td>
</tr>
</tbody>
</table>

| **MEDIUM VOLUME**       |         |
| lane 1 volume           | 1332 vph|
| lane 2 volume           | 1428 vph|
| lane 3 volume           | 1140 vph|
| percent truck           | 11.0%   |
| percent trailer         | 1.0%    |
| percent weaving from lane 1 | 4.0%  |
| percent weaving from lane 2 | 39.0% |
| percent weaving from lane 3 | 71.0% |
Section Length = 1831'
Mainline Curve Radius = 2900' Right
Superelevation = .05 (approx.)
Lane Width = 12'
Grade = -1% (approx.)
Shoulders = 3' Right
4' Left

Figure 28: HARBOR FREEWAY WEAVING SECTION
6.2.2 STATISTICAL TESTS

The following statistical procedures were performed to compare the simulated data with the observed data.

6.2.2.1 Kolmogrov-Smirnov test

To compare the observed vs. simulated distributions of the target variables, the Kolmogrov-Smirnov distribution free test was used. This test is a two-sample distribution free test of the hypotheses that both samples have been taken from the same population. It works only for continuous distributions. If we let:

\[
\begin{align*}
  \text{OBS} &= \text{Observed cumulative distribution function} \\
  \text{SIM} &= \text{Simulated cumulative distribution function} \\
  n,m &= \text{Sample size for observed and simulated distributions, respectively}
\end{align*}
\]

Then the null hypothesis is:

\[ H_0 : P(\text{OBS} \leq a) = P(\text{SIM} \leq a) \]

To test the null hypothesis, first compute the maximum vertical difference between the simulated and observed cumulative distribution functions:

\[ J = \text{MAX. } |\text{SIM}(a) - \text{OBS}(a)| \]

Then, by selecting a level of significance (\(\alpha\)), compute \(J_{cr}\):

\[ J_{cr} = K_{\alpha} / \sqrt{n.m/(n+m)} \]

were \(K\) is the critical value for cumulative probability of \(1-\alpha\) for null limiting distribution of the two sided Kolmogrov-Smirnov test. When the sample sizes \((n,m)\) are large, \(K = 1.36\) for level of significance of \(.05\), therefore:

\[ J_{cr} = 1.36 / \sqrt{n.m/(n+m)} \]
And:

reject Ho if \( J \geq J_{cr(a,m,n)} \)

accept Ho if \( J < J_{cr(a,m,n)} \)

6.2.2.2 T-test

The paired t-test was conducted in each case to compare mean values of the observed and simulated headways. This procedure tests the null hypothesis that in each case the means of the observed and simulated distributions are the same, subject to the assumption that the standard deviations for the two populations are equal. Let:

\[
X_{o}, X_{s} = \text{mean value of target variable for observed and simulated conditions, respectively}
\]

\[
S_{o}^2, S_{s}^2 = \text{Sample variance of the target variable for observed and simulated conditions, respectively}
\]

\[
S_{p}^2 = \text{Pooled estimator of the common standard deviation}
\]

In testing the difference between two means, the null hypothesis of interest is generally not only that the sample means were obtained from populations with equal means, but that the two sample were in fact obtained from the same population of values. This means that the two populations have same variance. Thus, the assumed common variance is often estimated by pooling the two sample variances, and this estimated value is then used as the basis for the standard error of the difference. The pooled estimator of the common standard deviation is:

\[
S_{p} = \frac{(n-1)S_{o}^2 + (m-1)S_{s}^2}{n + m - 2}
\]

Then the t-statistic has the form:

\[
t = \frac{X_{o} - X_{s}}{S_{p} \sqrt{\frac{1}{n} + \frac{1}{m}}}
\]
Now the null hypothesis is rejected at a significance level of .05 if \( t \) exceeds \( t_{\alpha/2(n+m-2)} \)

A \( t \) distribution is appropriate for inferences concerning the mean whenever the population is normally distributed, regardless of the sample size. However, as the sample size is increased, the assumption of normality becomes less crucial. A rule of thumb is that if sample size is greater than 25, the \( t \) distribution is insensitive to nonnormality. It also needs to be mentioned here that the observations are dependent and, therefore, the \( t \) statistics, reported in the tables, is computed from dependent data. However, since the observations are positively correlated, the variance of \( X_o \) and \( X_s \) are larger than \( \sigma_o^2/n \) and \( \sigma_s^2/m \). But the \( S_p \) in the denominator of the \( t \) statistic estimates \( \sigma_o^2/n + \sigma_s^2/m \) it implies that the computed \( t \) tends to be more variable than a \( t \)-random variable, making the p-value too small.

Also since observations are positively correlated, Confidence Intervals are not valid. But

\[
X_o - X_s + S_p \sqrt{1/n+1/m}
\]

gives a rough estimate of the accuracy of the difference between the means.

Similarly, the \( J \) computed for the Kolmogrov-Smirnov test is computed from correlated data. However, since the correlation is positive, the values reported in the tables are conservative estimates of the true values.

6.2.2.3 F-test

The F-distribution was applied to compare the variances of the observed and simulated target variables. The statistic which is used to test the null hypothesis that there is no difference between two variances is:
Since each sample variance is an unbiased estimator of the population variance, the expected value of this ratio is about 1.0, and the null hypothesis is:

\[
H_0: \frac{\sigma_o^2}{\sigma_s^2} = 1
\]

and since,

\[
p \left( \frac{n \sigma_o^2}{(n-1)} > f(n-1, m-1, \alpha); \frac{\sigma_o^2}{\sigma_s^2} = 1 \right) = \alpha
\]

then Ho will be rejected if:

\[
\frac{S_o^2}{S_s^2} > \left( \frac{m}{m-1} \right) \left( \frac{n-1}{n} \right) f(n-1, m-1, \alpha) \quad \text{or}
\]

\[
\frac{S_o^2}{S_s^2} < \left( \frac{m}{m-1} \right) \left( \frac{n-1}{n} \right) f(n-1, m-1, 1-\alpha)
\]

All statistical tests were two-sided and at 5% level of significance. The simulation results are the arithmetic mean of five replications. Following sections examine the results of the microscopic validation.

6.2.3 HEADWAY DISTRIBUTIONS

Figures (29)-(34) show headway distributions reproduced by the simulation and compared to those derived from both data sets at congested flow. An excellent agreement was obtained and statistical tests, shown in tables (10)-(11), reveal no significant difference in mean values or distributions.
Table 10

**COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)**

<table>
<thead>
<tr>
<th>HEADWAY</th>
<th>lane 1</th>
<th>lane 2</th>
<th>lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
</tr>
<tr>
<td>&lt;= 1.0</td>
<td>0.13</td>
<td>0.07</td>
<td>0.17</td>
</tr>
<tr>
<td>&lt;= 2.0</td>
<td>0.57</td>
<td>0.67</td>
<td>0.54</td>
</tr>
<tr>
<td>&lt;= 3.0</td>
<td>0.81</td>
<td>0.83</td>
<td>0.78</td>
</tr>
<tr>
<td>&lt;= 4.0</td>
<td>0.90</td>
<td>0.87</td>
<td>0.86</td>
</tr>
<tr>
<td>&lt;= 5.0</td>
<td>0.94</td>
<td>0.90</td>
<td>0.93</td>
</tr>
<tr>
<td>&lt;= 6.0</td>
<td>0.96</td>
<td>0.92</td>
<td>0.95</td>
</tr>
<tr>
<td>&lt;= 7.0</td>
<td>0.97</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>&lt;= 8.0</td>
<td>0.98</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;= 9.0</td>
<td>0.98</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;=10.0</td>
<td>0.98</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;=11.0</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>&lt;=12.0</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;=13.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=14.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=15.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

--

<table>
<thead>
<tr>
<th>no. of obs.</th>
<th>302</th>
<th>877</th>
<th>294</th>
<th>950</th>
<th>265</th>
<th>804</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>2.27</td>
<td>2.50</td>
<td>2.39</td>
<td>2.32</td>
<td>2.33</td>
<td>2.68</td>
</tr>
<tr>
<td>STD. DEV.</td>
<td>2.44</td>
<td>2.62</td>
<td>2.30</td>
<td>2.19</td>
<td>2.91</td>
<td>2.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J</th>
<th>0.060</th>
<th>0.070</th>
<th>0.080</th>
</tr>
</thead>
<tbody>
<tr>
<td>J(crt)</td>
<td>0.091</td>
<td>0.088</td>
<td>0.096</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t</th>
<th>-1.34</th>
<th>+0.47</th>
<th>-1.68</th>
</tr>
</thead>
<tbody>
<tr>
<td>t(crt)</td>
<td>-1.96</td>
<td>+1.96</td>
<td>-1.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIFF(Appr.SE)</th>
<th>-.23(0.17)</th>
<th>0.07(0.15)</th>
<th>-.35(0.21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.933</td>
<td>1.050</td>
<td>0.969</td>
</tr>
<tr>
<td>F(crt)</td>
<td>0.827</td>
<td>1.198</td>
<td>0.827</td>
</tr>
</tbody>
</table>
Figure 29: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE HARBOR SITE (HIGH VOLUME)
Figure 30: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE HARBOR SITE (HIGH VOLUME)
Figure 31: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE HARBOR SITE (HIGH VOLUME)
Table 11

**COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)**

<table>
<thead>
<tr>
<th>HEADWAY</th>
<th>lane 1</th>
<th>lane 2</th>
<th>lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
</tr>
<tr>
<td>&lt;= 1.0</td>
<td>0.32</td>
<td>0.26</td>
<td>0.16</td>
</tr>
<tr>
<td>&lt;= 2.0</td>
<td>0.74</td>
<td>0.71</td>
<td>0.76</td>
</tr>
<tr>
<td>&lt;= 3.0</td>
<td>0.90</td>
<td>0.82</td>
<td>0.88</td>
</tr>
<tr>
<td>&lt;= 4.0</td>
<td>0.95</td>
<td>0.90</td>
<td>0.93</td>
</tr>
<tr>
<td>&lt;= 5.0</td>
<td>0.97</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>&lt;= 6.0</td>
<td>0.99</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;= 7.0</td>
<td>0.99</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>&lt;= 8.0</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;= 9.0</td>
<td>1.00</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;=10.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=11.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=12.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=13.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=14.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=15.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

| # of obs. | 158 | 480 | 192 | 544 | 85 | 286 |
| MEAN      | 1.86 | 2.03 | 1.74 | 1.93 | 1.84 | 3.46 |
| STD. DEV. | 1.29 | 1.59 | 1.44 | 1.26 | 1.47 | 3.42 |
| J         | 0.080 | 0.050 | 0.200 |
| J(crt)    | 0.125 | 0.114 | 0.168 |
| t         | -1.22 | -1.73 | -4.40 |
| t(crt)    | -1.96 | +1.96 | -1.96 | +1.96 | -1.96 | +1.96 |
| DIFF(Appr.SE) | -.17(.14) | -.19(.11) | -1.62(.37) |
| F         | 0.805 | 1.147 | 0.433 |
| F(crt)    | 0.768 | 1.280 | 0.786 | 1.254 | 0.697 | 1.388 |
Figure 32: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 33: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 34: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE BALTIMORE SITE (HIGH VOLUME)
Figures (35)-(40) show headway distributions for medium traffic flow at both sites. Good agreement is obtained between the simulated and observed headways. Tables (12) and (13) provide a concise summarization of the results of statistical tests performed for comparison of simulated vs. observed headways. The results reveal that no significant difference in mean values or distributions is detected at either site. The only exception is in lane 3 at the Baltimore-Washington site where the average headway obtained from the field data was much lower than that obtained from simulation runs. This could be due to the fact that at this site the data for the ramp lane is deleted at both ends of the study area, mainly from 0-600 ft. and from 1400 ft. to the end of the study area. Therefore, at both ends of the weaving section, the leader or follower vehicles were often missing, making an accurate count of all headways impossible. Consequently, only the headways in the middle (most congested) part of the weaving section were measured. These headways constitute the major part of the small headways; and larger headways, even though existed, were impossible to measure.

The overall conclusion suggests the effectiveness of the model in replication of the observed car-following behavior.
Table 12

**COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)**

<table>
<thead>
<tr>
<th>HEADWAY</th>
<th>lane 1</th>
<th>lane 2</th>
<th>lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
<td>SIM.</td>
</tr>
<tr>
<td>&lt;= 1.0</td>
<td>0.26</td>
<td>0.15</td>
<td>0.24</td>
</tr>
<tr>
<td>&lt;= 2.0</td>
<td>0.61</td>
<td>0.50</td>
<td>0.57</td>
</tr>
<tr>
<td>&lt;= 3.0</td>
<td>0.76</td>
<td>0.68</td>
<td>0.75</td>
</tr>
<tr>
<td>&lt;= 4.0</td>
<td>0.85</td>
<td>0.74</td>
<td>0.84</td>
</tr>
<tr>
<td>&lt;= 5.0</td>
<td>0.91</td>
<td>0.83</td>
<td>0.89</td>
</tr>
<tr>
<td>&lt;= 6.0</td>
<td>0.94</td>
<td>0.89</td>
<td>0.93</td>
</tr>
<tr>
<td>&lt;= 7.0</td>
<td>0.96</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td>&lt;= 8.0</td>
<td>0.97</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;= 9.0</td>
<td>0.98</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>&lt;=10.0</td>
<td>0.99</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>&lt;=11.0</td>
<td>1.00</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;=12.0</td>
<td>1.00</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;=13.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=14.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=15.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

# of obs. 114 395 117 410 86 261

Mean 2.24 2.34 2.34 2.29 2.43 2.61

STD. DEV. 2.02 2.51 2.06 1.73 2.91 3.42

| J   | 0.110 | 0.110 | 0.130 |
| J(crt) | 0.145 | 0.143 | 0.169 |
| t   | -0.39 | +0.26 | -0.43 |
| t(crt) | -1.96 | +1.96 | -1.96 +1.96 |
| DIFF(Appr.SE) | -0.10 (.26) | .05 (.19) | -.18 (.41) |
| F   | 0.810 | 1.198 | 0.858 |
| F(crt) | 0.734 | 1.328 | 0.738 |

10.0 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Figure 35: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE HARBOR SITE (MEDIUM VOLUME)
Figure 36: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE HARBOR SITE (MEDIUM VOLUME)
Figure 37: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE HARBOR SITE (MEDIUM VOLUME)
Table 13

COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS
AT THE BALTIMORE SITE (MEDIUM VOLUME)

<table>
<thead>
<tr>
<th>HEADWAY</th>
<th>lane 1</th>
<th></th>
<th>lane 2</th>
<th></th>
<th>lane 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
<td>SIM.</td>
</tr>
<tr>
<td>&lt;= 1.0</td>
<td>0.38</td>
<td>0.25</td>
<td>0.25</td>
<td>0.12</td>
<td>0.29</td>
<td>0.06</td>
</tr>
<tr>
<td>&lt;= 2.0</td>
<td>0.75</td>
<td>0.61</td>
<td>0.58</td>
<td>0.63</td>
<td>0.64</td>
<td>0.31</td>
</tr>
<tr>
<td>&lt;= 3.0</td>
<td>0.85</td>
<td>0.73</td>
<td>0.77</td>
<td>0.79</td>
<td>0.79</td>
<td>0.43</td>
</tr>
<tr>
<td>&lt;= 4.0</td>
<td>0.91</td>
<td>0.83</td>
<td>0.87</td>
<td>0.87</td>
<td>0.88</td>
<td>0.52</td>
</tr>
<tr>
<td>&lt;= 5.0</td>
<td>0.94</td>
<td>0.89</td>
<td>0.92</td>
<td>0.93</td>
<td>0.92</td>
<td>0.60</td>
</tr>
<tr>
<td>&lt;= 6.0</td>
<td>0.96</td>
<td>0.95</td>
<td>0.94</td>
<td>0.96</td>
<td>0.95</td>
<td>0.69</td>
</tr>
<tr>
<td>&lt;= 7.0</td>
<td>0.97</td>
<td>0.97</td>
<td>0.95</td>
<td>0.98</td>
<td>0.97</td>
<td>0.76</td>
</tr>
<tr>
<td>&lt;= 8.0</td>
<td>0.98</td>
<td>0.98</td>
<td>0.97</td>
<td>0.99</td>
<td>0.98</td>
<td>0.81</td>
</tr>
<tr>
<td>&lt;= 9.0</td>
<td>0.99</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
<td>0.99</td>
<td>0.86</td>
</tr>
<tr>
<td>&lt;=10.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.91</td>
</tr>
<tr>
<td>&lt;=11.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.93</td>
</tr>
<tr>
<td>&lt;=12.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.96</td>
</tr>
<tr>
<td>&lt;=13.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=14.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;=15.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

# of obs. 106 334 106 279 35 122

MEAN 1.80 2.09 2.32 2.25 2.10 3.98

STD. DEV. 1.80 1.83 2.09 1.63 1.80 4.10

J 0.140 0.130 0.360
J(crt) 0.152 0.155 0.261

t -1.42 +0.35 -2.73

Diff(Appr SE) -0.29(-0.20) -0.07(-0.20) -1.88(-0.69)

F 0.990 1.289 0.448
F(crt) 0.724 1.347 0.719 1.358 0.561 1.645
Figure 38: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(1) AT THE BALTIMORE SITE (MEDIUM VOLUME)
Figure 39: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(2) AT THE BALTIMORE SITE (MEDIUM VOLUME)
Figure 40: COMPARISON OF SIMULATED VS. OBSERVED HEADWAY DISTRIBUTIONS FOR LANE(3) AT THE BALTIMORE SITE (MEDIUM VOLUME)
6.2.4 SPEED DISTRIBUTIONS

Figures (41)-(48) illustrate simulated versus observed cumulative distribution functions of weaving and non-weaving speeds at medium and high level of traffic volumes.

At high level of traffic volume the model reproduced speed distributions with great accuracy for both weaving and non-weaving traffic. Tables 14 through 17 summarize the results of the comparison of simulated vs. observed weaving and non-weaving speed distributions at both sites. These tables show generally good agreement between the field and simulated results. The only exception was at the Harbor site where the observed average weaving speed exceeds the average non-weaving speed. This contradicts the results of the simulation runs. One possible explanation for this occurrence is the observed influence of the downstream congestion, on the flow within the site, reported by the data collection crew.

Tables (16) and (17) show comparison of the field and simulated speed distributions at medium level of traffic volume. In general, the performance of the model in reproducing speed distributions, for both weaving and non-weaving traffic, was quite satisfactory.

In design and analysis of weaving sections operational conditions are represented by a level of service which is based on the average weaving and non-weaving speeds. As is shown in Table (1) the level of service for both weaving and non-weaving traffic changes with increase/decrease of 5 or more mph. in speed. Since the maximum difference between the speeds obtained from simulated and field data is less than 5 mph. (3.54 and 3.80 mph. for weaving and non-weaving speeds, respectively), the predicted level of service would accurately represent the actual operational conditions. Therefore, the discrepancy observed between speeds obtained from field data and
simulated data is not too crucial to interfere with the expected applications of the model.

Table 14

**COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)**

<table>
<thead>
<tr>
<th>SPEED mph.</th>
<th>WEAVING</th>
<th>NONWEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
</tr>
<tr>
<td>= 15.0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>= 20.0</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>= 25.0</td>
<td>0.42</td>
<td>0.56</td>
</tr>
<tr>
<td>= 30.0</td>
<td>0.81</td>
<td>0.91</td>
</tr>
<tr>
<td>= 35.0</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>= 40.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>= 45.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>= 50.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>* of obs.</td>
<td>112</td>
<td>339</td>
</tr>
<tr>
<td>MEAN</td>
<td>26.07</td>
<td>24.29</td>
</tr>
<tr>
<td>STD. DEV.</td>
<td>4.59</td>
<td>4.06</td>
</tr>
<tr>
<td>DIFF(Appr SE)</td>
<td>1.78(.46)</td>
<td>-2.44(.57)</td>
</tr>
<tr>
<td>J</td>
<td>0.140</td>
<td>0.260</td>
</tr>
<tr>
<td>J(crt)</td>
<td>0.148</td>
<td>0.147</td>
</tr>
<tr>
<td>F</td>
<td>0.990</td>
<td>1.289</td>
</tr>
<tr>
<td>F(crt)</td>
<td>0.724</td>
<td>1.347</td>
</tr>
</tbody>
</table>
Figure 41: COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)
Figure 42: COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)
### Table 15

**COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)**

<table>
<thead>
<tr>
<th>SPEED mph.</th>
<th>WEAVING</th>
<th>NONWEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
</tr>
<tr>
<td>&lt;= 15.0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>&lt;= 20.0</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>&lt;= 25.0</td>
<td>0.01</td>
<td>0.08</td>
</tr>
<tr>
<td>&lt;= 30.0</td>
<td>0.23</td>
<td>0.27</td>
</tr>
<tr>
<td>&lt;= 35.0</td>
<td>0.55</td>
<td>0.56</td>
</tr>
<tr>
<td>&lt;= 40.0</td>
<td>0.73</td>
<td>0.84</td>
</tr>
<tr>
<td>&lt;= 45.0</td>
<td>0.88</td>
<td>0.97</td>
</tr>
<tr>
<td>&lt;= 50.0</td>
<td>0.96</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;= 55.0</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;= 60.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;= 65.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

| # of obs.  | 77      | 239       | 170     | 496       |
| MEAN       | 35.92   | 35.87     | 43.70   | 39.90     |
| STD. DEV.  | 7.20    | 6.05      | 7.03    | 5.36      |
| DIFF(Appr. SE) | 2.05(.83) | 3.80(.51) |
| \( \bar{J} \) | 0.090   | 0.110     |
| \( J(\text{crt}) \) | 0.178   | 0.121     |
| \( F \)     | 1.013   | 1.310     |
| \( F(\text{crt}) \) | 0.682  | 1.416     | 0.775   | 1.271     |
Figure 43: COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 44: COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)
Table 16

**COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)**

<table>
<thead>
<tr>
<th>SPEED mph</th>
<th>WEAVING</th>
<th>NONWEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
</tr>
<tr>
<td>&lt;= 25.0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>&lt;= 30.0</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>&lt;= 35.0</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>&lt;= 40.0</td>
<td>0.09</td>
<td>0.22</td>
</tr>
<tr>
<td>&lt;= 45.0</td>
<td>0.28</td>
<td>0.47</td>
</tr>
<tr>
<td>&lt;= 50.0</td>
<td>0.68</td>
<td>0.80</td>
</tr>
<tr>
<td>&lt;= 55.0</td>
<td>0.86</td>
<td>0.95</td>
</tr>
<tr>
<td>&lt;= 60.0</td>
<td>0.97</td>
<td>0.99</td>
</tr>
<tr>
<td>&lt;= 65.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;= 70.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

# of Obs. 95 296 135 421

<table>
<thead>
<tr>
<th></th>
<th>OBS.</th>
<th>SIM.</th>
<th>OBS.</th>
<th>SIM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>50.86</td>
<td>47.46</td>
<td>52.33</td>
<td>49.09</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>4.89</td>
<td>6.46</td>
<td>5.38</td>
<td>5.94</td>
</tr>
<tr>
<td>DIFF (Appr. SE)</td>
<td>3.40(.72)</td>
<td>3.24(.57)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>0.130</td>
<td>0.110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J (crt)</td>
<td>0.160</td>
<td>0.135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>0.760</td>
<td>0.919</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (crt)</td>
<td>0.710</td>
<td>1.369</td>
<td>0.752</td>
<td>1.304</td>
</tr>
</tbody>
</table>
Figure 45: COMPARISON OF SIMULATED VS. OBSERVED WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)
Figure 46: COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)
Table 17

COMPARISON OF SIMULATED VS. OBSERVED SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME)

<table>
<thead>
<tr>
<th>SPEED mph.</th>
<th>WEAVING OBS.</th>
<th>SIM.</th>
<th>NONWEAVING OBS.</th>
<th>SIM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;= 25.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>&lt;= 30.0</td>
<td>0.01</td>
<td>0.03</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>&lt;= 35.0</td>
<td>0.04</td>
<td>0.06</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>&lt;= 40.0</td>
<td>0.28</td>
<td>0.16</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>&lt;= 45.0</td>
<td>0.51</td>
<td>0.38</td>
<td>0.12</td>
<td>0.18</td>
</tr>
<tr>
<td>&lt;= 50.0</td>
<td>0.79</td>
<td>0.66</td>
<td>0.38</td>
<td>0.50</td>
</tr>
<tr>
<td>&lt;= 55.0</td>
<td>0.92</td>
<td>0.89</td>
<td>0.69</td>
<td>0.81</td>
</tr>
<tr>
<td>&lt;= 60.0</td>
<td>1.00</td>
<td>0.98</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>&lt;= 65.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>&lt;= 70.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

# of obs. 62 192 149 459

<table>
<thead>
<tr>
<th></th>
<th>WEAVING</th>
<th>NONWEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>43.01</td>
<td>46.55</td>
</tr>
<tr>
<td>STD. DEV.</td>
<td>6.85</td>
<td>7.23</td>
</tr>
<tr>
<td>DIFF(Appr SE)</td>
<td>-3.54(1.04)</td>
<td>2.22(.57)</td>
</tr>
<tr>
<td>J</td>
<td>0.130</td>
<td>0.120</td>
</tr>
<tr>
<td>J(crt)</td>
<td>0.199</td>
<td>0.128</td>
</tr>
<tr>
<td>F</td>
<td>0.958</td>
<td>0.799</td>
</tr>
<tr>
<td>P(crt)</td>
<td>0.651</td>
<td>1.472</td>
</tr>
</tbody>
</table>
Figure 47: COMPARISON OF SIMULATED VS. OBSERVED WAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME)
Figure 48: COMPARISON OF SIMULATED VS. OBSERVED NON-WEAVING SPEED DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME)
6.2.5 DISTRIBUTION OF ACCEPTED GAPS

Distributions of accepted gaps, obtained from simulation and field data, are graphically illustrated in figures (49)-(52).

At both medium and high level of traffic volume the accepted gap distributions seemed to be structurally as good as expected, especially in congested traffic conditions. This proves the effectiveness of the gap-acceptance logic, incorporated in the lane-changing algorithm of the model, and its integration with the car-following algorithm.

In WEAVSIM lane-changing is the most critical area of the system performance and therefore ability of the model to accurately replicate lane-changing behavior is significant.
Figure 49: COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 50: COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)
Figure 51: COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE BALTIMORE SITE (MEDIUM VOLUME)
Figure 52: COMPARISON OF SIMULATED VS. OBSERVED ACCEPTED GAPS DISTRIBUTIONS AT THE HARBOR SITE (MEDIUM VOLUME)
6.2.6 DISTRIBUTION OF MERGING POINTS

The observed merging distances are aggregated by 100-ft increments from the entrance gore of the weaving section. Cumulative distribution function of merging points are given in tables (18) and (19) and illustrated in Figures (53)-(58).

Table 18

COMPARISON OF SIMULATED VS. OBSERVED MERGING POINT DISTRIBUTIONS AT THE HARBOR SITE (HIGH VOLUME)

<table>
<thead>
<tr>
<th>MERGING POINT</th>
<th>lane 3-2 OBS.</th>
<th>lane 3-2 SIM.</th>
<th>lane 2-3 OBS.</th>
<th>lane 2-3 SIM.</th>
<th>lane 2-1 OBS.</th>
<th>lane 2-1 SIM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.12</td>
<td>0.22</td>
<td>0.09</td>
<td>0.17</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>200</td>
<td>0.32</td>
<td>0.39</td>
<td>0.29</td>
<td>0.31</td>
<td>0.12</td>
<td>0.11</td>
</tr>
<tr>
<td>300</td>
<td>0.51</td>
<td>0.51</td>
<td>0.50</td>
<td>0.45</td>
<td>0.23</td>
<td>0.19</td>
</tr>
<tr>
<td>400</td>
<td>0.57</td>
<td>0.61</td>
<td>0.56</td>
<td>0.56</td>
<td>0.33</td>
<td>0.30</td>
</tr>
<tr>
<td>500</td>
<td>0.71</td>
<td>0.72</td>
<td>0.65</td>
<td>0.65</td>
<td>0.44</td>
<td>0.33</td>
</tr>
<tr>
<td>600</td>
<td>0.73</td>
<td>0.80</td>
<td>0.66</td>
<td>0.74</td>
<td>0.56</td>
<td>0.39</td>
</tr>
<tr>
<td>700</td>
<td>0.76</td>
<td>0.84</td>
<td>0.70</td>
<td>0.81</td>
<td>0.64</td>
<td>0.56</td>
</tr>
<tr>
<td>800</td>
<td>0.78</td>
<td>0.88</td>
<td>0.74</td>
<td>0.85</td>
<td>0.77</td>
<td>0.66</td>
</tr>
<tr>
<td>900</td>
<td>0.83</td>
<td>0.91</td>
<td>0.77</td>
<td>0.88</td>
<td>0.73</td>
<td>0.89</td>
</tr>
<tr>
<td>1000</td>
<td>0.87</td>
<td>0.94</td>
<td>0.81</td>
<td>0.91</td>
<td>0.83</td>
<td>0.79</td>
</tr>
<tr>
<td>1100</td>
<td>0.90</td>
<td>0.96</td>
<td>0.84</td>
<td>0.94</td>
<td>0.90</td>
<td>0.88</td>
</tr>
<tr>
<td>1200</td>
<td>0.93</td>
<td>0.96</td>
<td>0.87</td>
<td>0.97</td>
<td>0.96</td>
<td>0.94</td>
</tr>
<tr>
<td>1300</td>
<td>0.97</td>
<td>0.99</td>
<td>0.90</td>
<td>0.99</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>1400</td>
<td>0.98</td>
<td>1.00</td>
<td>0.95</td>
<td>1.00</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td>1500</td>
<td>0.99</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>1600</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

no. of obs. 110 344 127 365 27 92

| J          | 0.110        | 0.110        | 0.170        |
| J(crt)     | 0.149        | 0.140        | 0.298        |
Figure 53: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (3 to 2) AT THE HARBOR SITE (HIGH VOLUME)
Figure 54: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 3) AT THE HARBOR SITE (HIGH VOLUME)
Figure 55: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 1) AT THE HARBOR SITE (HIGH VOLUME)
Table 19

COMPARISON OF SIMULATED VS. OBSERVED Merging Point Distributions At the Baltimore Site (High Volume)

<table>
<thead>
<tr>
<th>MERGING POINT</th>
<th>lane 3-2</th>
<th>lane 2-3</th>
<th>lane 2-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBS.</td>
<td>SIM.</td>
<td>OBS.</td>
</tr>
<tr>
<td>100</td>
<td>0.28</td>
<td>0.34</td>
<td>0.43</td>
</tr>
<tr>
<td>200</td>
<td>0.60</td>
<td>0.52</td>
<td>0.69</td>
</tr>
<tr>
<td>300</td>
<td>0.78</td>
<td>0.72</td>
<td>0.90</td>
</tr>
<tr>
<td>400</td>
<td>0.87</td>
<td>0.88</td>
<td>0.97</td>
</tr>
<tr>
<td>500</td>
<td>0.92</td>
<td>0.94</td>
<td>0.99</td>
</tr>
<tr>
<td>600</td>
<td>1.00</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>700</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>no. of obs.</td>
<td>60</td>
<td>191</td>
<td>72</td>
</tr>
</tbody>
</table>

\[ \begin{array}{c}
J \\
J(\text{ort})
\end{array} \begin{array}{ccc}
0.080 & 0.140 & 0.180 \\
0.201 & 0.183 & 0.472
\end{array} \]

At high level of traffic volume the performance of the model in reproducing the merging point distribution was quite satisfactory. Lane-changings performed from lane 2 to lane 1 are non-essential lane-changings. The simulated merging point distributions for non-essential lane-changings did also coincide with the field data. This verifies the effectiveness of the calibrated Probability of Lane-changing (PLC) used in WEAVSIM.

At medium flow rate, however, it was found that the simulated merging points did not coincide with the ones derived from the field data. One possible explanation for this is the fact that the exact position of the lane changes greatly depends on the local geometrics, signing, and traffic characteristics which can't be introduced into the
Figure 56: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (3 to 2) AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 57: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 3) AT THE BALTIMORE SITE (HIGH VOLUME)
Figure 58: COMPARISON OF SIMULATED VS. OBSERVED MERGING-POINT DISTRIBUTIONS FOR LANE (2 to 1) AT THE BALTIMORE SITE (HIGH VOLUME)
simulation model. In general, in the simulation model vehicles will accept the very first acceptable gap regardless of the size of other gaps in their vicinity. This does not seem to be the case in the real world in which vehicles evaluate various gaps simultaneously, especially at low-to-medium traffic flow.

In general, the performance of the model exceeded expectations and suggests that the simulation model replicates the observed lane-changing behavior in a satisfactory manner.

**6.2.7 VEHICLE TRAJECTORIES**

For comparison of trajectories WEAVSIM was run for 600 seconds and time-space trajectories were plotted for the last 100 seconds. The inputs were adjusted to represent the condition presented in the empirical data. Figures (59)-(64) show the trajectories for each lane for both WEAVSIM and field data. The performance of the model seems realistic.

To test the model behavior at extreme traffic conditions, an artificial disturbance was introduced by applying a deceleration of -18 fts/s (maximum emergency deceleration rate) to a leader vehicle for a period of 40 seconds. Figures (65)-(68) show the vehicle trajectory plot for this situation. The introduction of this disturbance and the recovery behavior of the following vehicles is clearly seen in these graphs. This indicates that the model performs satisfactorily even under extreme traffic conditions that are not normally anticipated.
Figure 59: VEHICLE TRAJECTORIES FOR LANE (1) OBTAINED FROM FIELD DATA
Figure 60: VEHICLE Trajectories for Lane (1) Obtained from WEAVSIM
Figure 61: VEHICLE TRAJECTORIES FOR LANE (2) OBTAINED FROM FIELD DATA
Figure 62: VEHICLE TRAJECTORIES FOR LANE (2) OBTAINED FROM WEAVSIM
Figure 63: VEHICLE TRAJECTORIES FOR LANE (3) OBTAINED FROM FIELD DATA
Figure 64: VEHICLE TRAJECTORIES FOR LANE (3) OBTAINED FROM WEAVSIM
Figure 65: VEHICLE TRAJECTORIES FOR EXTREME TRAFFIC CONDITIONS
Figure 66: VEHICLE TRAJECTORIES FOR SPEED DISTURBANCE CONDITIONS
Figure 67: PLATOON BEHAVIOR TO A SPEED DISTURBANCE
Figure 68: ACCELERATION CHANGES DURING A SPEED DISTURBANCE
CHAPTER VII
SIMULATION EXPERIMENTS

One of the objectives of this research, as stated in chapter 1, was demonstration of some simulation experiments. The objective of the simulation experiment selected for this study is to investigate the impact of upstream traffic flow conditions on the operational characteristics within the weaving sections. To justify the need for this particular study, a brief description of the problem statement seems appropriate.

7.1 PROBLEM STATEMENT
Weaving sections are formed where an on-ramp is followed by an off-ramp with a continuous auxiliary lane between the ramps, or where two highways join at a merge point and separate at a diverge point. The first one is referred to as Ramp-Weave and the second one is called Major Weaving sections.

When Major Weaving sections have a crown line which connects the nose of the entrance gore area to the nose of the exit gore area they are categorized, in the new Highway Capacity Manual, under same catagory (type A) as Ramp-Weaves. The same analysis and design procedures are, consequently, applied to these two types of weaving sections.
Although type A Major Weaving sections and Ramp-Weaves are similar in geometry (both have crown line), their operating conditions are quite different. In the Ramp-Weave sections, the speed of ramp vehicles is influenced by the restrictions on the ramp geometrics. The speed of these vehicles is usually significantly lower than that of the freeway vehicles. To facilitate weaving maneuvers On-ramp vehicles must, therefore, accelerate to reach a desired speed compatible with that of the freeway vehicles. Similarly, the off-ramp vehicles must decelerate to the design speed of the off-ramp. These speed adjustments create a high level of turbulence within the Ramp-Weave sections. In Major Weaving sections, on the other hand, the design of the entry and the exit legs are more compatible with the design of the freeway mainline. Therefore, the speed on entry and exit legs is usually very close to that of the mainline, requiring fewer speed adjustments for weaving vehicles.

In general, a major difference between these two types of weaving sections is in their upstream operational conditions which significantly influences the operations within the weaving section.

Let us define arrival speed as the speed at which vehicles enter the weaving section. Since this speed is restrained by the operating characteristics of the traffic stream just before the weaving section, it is a good indicator of the operational conditions upstream of the weaving sections. In type A major weaving sections, where arrival speeds of the two merging traffic streams are somewhat compatible, weaving maneuvers are easily performed and usually a level of service compatible to that of the mainline freeway is observed. In Ramp-Weave sections, on the other hand, ramp vehicles enter the weaving section at a speed much lower than that of the freeway vehicles. This speed difference adversely effects operations within the weaving section, resulting in a level of service lower than that of the major weaving sections.
In summary, assuming all factors being constant, the level of service (speed) should be lower in Ramp-Weaves than in Major Weaving sections. This, in major part, is due to the difference in operational conditions upstream of these two types of weaving sections. This, even though recognized in the new HCM, has by no means been reflected in the procedures provided for analysis and design of the weaving sections. This is mainly due to lack of information concerning the impact of upstream conditions on the operations within such sites. WEAVSIM provides the means of obtaining such information.

In WEAVSIM, the upstream conditions can be easily varied by controlling the arrival speed of vehicles in each lane. Information on the effect of arrival speed on various factors controlling the operations within the weaving sections can, therefore, be obtained. This information would, subsequently, provide an excellent basis for development of new procedures or modification of current procedures for design and analysis of weaving sections. In the following sections an attempt will be made to assess the impact of upstream conditions, arrival speed in particular, on the operational conditions within weaving sections.

7.2 STUDY PROCEDURE

The stochastic nature of any simulation model causes the results of simulation to fluctuate as the simulation proceeds. Therefore, to obtain any meaningful statistical information about the true value of the response variables, the simulation model must be either run for a long period of time or replicated many times. In other words, to achieve a specified level of confidence, the variance of the response variable should be minimized. Several methods have been developed for reduction of the variance of the response variables; they are usually referred to as variance reduction techniques. An
application of two of these techniques (Antithetic Variates and Common Random Numbers) in traffic simulation modeling has been demonstrated by Rathi (1983).

In this study, for reduction of the variance the batch means method was selected over the replication of several independent runs. Batch means reduces the high cost of the computer resources and the time required to run each individual simulation run, especially in a study with large number of experiments. The batch means method batches the observations and assumes independence among the means of various batches. Each simulation experiment was run for a period of 45 minutes plus a 200 sec. warmup period. At the start of each 15 minute period all statistics collected on the response variables were set to zero. This provided 3 different values for each response variable for each of the combinations.

To achieve the objective of this study a set of four (4) dependent variables, which are indicators of the operational conditions, and five (5) independent variables, which control the operation through weaving sections, have been selected. This formed 243 various combinations and since from each combination three (3) independent set of outputs are obtained, a total of 729 values for each one of the response variables were obtained. Finally the outputs were subjected to a multiple regression analysis involving the first and second order parameters, as well as the one-way interactions.

The following multiple regression analysis was applied to the outputs of the simulation runs:

\[
MOP = \beta_0 + \sum_{i=1}^{5} \beta_i x_i + \sum_{i=1}^{4} \sum_{j=i+1}^{5} \beta_{ij} x_i x_j + \sum_{i=1}^{5} \alpha_i x_i^2
\]
MOP = Predicted Measure of Performance
\( \beta_0, \beta_1, \beta_{ij} \) = Estimates of the Constants
\( X_i, X_j \) = Input Parameters

A stepwise regression approach was deployed in order to evolve the best fitting model for each individual measure of performance. In this approach one independent variable is added to the model at each step of analysis, with the constant and the partial regression coefficients, as well as the standard error of estimate being recalculated at each step. Independent variables enter the model based on their degree of association with the dependent variable.

What follows is a description of assumptions, input parameters, and the response variables.

7.3 TRAFFIC STREAM PARAMETERS

Available analysis and design techniques developed for weaving sections, including the one presented in the new HCM, in one way or another, reflect the effect of the weaving section length and weaving and non-weaving flow on the operation conditions at these sections. Here, for the first time an attempt is made to include a new variable, which reflects the effect of the upstream conditions on the operational conditions at weaving sections. This variable, as discussed earlier, is the difference between arrival speeds of mainline freeway and ramp vehicles. For this study the following parameters have been selected:

\[ L = \text{Weaving Section Length (ft.)} \]

\[ \text{MJRVOL} = \text{Mainline (Major Entrance) Total Volume (vph)} \]

\[ \text{MINVOL} = \text{Ramp (Minor Entrance) Volume (vph)} \]
RATIO = Proportion of Weaving Vehicles to Total volume

SPDDIF = Difference in Arrival Speeds of Mainline and ramp

To determine the effect of each of the above parameters on the response variables the following levels were selected:

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>800, 1400, 2000</td>
</tr>
<tr>
<td>MJRVOL</td>
<td>2000, 3000, 4000</td>
</tr>
<tr>
<td>MINVOL</td>
<td>800, 1200, 1600</td>
</tr>
<tr>
<td>RATIO</td>
<td>0.3, 0.4, 0.5</td>
</tr>
<tr>
<td>SPDDIF</td>
<td>0, 10, 20</td>
</tr>
</tbody>
</table>

The study involves 243 experiments. It needs to be mentioned here that to develop any reliable model of this kind a more concise selection of factor levels is required.

Throughout the experiments the following input parameters and distributions were kept constant:

1. Simulation time was 2700 seconds plus a warmup period of 200 seconds.
2. Vehicle interarrival times were generated from a shifted negative exponential distribution based on traffic volume.
3. Vehicles maximum speed were generated from a truncated normal distribution with mean of 55, 50, and 45 mph, from the outer lane to the ramp lane respectively, and variance of 10 mph.
4. The distribution of the brake reaction times followed a gamma distribution with mean and variance of 0.745 and 0.073 seconds, respectively. The generated values were truncated at .25 and 1.5 seconds.
5. The maximum emergency deceleration rate for all drivers was 18.0 ftpss.
6. Distribution of weaving vehicles in the major approach, upon entrance to the weaving section, are 6.6 and 93.4% for the far left lane and the middle lane, respectively. This means that 6.6% (93.4%) of the total major approach weaving volume is from the far left (middle) lane. This is based on the results of the study done by Fazio (1985) on the data collected at five sites.

7.4 RESPONSE VARIABLES

Speed and delay are generally used to indicate the operational conditions at any traffic facility. No empirical or theoretical model has yet been developed to estimate the delay at weaving sections. Consequently, speed has been the sole indicator of the operational conditions at these sites. As indicated in chapter IV, several measures of performance are obtained as outputs from the WEAVSIM model. WEAVSIM computes average delay for weaving and non-weaving vehicles as the difference between actual travel time through the section and minimum travel time at the desired speed. It also provides average running speed for weaving and non-weaving vehicles. Weaving and non-weaving speeds and delays have been selected as measures of performance for this study.

In the following sections each model is investigated separately.

7.4.1 WEAVING SPEED MODEL

Table (20) shows the regression model for weaving speed. In this model the dominant factor was the interaction of the freeway and ramp volumes, which explained 55% of the observed variation in the response variable. The effect of weaving section length and proportion of weaving vehicles in total volume, as well as the difference in arrival speeds of freeway and ramp vehicles was also pronounced. Included in
The weaving speeds computed for a ramp weave section based on the data given in example (3) in chapter (4) of the new HCM. The speeds are computed for various values of SPDDIF. The effect of this parameter on weaving speed is clearly seen from these values.

Table 20

REGRESSION MODEL FOR WEAVING SPEED

\[
SPDW = 49.796 + 6.081 \times 10^{-3} \cdot (WVL) - 0.226 \cdot (SPDDIF) - 4.734 \times 10^{-3} \cdot (MINVOL) - 29.213 \cdot (RATIO)^2 \\
- 2.552 \times 10^{-4} \cdot (SPDDIF) \cdot (MJRVOL) - 3.15 \times 10^{-6} \cdot (MJRVOL) \cdot (MINVOL)
\]

When:  
\begin{align*}
WVL &= 1000 \text{ ft.} \\
MINVOL &= 794 \text{ vph} \\
MJRVOL &= 2483 \text{ vph} \\
RATIO &= 0.55
\end{align*}

Then:  
\begin{align*}
\text{If } SPDDIF = 0 & \quad SPDW = 36.68 \text{ mph} \\
\text{If } SPDDIF = 10 & \quad SPDW = 32.39 \text{ mph} \\
\text{If } SPDDIF = 20 & \quad SPDW = 28.11 \text{ mph}
\end{align*}

Weaving speed computed in HCM for this particular example is 34.5 mph. As indicated in the HCM, this value overestimates the actual operation of the weaving section.

"...the VR of .55 exceeds the maximum recommended value of .45 for a three lane type A section. Thus, it might be expected that operations will be somewhat worse than those indicated by speed predictions.

Highway Capacity Manual (1985)"
This overestimation of speed by HCM procedure could be due to the fact that the effect of upstream condition, arrival speed in particular, has been ignored. As evidenced in table (20), a speed of 32.39 mph, with assumption of 10 mph for SPDDIF, is a better indicator of the actual operational conditions within this particular section.

7.4.2 NON-WEAVING SPEED

Table (21) shows the regression model for non-weaving speed. The dominant factors are the interaction of freeway and ramp volumes, as well as the proportion of weaving vehicles in total volume. The effect of difference in arrival speeds of freeway and ramp vehicles was less pronounced for non-weaving speed than it was for weaving speed. This could be explained by the fact that most of the non-weaving vehicles are in the far left lane and are least affected by any speed variation between the ramp lane and the middle lane vehicles.

Values of non-weaving speeds calculated for a ramp weave section with various values for SPDDIF are given in table (21).
Table 21

REGRESSION MODEL FOR NON-WEAVING SPEED

\[ SPDNW = 52.646 + 4.50 \times 10^{-3} (WVL) - 2.37 \times 10^{-2} (SPDDIF)^2 - 5.784 \times 10^{-4} (MINVOL)(RATIO) - \\
1.37 \times 10^{-6} (WVL)(MINVOL) - 3.71 \times 10^{-6} (MJRVL)(MINVOL) \]

When:
- \( WVL = 1000 \text{ ft.} \)
- \( MINVOL = 794 \text{ vph} \)
- \( MJRVL = 2483 \text{ vph} \)
- \( RATIO = 0.55 \)

Then:
- If \( SPDDIF = 0 \), \( SPDNW = 40.86 \text{ mph} \)
- If \( SPDDIF = 10 \), \( SPDNW = 38.49 \text{ mph} \)
- If \( SPDDIF = 20 \), \( SPDNW = 36.12 \text{ mph} \)
- From \( \text{HCM} \), \( SPDNW = 42.00 \text{ mph} \)

7.4.3 DELAY MODELS

Regression models developed for weaving and non-weaving delays are shown in table (22). Again the dominant factor for both weaving and non-weaving delays is the interaction of freeway and ramp volumes. To show the effect of \( SPDDIF \) on the predicted delays, Table (22) includes values of delays computed for various values of \( SPDDIF \). It is clearly seen, from this table, that as the \( SPDDIF \) has direct impact on both weaving and non-weaving delays. An interesting founding is, however, that the effect of \( SPDDIF \) is more pronounced for weaving vehicles than it is for non-weaving vehicles.
Table 22

**REGRESSION MODEL FOR WEAVING AND NON-WEAVING DELAYS**

\[ WVDEL = 11.55 - 4.58 \times 10^{-3} \times WVL + 1.662 \times 10^{-2} \times (SPDDIF)^2 + 1.664 \times 10^{-2} \times (MINVOL) \times (RATIO) + 3.331 \times 10^{-4} \times (SPDDIF) \times (MINVOL) + 7.94 \times 10^{-6} \times (MJRVOL) \times (MINVOL) \]

When:  
\[ WVL = 1000 \text{ ft.} \]  
\[ MINVOL = 794 \text{ vph} \]  
\[ MJRVOL = 2483 \text{ vph} \]  
\[ RATIO = 0.55 \]

Then:  
\[ \text{If SPDDIF} = 0 \quad WVDEL = 24.89 \text{ sec./mile} \]  
\[ \text{If SPDDIF} = 10 \quad WVDEL = 29.19 \text{ sec./mile} \]  
\[ \text{If SPDDIF} = 20 \quad WVDEL = 34.18 \text{ sec./mile} \]

\[ NWDEL = -6.33 - 5.31 \times 10^{-3} \times WVL + 24.524 \times (RATIO) + 2.851 \times 10^{-4} \times (SPDDIF) \times (MINVOL) + 8.10 \times 10^{-6} \times (MJRVOL) \times (MINVOL) \]

When:  
\[ WVL = 1000 \text{ ft.} \]  
\[ MINVOL = 794 \text{ vph} \]  
\[ MJRVOL = 2483 \text{ vph} \]  
\[ RATIO = 0.55 \]

Then:  
\[ \text{If SPDDIF} = 0 \quad NWDEL = 17.82 \text{ sec./mile} \]  
\[ \text{If SPDDIF} = 10 \quad NWDEL = 20.08 \text{ sec./mile} \]  
\[ \text{If SPDDIF} = 20 \quad NWDEL = 22.35 \text{ sec./mile} \]
7.5 STUDY CONCLUSIONS

As was indicated earlier, the intent of this study was not development of a new analysis and design procedures for weaving sections, but it was to assess the effect of arrival speed on the response variables describing the operational conditions of the weaving sections. This study was carried out for a three lane type A weaving section and the conclusions drawn hereafter are for this type of weaving sections subject to the aforementioned assumptions. Nevertheless, similar studies can be done for various types of weaving sections and more general conclusions could, therefore, be obtained.

Regression models evolved from this study reveal the fact that arrival speed has direct impact on the speeds and delays computed at weaving sections. This impact is more pronounced for weaving traffic than it is for non-weaving traffic. As discussed earlier, arrival speed is an indicator of the operational conditions upstream of the weaving sections. Therefore, it can be concluded, as the result of this study, that upstream operational conditions directly influence the operational conditions at weaving sections.

Conclusions drawn from this study suggest modifications of the current procedures as to inclusion of a factor reflecting the effect of upstream conditions. This could improve the effectiveness of these models in prediction of the factors representing the actual operational conditions at weaving sections. Also in development of any new procedure for design and analysis of these complicated traffic facilities attention should be devoted to the upstream conditions, as well as the conditions within the weaving sections.
CHAPTER VIII
SUMMARY AND CONCLUSIONS

8.1 PROBLEM STATEMENT
Weaving sections represent the physical space along a freeway where two or more traffic streams traveling in the same general direction cross each other. As drivers must access lanes appropriate to their desired destinations, excessive number of lane-changing maneuvers are required in these sections. This often results in traffic congestion deteriorating the traffic conditions within the weaving sections and, consequently, limiting the capacity of the freeway. Thus, weaving sections have been recognized as one of the most critical elements of the freeway requiring individual attention in design and operation. A study of the dynamics of weaving traffic is, therefore, of particular interest in both design and analysis of freeways.

The original Highway Capacity Manual, published in 1950, provides one of the earliest procedures for the operational analysis and design of weaving sections. Since then several macroscopic models have been developed to assist engineers in design and analysis of these sections. These procedures, which are essentially based on empirical analysis of field data, provide some basic information regarding the relations between geometric features of weaving and some traffic characteristics parameters. A literature review of these models reveals the fact that in development of these models one of the most critical problems researchers had to deal with was the availability of pertinent and reliable data. Perhaps the best articulation of this problem was found in a study by Bullen (1982).
"The potential exists for research to obtain a more detailed understanding of merging and weaving behavior."
(Bullen, 1982)

Bullen further adds that:

"The amount of field data available is much less than that required to fully calibrate and validate the macro methods in more detail."

Therefore, development of concepts and equations were based on rather limited data and guidelines were developed mostly based on existing knowledge and experiments.

8.2 MOTIVATION
In recognition of the need for a more detailed understanding of the weaving behavior, a series of data sets on microscopic vehicular movements through weaving sections were collected for Federal Highway Administration (Smith, 1985). The data is perhaps the richest source of its type that has been developed to date and is expected to be useful in enhancing freeway simulation models, as well as in direct empirical research.

The desire to study the traffic operational characteristics of freeway weaving sections complimented with the availability of the above mentioned data, has established the motivation for this research.

8.3 APPROACH
Computer simulation has been applied effectively in development of new concepts and designs in traffic management. Simulation allows the traffic engineer to investigate traffic situations which are difficult to analyze either directly or indirectly. The
great appeal of simulation modeling is that it can provide an indication as to the important variables that control the smooth and efficient movement of traffic, as well as the relationship between the variables, possibly leading to analytic solutions. While several simulation models have been developed for study of ramp flow, merging capacity and lane closures; no attempt has yet been made to develop a detailed model of the dynamics of traffic flow at weaving sections. Development of a systematic, well-designed simulation model is the most effective method of studying the time varying, complex, and stochastic process of traffic flow through weaving sections. It provides the highest level of detail and accuracy of available analysis techniques.

It was, therefore, the intent of this study to develop a realistic and reliable microscopic simulation model (WEAVSIM) which provides the means for study of dynamics of traffic flow at weaving sections.

8.4 SIMULATION MODEL

WEAVSIM is written in SIMSCRIPT II.5 simulation programming language. SIMSCRIPT II.5 is a free-format, english-like language which is readable and understandable even for a nonprogrammer who is primarily interested in the system under study and not necessarily in the computer programming. WEAVSIM is thoroughly commented for easy understanding of the logic and its computer time requirements are reasonable when compared to other traffic simulation models.

In WEAVSIM, vehicles are generated randomly at the system entry points. 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 system is a three lane type A weaving section. The model is
based on a rational description of the behavior of the vehicles in the system. At
each one second of real time all vehicles are processed through the system using a
car-following algorithm, which updates their longitudinal movements, and a lane-
changing algorithm, which controls their lateral movements. Results from analysis of
the data provided by FHWA, as well as the results from various human factor
studies have been utilized in the development of the logic for car-following and
lane-changing algorithms. The car-following algorithm of WEAVSIM prescribes the
behavioral response mechanism of individual vehicles. It is considered as the heart of
the microscopic simulation process and it determines the distance a vehicle will
advance during any time interval. All vehicles are advanced through the system in
accordance with their desired speeds and destinations inhibited by the immediate traf­
fic and control environment. The lane-changing algorithm moves vehicles from one
lane to another by first establishing a desire for such a move and then accepting a
suitable gap in the adjacent lane. The lane-changing logic of WEAVSIM has been
carefully tailored to represent the lane-changing behavior of traffic in weaving areas.

The model input includes some traffic characteristics and simulation parameters,
as well as roadway parameters describing the geometry of the simulated section. The
standard output of the model includes an echo of the input parameters and statistics
on measures of performance describing the operational conditions of the weaving sec­
tion. A set of statistics on measures of performance collected at user specified time
intervals, as well as a graphical presentation of these statistics are the optional out­
puts of the model.
The reliability aspect of WEAVSIM is addressed through a sensitivity analysis of measures of effectiveness to exogeneous (input) variables and a comprehensive validation procedure using the data provided by FHWA. Following sections provides a brief description of the sensitivity analysis and validation studies.

8.4.1 SENSITIVITY ANALYSIS

To ascertain the realism of the simulation results and establish confidence in its validity it was necessary to determine that reasonable changes in models input do not lead to unreasonable changes in the model's performance. Therefore, a set of input variables were subject to sensitivity analysis. These variables include: maximum emergency deceleration rate, safety distance, brake reaction time, probability of non-essential lane-changing and traffic composition. The response variables used in the sensitivity analysis include: lane mean headway, average running weaving and non-weaving speeds, and average weaving and non-weaving delays. Simulation runs were made for various levels of input variables. Results of the sensitivity analysis indicated that the measures of performance were not appreciably affected by maximum emergency deceleration rate and the probability of non-essential lane-changing. However, the measures of performance were found to be sensitive to changes in brake reaction time, traffic composition, and the safety distance. Reasonable values were, therefore, developed for the sensitive parameters using a calibration process of the model with field data.

8.4.2 VALIDATION

After writing and debugging the computer program, it is imperative to test the validity of the model for reasonable predictions of the behavior of the system being simulated. This would in return increase the creditability of the model and, conse-
quently, expand its applicability as a useful tool. Validation of WEAVSIM involves comparison of the simulated observations with observations obtained from two sets of field data provided by FHWA. The Kolmogrov- Smirnov distribution free test was used for comparison of the simulated with observed distributions of the target variables. The paired t-test was conducted to compare mean values of the observed and simulated headways. The validation results reveal that in general no significant difference in mean values or distributions is detected at either site. The performance of the model in reproducing speed distributions, for both weaving and non-weaving traffic, was quite satisfactory. The accepted gaps and merging points distributions, although not exactly reproduced, were structurally as good as expected.

In addition to the comparison of the simulated observations with field data, model behavior was tested at extreme traffic conditions. This was done by introduction of an artificial disturbance to the leader of a platoon and observing the recovery behavior of the following vehicles. Results of this test indicates that the model performs satisfactorily even under extreme traffic conditions that are not normally anticipated.

Overall, the validation results indicate that the simulation model adequately describes driver behavior observed at two different weaving sites.

Now that the validity of the model has been positively tested, and some confidence has been established in its capability of accurately reproducing behavior of the real system, one of its applications in development of new concepts and designs in traffic management will be presented in the following sections.
8.5 SIMULATION STUDY

One of the objectives of this research was model implementation by demonstration of some simulation experiments. WEAVSIM was used to investigate the impact of upstream traffic flow conditions on the operational characteristics within the weaving sections.

Available analysis and design techniques developed for weaving sections, in one way or another, reflect the effect of the weaving section length and weaving and non-weaving flow on the operational conditions at these sites. The impact of upstream conditions, even though recognized by HCM, has not been reflected in any of the current procedures. This is due mainly to lack of information concerning the influence of the upstream traffic conditions on operations of weaving section. WEAVSIM is capable of providing such information.

Arrival speed of vehicles, which is the speed just before entering the weaving section, is constrained by the operational characteristics of the traffic flow upstream of the weaving section. This variable is, therefore, a good indicator of the upstream operational conditions. In WEAVSIM, the upstream conditions can be easily varied by controlling the arrival speed of vehicles in each lane. Information on the effect of arrival speed on various factors controlling the operations within the weaving sections can then be obtained. This information would, consequently, provide an excellent basis for development of new procedures or modification of current procedures for design and analysis of weaving sections.

A set of four (4) dependent variables, which are indicators of the operational conditions, and five (5) independent variables, which control the operation through weaving sections, have been selected for this study. The dependent variables are:
weaving and non-weaving speeds and delays. The independent variables are: weaving section length, mainline volume, ramp volume, proportion of weaving vehicles to total volume, and difference in arrival speeds of mainline and ramp vehicles. Three levels of each variable were selected for this study. Using various combinations of the independent variables a total of 243 experiments were performed. Each simulation experiment was run for a period of 45 minutes plus a warmup period of 200 seconds. Using batch means with batches of size 15 minutes, three approximately independent sets of outputs were obtained from each experiments. These outputs were then subjected to a multiple regression analysis involving first and second order parameters, as well as the one-way interactions. Finally a stepwise regression approach was deployed to evolve the best fitting model for each individual measure of performance. As was expected the dominant factor affecting both weaving and non-weaving speeds was the interaction of the freeway and ramp volumes, which explained over 50% of the variation in the response variables. The effect of the difference in arrival speeds of freeway and ramp vehicles was evidenced by computing the weaving and non-weaving speeds for various values of this parameter using the regression models. Results indicate a direct impact of this parameter on speeds, with a more pronounced effect on weaving traffic than on non-weaving traffic. Delay models developed for weaving and non-weaving traffic reveal practically the same results obtained from speed models.

8.5.1 CONCLUSIONS
The intent of this study was not the development of new freeway weaving sections design procedures, but to develop a tool (WEAVSIM) which provides the means for such endeavour. Therefore, a microscopic simulation model of traffic operations through freeway weaving sections has been developed, successfully validated, and
implemented. The model allows simulation of traffic through a three lane weaving section of practically any length at various traffic compositions. It gives various measures of performances and provides the means for a detailed analysis and design of weaving sections.

The model was applied in the study of the effect of upstream conditions (represented by arrival speed) on the operations within weaving sections. Results of the simulation experiments revealed that the difference in the arrival speeds of the two merging streams determines to a large degree the speeds and delays at weaving sections. This suggests that the inclusion of a factor reflecting the upstream conditions could improve the effectiveness of these procedures in the prediction of the operational conditions at weaving sections.

This study was carried out for a three lane Type A weaving section. Similar studies can be carried out for other types of weaving sections and more general information regarding the behavior of traffic flow through these complex facilities could be obtained.
BIBLIOGRAPHY


38. JHK and Associates, 1984, "Documentation For Freeway Traffic Data Bases." Data Gathered for FHWA.


55. Paul. J. "Lane Change Frequencies in Freeway Traffic Flow", Highway Research Record 409 PP. 17-25


59. Rath, A.K., "Development of a Microscopic Simulation Model For Freeway Lane Closure." Ph.D Dissertation, The Ohio State University, Columbus, Ohio, 1983.


APPENDIX A : LISTING OF THE COMPUTER PROGRAM

```
// JOB
// TIME=(4,40),REGIST=1024K
// JOBPARAM LINES=16000,DISKID=26000,V=5
// SINC EXEC SIMCG, TIME=(3),
// PARX CHP='LOAD,ID,TRACE2,MOTERM,NOCHK,REH=NEW,GLOBAL',TIME.GO=(3)
// SYSPRINT DD DUMMY
// CHP SYSIBM DD
PREAMBLE

THE PREAMBLE IS PURELY DECLARATIVE IN NATURE
AND DOES NOT CONTAIN ANY EXECUTABLE STATEMENT.
IT GIVES A STATIC DESCRIPTION OF THE SYSTEM BY
DEFINING ALL ENTITIES, THEIR ATTRIBUTES, AND
THE SETS TO WHICH THEY MAY BELONG. IN PREAMBLE
THE COMPUTATIONAL MODES AND GLOBAL VARIABLES
ARE DEFINED ALONG WITH A LIST OF THE STATISTICS
WHICH ARE TO BE COLLECTED ON CERTAIN VARIABLES.

TEMPORARY ENTITIES  'VEHICLE ATTRIBUTES

EVERY VEHICLE HAS A D SPEED, A MOV STATUS, AN ARR TIME, A BRANT,
A CURRENT LANE, A DESTINATION, A W ARR T, A W EXT T, AN ADJUST,
A LENGTH, A S AFTER, A S BEFORE, A STATUS, A T L C, AN ID, A NEW L H,
A P AFTER, A P BEFORE, AN ACCELERATION, A NO L CH, A HEAD WY,
AN ORIGIN, A TYPE, A S D,

MAY BELONG TO A LN
MAY BELONG TO A W

PERMANENT ENTITIES

EVERY LANE OWNS A LN
EVERY W E A V OWNS A W

218 -
EVENT NOTICES INCLUDE PRE.PROCESS,L.CHANGE.LIST.INPUT,STAT.Collect,
RESTART,RESULT AND INITIALIZATION.BIAS

EVERY ARRIVAL HAS A LA
EVERY PROCESS HAS A LA

PRIORITY ORDER IS LIST.INPUT, ARRIVAL, PRE.PROCESS, PROCESS,L.CHANGE,
STAT.Collect,RESULT

BREAK ARRIVAL TIES BY LOW LA
BREAK PROCESS TIES BY LOW LA

DEFINE TYPE,STATUS,TRUCK,PASGR,TRAILER,ON,OFF,YES,NO,ATT,INT.OUTPUT,
HG.DIST,GP.DIST,SPEED.DIST,HVY.DIST,WEAVE,ADJUST,FASTER,O.K,
GP.GRAPH, Y.SPD.GRAPH, w.SPD.DIST,HVY.GRAPH, TRAJ.DATA,
SLOWER, NON.WEAVE, W.LOS,HWY.LOS,A,B,C,D,E,F AS TEXT VARIABLES

DEFINE SIM.TIME, SIM.LENGTH,WW.LENGTH, B.MEAN, B.PARMA, AFD, PFD, VFD,
BR, UP.TLC, PLC, VED, PROTRUCK, PROTRAILER, SPD1, SPD2, SPD3,
H1.2MGPT, H2.1MGPT, H3.2MGPT, TRAVEL.TIME, DELAY.IGN,
INPUT.SPD, DLY.LCH, HDWY1, HDWY2, HDWY3, HVY.SPD, NON.HV.SPD,
DEIS1, DEIS2, DEIS3, C.GAP, P.DESTROY, SPEED, AR.SIGMA,
ARR1.SPD, ARR2.SPD, ARR3.SPD, M.AR.SPD, UP.AR.SPD, LOW.AR.SPD,
GAP1, GAP2, GAP3, B.BUFFER.L, E.BUFFER.L, V.TIME, INV.TIME,
V.R.C.F, 1.2MGPT, 2.1MGPT, 2.3MGPT, 3.2MGPT, INTERVAL,
ARR.TIME, T.B.TRAJ, T.E.TRAJ, V.A.V.UP AS REAL VARIABLES

DEFINE DESTINATION, ORIGIN, CURRENT.LANE,LENGTH,T.L.C,ID,MV STATUS,
FAIL.WW, NW.LU, NO.ACCIDENT, KM, NO LCH, N.E.L.C, N.INT,
SEARCH, TOT.VOL, WW.VOLUME, L.PASGR,L.TRAILER,L.TRUCK,HUBER,
L.C.VOLUME, T.EXIT.VOL, T.EXIT.VOL, 1.2LC.HG, 2.3LC.HG, 3.2LC.HG,
2.1LC.HG, TOT.WV, LA, LAH AS INTEGER VARIABLES

DEFINE I.LCH.AV.D, I.W.AV.SPD, I.W.W.AV.SPD, I.W.V.SD.SPD, I.N.S.D.SPD,
I.W.MX.SPD, I.MAX.MV.SPD, I.N.AV.D, I.SUM.LCH.D, I.R.TOT.D,
I.LH.SD.D, I.R.MX.D, SUM.VOL, SUM.CUR.VOL, I.T.EXIT, SUM.LC,
I.LC.MX.D, I.AV.TRAT, I.TOT.TRAT, I.SD.TRAT, I.NO.SD.D, VL,
IDV, M.MX.SPD, M.X.SIGMA, PRVEAV, UP.MX.SPD, LOW.MX.SPD,
WV.FACT, I.MX.TRAT, M.S.F, LST.UDP AS 1-DIM VARIABLES

DEFINE S.M.SPD, DENSITY, IN.VOL, NOW.VOL, OUT.VOL, LCH.FR, LCH.TO,
I.AVHDWY AS 2-DIM VARIABLES

DEFINE REJ.VEH, REJ.LCH, EXIT.VOL, ENT.VOL AS 1-DIM INTEGER VARIABLES

DEFINE CONF.DECEL, MAX.ACCEL, CRITICAL.GAP AS REAL FUNCTIONS
DEFINE FINAL.CHECK, SAFE, INESSENTIAL.LC, LD.CHECK, LG.CHECK, 
LD SPD.ADJ, LG SPD.ADJ AS INTEGER FUNCTIONS

DEFINE LN, VV AS A SET RANKED BY HIGH P AFTER
DEFINE SECONDS TO MEAN UNITS
DEFINE OKAY TO MEAN 1
DEFINE NOT OKAY TO MEAN 0
DEFINE S.PROGRAM TO MEAN ROUTINE

' MERGING-POINT STATISTICS
' ===============
TALLY MG1.2 (600 TO 2000 BY 100) AS THE HISTOGRAM, AVG1.2 AS THE MEAN, SDMG1.2 AS THE STD.DEV, NMG1.2 AS THE NUMBER OF MG1.2MGPT
TALLY MG2.1 (600 TO 2000 BY 100) AS THE HISTOGRAM, AVG2.1 AS THE MEAN, SDMG2.1 AS THE STD.DEV, NMG2.1 AS THE NUMBER OF MG2.1MGPT
TALLY MG2.3 (600 TO 2000 BY 100) AS THE HISTOGRAM, AVG2.3 AS THE MEAN, SDMG2.3 AS THE STD.DEV, NMG2.3 AS THE NUMBER OF MG2.3MGPT
TALLY MG3.2 (600 TO 2000 BY 100) AS THE HISTOGRAM, AVG3.2 AS THE MEAN, SDMG3.2 AS THE STD.DEV, NMG3.2 AS THE NUMBER OF MG3.2MGPT
TALLY AV32.MGPT AS THE AVERAGE, SD32.MGPT AS THE STD.DEV, MIN32.MGPT AS THE MINIMUM, MAX32.MGPT AS THE MAXIMUM, N32.MGPT AS THE NUMBER OF 3.2MGPT

' DELAY STATISTICS
' ===============
TALLY AV.DEL.LCH AS THE MEAN, MAX.DEL.LCH AS THE MAXIMUM, SD.DEL.LCH AS STD.DEV, TOT.DEL.LCH AS THE SUM., MIN.DEL.LCH AS THE MINIMUM OF DEL.LCH

' TRAVEL TIME STATISTICS
' ===============
TALLY AV.TRT AS THE MEAN, MAX.TRT AS THE MAXIMUM, MIN.TRT AS THE MINIMUM, SD TRT AS THE STD.DEV, TOTAL.TRT AS THE SUM. OF TRAVEL.TIME
SPEED STATISTICS

TALLY AV. INPUT SPD AS THE AVERAGE, SD. INPUT SPD AS THE STD.DEV,
MIN. INPUT SPD AS THE MINIMUM, MAX. INPUT SPD AS THE MAXIMUM OF
INPUT SPD

TALLY AV. ARR1. SPD AS THE AVERAGE, SD. ARR1. SPD AS THE STD.DEV,
MIN. ARR1. SPD AS THE MINIMUM, MAX. ARR1. SPD AS THE MAXIMUM,
N. ARR1. SPD AS THE NUMBER OF ARR1. SPD

TALLY AV. ARR2. SPD AS THE AVERAGE, SD. ARR2. SPD AS THE STD.DEV,
MIN. ARR2. SPD AS THE MINIMUM, MAX. ARR2. SPD AS THE MAXIMUM,
N. ARR2. SPD AS THE NUMBER OF ARR2. SPD

TALLY AV. ARR3. SPD AS THE AVERAGE, SD. ARR3. SPD AS THE STD.DEV,
MIN. ARR3. SPD AS THE MINIMUM, MAX. ARR3. SPD AS THE MAXIMUM,
N. ARR3. SPD AS THE NUMBER OF ARR3. SPD

TALLY 1. AVSPD AS THE MEAN, 1. MINSPD AS THE MINIMUM, MAX1. SPD AS THE
MAXIMUM, 1. SDSPD AS THE STD.DEV, H1. SPD (20 TO 70 BY 5) AS THE
HISTOGRAM, 1. NSPD AS THE NUMBER OF SPD1

TALLY 2. AVSPD AS THE MEAN, 2. MINSPD AS THE MINIMUM, MAX2. SPD AS THE
MAXIMUM, 2. SDSPD AS THE STD.DEV, H2. SPD (20 TO 70 BY 5) AS THE
HISTOGRAM, 2. NSPD AS THE NUMBER OF SPD2

MAXIMUM, 3. SDSPD AS THE STD.DEV, H3. SPD (20 TO 70 BY 5) AS THE
HISTOGRAM, 3. NSPD AS THE NUMBER OF SPD3

TALLY AV. WV SPD AS THE MEAN, SD. WV SPD AS THE STD.DEV, MIN. WV SPD AS
THE MINIMUM, MAX. WV SPD AS THE MAXIMUM, N. WV SPD AS THE
NUMBER, H.W. SPD (0 TO 60 BY 5) AS THE HISTOGRAM OF WV SPD

TALLY AV. NW. SPD AS THE MEAN, SD. NW. SPD AS THE STD.DEV, MIN. NW. SPD AS
THE MINIMUM, MAX. NW. SPD AS THE MAXIMUM, N. NW. SPD AS THE
NUMBER, H.NW. SPD (0 TO 60 BY 5) AS THE HISTOGRAM OF NW. SPD

HEADING STATISTICS

TALLY AV. 1. HDVY AS THE MEAN, 1. HDVY AS THE STD.DEV, MIN. 1. HDVY AS
THE MINIMUM, MAX. 1. HDVY AS THE MAXIMUM, N. 1. HDVY AS THE NUMBER,
H1. HDVY (0 TO 15 BY 1.0) AS THE HISTOGRAM OF HDVY1

TALLY AV. 2. HDVY AS THE MEAN, 2. HDVY AS THE STD.DEV, MIN. 2. HDVY AS
THE MINIMUM, MAX. 2. HDVY AS THE MAXIMUM, N. 2. HDVY AS THE NUMBER,
H2. HDVY (0 TO 15 BY 1.0) AS THE HISTOGRAM OF HDVY2

TALLY AV. 3. HDVY AS THE MEAN, 3. HDVY AS THE STD.DEV, MIN. 3. HDVY AS
THE MINIMUM, MAX. 3. HDVY AS THE MAXIMUM, N. 3. HDVY AS THE NUMBER,
H3. HDVY (0 TO 15 BY 1.0) AS THE HISTOGRAM OF HDVY3

ACCEPTED GAP STATISTICS

TALLY H1. GAP (0 TO 10 BY 1) AS THE HISTOGRAM, 1. AVGAP AS THE MEAN,
1. SDGAP AS THE STD.DEV, 1. MINGAP AS THE MINIMUM, 1. NGAP AS THE
NUMBER OF GAP1

TALLY H2. GAP (0 TO 10 BY 1) AS THE HISTOGRAM, 2. AVGAP AS THE MEAN,
2. SDGAP AS THE STD.DEV, 2. MINGAP AS THE MINIMUM, 2. NGAP AS THE
NUMBER OF GAP2

TALLY H3. GAP (0 TO 10 BY 1) AS THE HISTOGRAM, 3. AVGAP AS THE MEAN,

```
  DESENSITY STATISTICS
  TALLY AV1.DEHS AS THE MEAN OF DEHS1
  TALLY AV2.DEHS AS THE MEAN OF DEHS2
  TALLY AV3.DEHS AS THE MEAN OF DEHS3
```

END 'PREANBLE
** MAÎ'.' **

THE MAIN PROGRAM PROVIDES INSTRUCTIONS TO CONTROL THE SIMULATION. IT READS THE VALUES OF INPUT PARAMETERS AND ALOCATES COMPUTER MEMORY TO ARRAYS. IT ALSO STARTS THE SIMULATION BY SCHEDULING SOME INITIAL EVENTS.

```
DEFINE K, I AS INTEGER VARIABLES
RESERVE V.L, M.X, SPD, M.S.F, PRV.EAV, LST_UPD, EXIT_VOL, EUT_VOL, REJ.VEH, REJ_LCH, W.V.FACT, MX.SIGMA, UP.MX.SPD, LOW.MX.SPD AS 3

READ INPUT DATA

```

SIMULATION RUN PARAMETERS

```
```

```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
```
== PRIMIER CHARACTERISTICS ==

== VEHICLE CHARACTERISTICS ==

READ 1 CARD
SKIP 2 CARS

READ 1 CARD
READ N'S P(I)
FOR I = 1 TO 2. DO
SKIP 7 CARS

--------
ARRIVAL SPEED
--------

READ 1 CARD
READ N'3 P(I)
FOR I = 1 TO 3. DO
SKIP 11 CARS

--------
MAXIMUM SPEED
--------

== PRIMARY DATA ==

READ PRIMARY
SKIP 1 CARD
READ PRIMARY
SKIP 1 CARD

LOOP
SKIP 1 CARD

224
READ B.PAR: "" BRAKE REACTION TIME PARAMETER FOR "" GAUSS DISTRIBUTION

"" LIST OF DESIRED OUTPUTS
"" -----------------------------------------------

SKIP 8 CARDS
READ ATT "" YES IF A LIST OF ATTRIBUTES OF ALL VEHICLES AT "" USER SPECIFIED TIME INTERVAL IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ INT.OUTPUT "" YES IF INTERMEDIATE OUTPUTS ARE REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ N.INT "" NUMBER OF INTERVALS THE INTERMEDIATE OUTPUTS "" ARE TO BE PRINTED
SKIP 2 CARDS
READ MRG.DIST "" YES IF MERGING-POINT DISTRIBUTIONS ARE REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ GP.DIST "" YES IF DISTRIBUTION OF ACCEPTED GAPS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ GP.GRAPH "" YES IF GRAPH OF C.D.F OF ACCEPTED GAPS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ SPEED DIST "" YES IF DISTRIBUTION OF SPEEDS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ W.SPD.DIST "" YES IF DISTRIBUTION OF WEAVING AND NON-WEAVING "" SPEEDS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ W.SPD.GRAPH "" YES IF GRAPH OF C.D.F OF WEAVING AND NON-WEAVING "" SPEEDS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ HGY.DIST "" YES IF DISTRIBUTION OF HEADWAYS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ HGY.GRAPH "" YES IF GRAPH OF C.D.F OF HEADWAYS IS REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ TRAJ.DAT "" YES IF VEHICLE TRAJECTORIES ARE REQUIRED "" NO OTHERWISE
SKIP 2 CARDS
READ T.B.TRAJ.T.E TRAJ

CREATE EVERY LANE(3)
CREATE EVERY WEAV(2)
THE SYSTEM OWNS 3-UNIDIRECTIONAL LANES. LANES ARE NUMBERED SEQUENTIALLY FROM RIGHT TO LEFT.

THE SYSTEM ALSO OWNS 2 DUMMY LANES WHERE THE VEHICLES ARE STORED TEMPORARILY DURING UPDATE AND LANE-CHANGING PROCESSES.

LET C.F = 360/628
LET TOT.VOL = VL(1) + VL(2) + VL(3)
LET PRVEAV(3) = .70
LET PRVEAV(1) = .06 * (TOT.VOL - PRVEAV(3) - VL(3))/VL(1)
LET PRVEAV(2) = .94 * (TOT.VOL - PRVEAV(3) - VL(3))/VL(2)
LET VV.VOLUME = PRVEAV(1) * VL(1) + PRVEAV(2) * VL(2) + PRVEAV(3) * VL(3)
LET TOT.WV = VV.VOLUME + PRVEAV(1) * VL(1)
LET VV.FACT(1) = PRVEAV(3) * VL(3)
LET VV.FACT(2) = PRVEAV(3) * VL(3) + PRVEAV(1) * VL(1)
LET VV.FACT(3) = PRVEAV(2) * VL(2) + PRVEAV(1) * VL(1)
LET INTERVAL = (SIM.TIME - WARM.UP) / MAX.F(1, N.INT)
LET SIM.LENGTH = B.BUFFER.L + WV.LENGTH + E.BUFFER.L

** ALOCATE COMPUTER MEMORY TO ARRAYS **

RESERVE S.M.SPD, III.VOL, HOM.VOL, OUT.VOL, LCH.FR, LCH.TO, I.AVHD/Y, DENSITY AS N.INT 1 BY 4
RESERVE I.LCH.AV.D, I.H.AV.D, I.SUM.LCH.D, I.H.TOT.D, I.H.SD.D, SUM.LC.
I.H.MX.D, I.LC.MX.D, I.AV.TR.T, I.H.MX.TR.T, I.TOT.TR.T, I.SD.TR.T,
I.MX.AV.SPD, I.MV.AV.SPD, I.WV.SD.SPD, I.H.SD.SPD, I.H.MX.SPD,
I.MAX.UX.SPD, SUM.VOL, SUM.CUR.VOL, I.T.EXIT, I.LH.SD.D AS N.INT

** SCHEDULE INITIAL EVENTS **

FOR K = 1 TO 3, DO
  IF VL(K) > 0
    SCHEDULE AN ARRIVAL(K) NOW
  ALWAYS
LOOP

SCHEDULE A PRE.PROCESS IN 1.00 SECONDS
SCHEDULE AN INITIALIZATION.BIAS IN WARM.UP SECONDS
SCHEDULE A STAT.COLLECT IN INTERVAL+WARM.UP SECONDS
SCHEDULE A LIST.INPUT NOW
SCHEDULE A RESULT IN SIM.TIME SECONDS
START SIMULATION

START SIMULATION

EUD " MAIN"
EVENT LIST INPUT

'' THIS EVENT PRINTS THE TITLE PAGE AND LISTS ALL
'' THE INPUT PARAMETERS INCLUDING SUMMARY DESC-
'' RIPTION OF THE SIMULATED WEAVING SECTION.

DEFINE I AS INTEGER VARIABLE
START NEW PAGE
SKIP 14 LINES
PRINT 16 DOUBLE LINES LIKE THIS

W A Y

+++ SIMULATION OF FREE

+++ WEAVING SECTIONS

+++ SCANING INTERVAL = 1 SECOND
INTERMEDIATE OUTPUT CONIDES --- SECONDS AFTER BEGINNING

G OF SIMULATION

```
** LIST OF INPUT DATA
                      ===========
```

START NEW PAGE

PRINT 11 DOUBLE LINES LIKE THIS

```
+++++++                          +-----------------------------------------------+
+++++++                          +-----------------------------------------------+
+++++++                          +-----------------------------------------------+
       +++                          +-----------------------------------------------+
       +++                          +-----------------------------------------------+
+++++++                          +-----------------------------------------------+
+++++++                          +-----------------------------------------------+
+++++++                          +-----------------------------------------------+
```

SKIP 4 LINES

PRINT 33 LINES WITH (SIM.TIME-WARM.UP)/60.0,WARM.UP,SIM.LENGTH,WV.LENGTH,
B.BUFFER.L,E.BUFFER.L,WV.VOLUME,TOT.VOL,
VL(1),PRV/EA/(1),VL(2),PRV/EA/(2),VL(3),PRV/EA/(3),
PLC,L.PASOR,L.TRUCK,L.TRAILER,PRTRUCK,PRTRAILER,
MED,B.MEAN,B.PARM THUS

... WII. ACTUAL SIMULATION TIME
... SEC. WARM UP PERIOD
... FT. SIMULATED LENGTH OF FREDWAY SECTION
... FT. SIMULATED LENGTH OF WEAVING SECTION
... FT. DOWN STREAM BUFFER LENGTH
... FT. UP STREAM BUFFER LENGTH
... VPH WEAVING VOLUME
... VPH TOTAL VOLUME

VOLUME, PROPORTION OF VEHICLES WEAVING FOR EACH LANE ARE AS FOLLOWS:

<table>
<thead>
<tr>
<th>VOLUME</th>
<th>%WEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>-------</td>
<td>----------</td>
</tr>
</tbody>
</table>

LAI 

LANE 2

LANE 3

PROBABILITY OF LANE CHANGING

FT.

AVERAGE LENGTH OF A PASSENGER CAR

FT.

AVERAGE LENGTH OF A TRUCK

FT.

AVERAGE LENGTH OF A TRAILER

PERCENT TRUCK

PERCENT TRAILER

FT./SEC./SEC.

MAXIMUM EMERGENCY DECELERATION RATE

SEC.

MEAN BRAKE REACTION TIME

SEC.

BRAKE REACTION TIME FOR GAMMA DISTRIBUTION

PRINT 4 LINES WITH VV.LENGTH,VR,VL(1),VL(2),VL(3),

M.R.SPD+M.S.F(2)-M.R.SPD+M.S.F(3) THUS

PPP VV.LENGTH VR LANE 1 LANE 2 RAMP SPD.DIF

========================= ======== ======== ======== ========

PRINT 3 LINE LIKE THIS

RANDOM NUMBER SEEDS FOR STREAM I-5

=================================================================

FOR I= 1 TO 6, DO

PRINT 1 LINE WITH I,SEED,V(I) THUS

STREAM #

LOOP

SKIP 4 LINES

PRINT 11 LINES WITH M.MX.SPD(1),M.X.SIGMA(1),UP.MX.SPD(1),LOW.MX.SPD(1),

M.MX.SPD(2),M.X.SIGMA(2),UP.MX.SPD(2),LOW.MX.SPD(2),

M.MX.SPD(3),M.X.SIGMA(3),UP.MX.SPD(3),LOW.MX.SPD(3),

M.R.SPD+M.S.F(1),AR.SIGMA+M.S.F(1),

M.R.SPD+M.S.F(2),AR.SIGMA+M.S.F(2),

M.R.SPD+M.S.F(3),AR.SIGMA+M.S.F(3),

UP.AR.SPD+M.S.F(3),LOW.AR.SPD+M.S.F(3),M.S.F(3) THUS

AVERAGE STD.DEV MAXIMUM MINIMUM M.S.F

========================= ======== ======== ========

MAXIMUM SPEED

* * *

* * *

* * *

* * *

* * *

* * *

* * *

* * *

* * *
ARRIVAL SPEED

START NEW PAGE
SKIP 10 LINES
PRINT 26 LINES WITH ATT, INT. OUTPUT, INTERVAL, MERG. DIST, GP. DIST,
GP. GRAPH, SPEED. DIST, V. SPD. DIST, W. SPD. GP. GRAPH,
HEVY DIST, HEVY GRAPH, TRAJ DATA, T B. TRAJ,
T.E. TRAJ THIS

1. DOES THE OUTPUT INCLUDE A LIST OF ATTRIBUTES OF ALL VEHICLES? 
2. DOES THE OUTPUT INCLUDE INTERMEDIATE OUTPUTS?
   HOW OFTEN INTERMEDIATE OUTPUTS ARE TO BE PRINTED?
   EVERY >..< SEC.
3. DOES THE OUTPUT INCLUDE A DISTRIBUTION OF MERGING-POINTS?
4. DOES THE OUTPUT INCLUDE A DISTRIBUTION OF ACCEPTED GAPS?
5. DOES THE OUTPUT INCLUDE A C.D.F GRAPH OF ACCEPTED GAPS?
6. DOES THE OUTPUT INCLUDE A DISTRIBUTION OF LANE SPEEDS?
7. DOES THE OUTPUT INCLUDE A DISTRIBUTION OF WEAVING AND
   NON-WEAVING SPEEDS?
8. DOES THE OUTPUT INCLUDE A C.D.F GRAPH OF WEAVING AND
   NON-WEAVING SPEEDS?
9. DOES THE OUTPUT INCLUDE A DISTRIBUTION OF HEADWAYS?
10. DOES THE OUTPUT INCLUDE A C.D.F GRAPH OF HEADWAYS?
11. DOES THE OUTPUT INCLUDE VEHICLE TRAJECTORIES?
    AT WHAT INTERVAL ARE TRAJECTORIES TO BE PRINTED?
    FROM >..< TO >..<

START NEW PAGE
PRINT 2 DOUBLE LINE LIKE THIS

WV. SPD  WV. SPD  WV. DEL  WV. DEL  WV. L  VR  MAJ. VOL  MIN. VOL  SPD. DIF
TOT. VL  WV. VL  % WEAV 1  % WEAV 2  %WEAV 3

END ''EVENT LIST. INPUT
EVENT INITIALIZATION BIAS

'' TO ELIMINATE THE INITIALIZATION BIAS, THIS EVENT
'' RESETS ALL COUNTERS AND VARIABLES ASSOCIATED
'' WITH STATISTICS COLLECTION, AT THE END OF THE
'' WARM UP PERIOD.

DEFINE I AS INTEGER VARIABLE

RESET TOTALS OF H1.2MGPT,H2.1MGPT,H2.3MGPT,H3.2MGPT,DLY.LCH,INPUT.SPD,
1.2MGPT,2.1MGPT,2.3MGPT,3.2MGPT,DEMS1,DEMS2,DEMS3,
DELAY.ROD,TRAVEL.TIME,SPD1,SPD2,SPD3,WW.SPD,
NON.VV.SPD,HDMY1,HDMY2,HDMY3,GAP1,GAP2,GAP3,
ARR1.SPD,ARR2.SPD,ARR3.SPD

FOR I = 1 TO 3.DO
  LET REJ.LCH(I) = 0
  LET REJ.VEH(I) = 0
  LET EXIT.VOL(I) = 0
  LET ENT.VOL(I) = 0
LOOP

  LET L.C.VOLUME = 0
  LET T.EXIT.VOL = 0
  LET T.ENT.VOL = 0
  LET NO.ACCIDENT = 0
  LET 2.3LCHG = 0
  LET 3.2LCHG = 0
  LET 1.2LCHG = 0
  LET FAIL.WV = 0

RETURN
END ''EVENT INITIALIZATION BIAS
EVENT ARRIVAL GIVEN LANE

** This event creates one vehicle at each interarrival time. By calling routine speed.br.t
** assigns a speed and brake reaction time to
** that vehicle. To insure safe entrance to the
** system, necessary adjustments are made to the
** speed and brake reaction time of the vehicle
** prior to its entrance to the system. Arrival
** time of each vehicle is recorded and other
** attributes such as: id, type, origin and
** destination are also assigned to the vehicle.
** total volume and lane volume are both incre-
** mented, and finally the vehicle is filed in
** one of the available three lanes. This event
** is rescheduled at interval times generated by
** routine arrival dist.

DEFINE LANN AS INTEGER VARIABLE
DEFINE U.V AS VARIABLES

CREATE A VEHICLE

CALL SPEED.BRT(LANN) YIELDING ARR.SPEED, BR, MAX.SPD

IF BR<=0.25 OR ARR.SPEED < 0.0

** entry to the system is rejected for this vehicle
** (brake reaction time is too small)

DESTROY THIS VEHICLE
ADD 1 TO REJ.VEH(LANN)
GO TO 36

ALWAYS
ADD 1 TO NUMBER
ADD 1 TO EXT.VOL(LANN)
ADD 1 TO T.ENT.VOL

** assign attributes
** =============

LET CURRENT.LANE(VEHICLE) = LANN
LET ARR.TIME(VEHICLE) = TIME.V
LET D.SPEED(VEHICLE) = MAX.SPD
LET S.AFTER(VEHICLE) = ARR.SPEED
LET ORIGIN(VEHICLE) = LANN
LET BRAKT(VEHICLE) = BR
LET ID(VEHICLE) = NUMBER
LET INPUT.SPD = ARR.SPEED*C.F

'' COMPUTE THE SAFE-FOLLOWING DISTANCE
'' ===============================

LET R = (UP.MAX.SPD(LANN) - MAX.SPD.C.F)/ (UP.MAX.SPD(LANN) - LOW.MAX.SPD(LANN))
LET R = MAX.F(0.0, R)
LET R = MIN.F(1.0, R)
LET S.D(VEHICLE) = 10.0*R*R

' GENERATE A RANDOM NUMBER UNIFORMLY DISTRIBUTED
' BETWEEN (0,1) FOR ASSIGNMENT OF VEHICLE TYPE
' TO EACH VEHICLE.

LET U = RANDOM.F(1)
IF U < PRTRUCK
  LET TYPE(VEHICLE) = "TRUCK"
  LET LENGTH(VEHICLE) = L.TRUCK
ELSE
  IF U < (PRTRUCK + PRTRAILER)
    LET TYPE(VEHICLE) = "TRAILER"
    LET LENGTH(VEHICLE) = L.TRAILER
  ELSE
    LET TYPE(VEHICLE) = "PASGR"
    LET LENGTH(VEHICLE) = L.PASGR
    ALWAYS

'' GENERATE A RANDOM NUMBER UNIFORMLY DISTRIBUTED
'' BETWEEN (0,1) FOR ASSIGNMENT OF VEHICLE DESTINATION.

LET W = RANDOM.F(2)
IF W <= PRWEAV(LANN)
  IF LANN == 3
    LET DESTINATION(VEHICLE) = 3
  ELSE
    LET DESTINATION(VEHICLE) = 2
    ALWAYS
ELSE
  LET DESTINATION(VEHICLE) = LANN
  ALWAYS

IF ORIGIN(VEHICLE) NE DESTINATION(VEHICLE)
  LET STATUS(VEHICLE) = "WEAVE"
ELSE
  LET STATUS(VEHICLE) = "NON.WEAVE"
ALWAYS

FILE THIS VEHICLE IN LOCATION

'36' CALL HEADWAY.ARRIVAL(VL(LAII)) YIELDING HEADWAY
     SCHEDULE AN ARRIVAL(LAII) IN HEADWAY SECONDS

RETURN

END ' ' EVENT ARRIVAL
EVENT PRE-PROCESS

This event computes density for each lane and schedules event process for lane 1, 2, and 3, respectively. It also schedules the L.CHANG event right after all vehicles have been updated by event process. This event is scheduled in every 1-second interval.

Define I.K as an integer variable

If Time.V >= 4600 AND Time.V <= 600
  For K = 1 TO 3, Do
    Until LN(K) is empty, Do
      Remove the first vehicle from LN(K)
      Print 1 double line with ID, Origin, Destination, current lane, brkt, length, s.after, s.before, acceleration, P.after, P.before, head vy, d.speed, adjust, status, new ln, T.L.C, mov. status thus
      ID=... OR=... DES=... C.L=... BR=... LL=... S.AF=... S.BEF=... P.AF=... P.BEF=... H=... D.S=... ADJ=... ST=... IL=... TL=... MVS=...
      File this vehicle in WV(1)
  Loop
  Until WV(1) is empty, Do
    Remove the first vehicle from WV(1)
    File this vehicle in LN(K)
  Loop
Loop
Always

Compute lane density

If Time.V >= 10000000
  If VL(1) > 0.0
    Let DENS1 = ((LN(1)-1)/(P.AFTER(F.LN(1))-P.AFTER(L.LN(1))))*6280
 Always
  If VL(2) > 0.0
    Let DENS2 = ((LN(2)-1)/(P.AFTER(F.LN(2))-P.AFTER(L.LN(2))))*6280
 Always
  If VL(3) > 0.0
    Let DENS3 = ((LN(3)-1)/(P.AFTER(F.LN(3))-P.AFTER(L.LN(3))))*6280
 Always
Always
For I=1 TO 3, Do
  Schedule a Process(I) now.
LOOP

SCHEDULE A CHANGE NOW
SCHEDULE A PRE.PROCESS IN 1.00 SECONDS
RETURN
END " " PRE.PROCESS

EVENT PROCESS GIVEN LIN

\[\text{"" THIS EVENT IS SCHEDULED AT EACH 1-SECOND INTERVAL. IN THIS EVENT, THROUGH A COMPLETE SCAN OF THE SYSTEM, THE FOLLOWING TASKS ARE ACCOMPLISHED:"
\]

1. UPDATE SPEED AND POSITION OF ALL VEHICLES, STARTING THE VEHICLE MOST DISTANT FROM THE SYSTEM ENTRY POINT.

2. BASED ON THE UPDATED POSITION AND SPEED A CURRENT HEADWAY IS COMPUTED AND ASSIGNED TO EACH VEHICLE.

3. AT USER SPECIFIED TIME INTERVALS, ROUTINE SPD.HDWAY.DATA AND VEH ATTRIBUTE ARE CALLED UPON TO COLLECT VEHICLE TRAJECTORY DATA AND VEHICLE ATTRIBUTES FOR EACH LANE AND FOR THE SYSTEM AS A WHOLE.

4. BY CALLING ROUTINE DESIRED LANE A NEW LANE IS DETERMINED AND ASSIGNED TO EACH CHANGING VEHICLE.

5. AT EACH TIME INTERVAL THE UPDATED POSITION OF EACH VEHICLE IS COMPARED TO THE POSITION OF ITS LEADER TO DETERMINE WHETHER OR NOT THE VEHICLE IS INVOLVED IN A COLLISION. IN CASE OF A COLLISION THE NO-ACCIDENT WILL BE INCREASED AND APPROPRIATE ROUTINE WILL BE CALLED UPON TO PROVIDE INFORMATION AS TO THE REASON FOR THE COLLISION.

6. FOR THOSE VEHICLES WHICH HAVE PASSED THE SYSTEM EXIT POINT DATA ON MEASURES OF PERFORMANCE IS COLLECTED. THESE VEHICLES ARE THEN REMOVED FROM THE SYSTEM.
DEFINE ARR.T,DES.V,BRT,PFT,HED.V,LEAD.H,T AS VARIABLES
DEFINE UP.TLC,ORIGIN?,DEST,CUR.LANE,LIN.,NEW.LANE,Mov.ST.,HEL.C,LP.,
N.LCH.,LLP.,M.S.L.,KP,LEAD.TLC,LEAD.ST AS INTEGER VARIABLES
DEFINE STAT.TYP.,STATUSP.,ADJ AS TEXT VARIABLES

LET LST.UPD(LIN)=TIME.V

UNTIL LIN(LIN) IS EMPTY,DO
REMOVER THE FIRST VEHICLE FROM LIN(LIN)
LET KP=KP+1

'' COPY ATTRIBUTES''
''==================''

LET CUR.LANE=CURR.EAT.LANE(VEHICLE)
LET AFT=ACCELERATION(VEHICLE)
LET DEST=DESTINATION(VEHICLE)
LET MOV.ST=Mov.STATUS(VEHICLE)
LET ARR.T=ARR.TIME(VEHICLE)
LET DES.V=D.SPEED(VEHICLE)
LET LEAD.H=HEAD.HY(VEHICLE)
LET VFT=S.AFTER(VEHICLE)
LET PFT=P.AFTER(VEHICLE)
LET STATUSP=STATUS(VEHICLE)
LET N.LCH=NO.LCH(VEHICLE)
LET ADJ=ADJUST(VEHICLE)
LET ORIGIN=P=ORIGIN(VEHICLE)
LET LLP=LENGTH(VEHICLE)
LET UP.TLC=T.L.C(VEHICLE)
LET BRT=BRAKT(VEHICLE)
LET TYP=TYPE(VEHICLE)
LET HUM.=ID(VEHICLE)
LET SD=S.D(VEHICLE)

IF TIME.V - ARR.T < 1.00

'' THIS VEHICLE HAS ARRIVED SOMETIMES AFTER THE''
'' LAST UPDATE''

LET T=TIME.V-ARR.T

ELSE
LET T=1.00

ALWAYS

CALL CAR.FOLLOWING(LIN.,VFT,PFT,DES.V,BRT,LP.,VLD.,PLD.T,KP,TYP.,
STATUSP.,LIN.,ADJ.AFT.,LEAD.ST,Mov.ST.,SD)
YIELDING VFD,PFD,AFD

IF KP=1 ''THE FIRST VEHICLE''

LET HEAD.HY(VEHICLE)=P.DESTROY-PFD
ELSE
  LET HEAD.WY(VEHICLE)=PLD-PFD
ALWAYS

  ''
  COLLECT TRAJECTORY DATA
  ''
  ===============================

IF TRAJ.DATA = "YES" AND TIME.V >= T.B.TRAJ AND TIME.V <= T.E.TRAJ
  WRITE LIN,TIME.V,NUM.,PFD AS BINARY USING 4
  WRITE AS / USING 4
ALWAYS

LET HED.WY=HEAD.WY(VEHICLE)/MAX.F(1,VFD)

  ''
  COLLECT SPEED AND HEADWAY DATA
  ''
  ===============================

IF PFD>=B.BUFFER.L AND PFD<B.BUFFER.L+V.V.LENGTH AND KP>1
  CALL SPD.HDWY.DATA(VFD,HED.WY,LIN)
ALWAYS

IF (TIME.V=INTERVAL OR TIME.V=2 INTERVAL OR TIME.V=3 INTERVAL OR
  TIME.V=4 INTERVAL) AND ATT = "YES" AND PFD>B.BUFFER.L
  CALL VEH.ATTRIBUTE(HUE.,TYP,PFD,VFD,ADF,LEAD,H.U,LCH,ORIGINP,
  DEST,LIN,KP,ADJ,STATUSP)
ALWAYS

  IF HED.WY < 0 AND KP >1

    ''
    THIS VEHICLE HAS BEEN INVOLVED IN AN ACCIDENT
    ''
    CALL SNAP.R
    LET NO.ACCIDENT=NO.ACCIDENT+1
    PRINT 3 LINES WITH TIME.V,ID(VEHICLE),LIN,HED.WY
    AT TIME .... VEHICLE NO. .... IN LANE .... WAS INVOLVED IN AN ACCIDENT
    ALWAYS

IF PFD>=B.BUFFER.L AND PFD<B.BUFFER.L+V.V.LENGTH AND W.ARR.T(VEHICLE)=0.

  ''
  THIS VEHICLE HAS JUST ENTERED THE WEAVING SECTION
  ''
  IF LIN =1
    LET ARR1.SPD=VFD.C.F
  ELSE
    IF LIN = 2
      LET ARR2.SPD = VFD.C.F
    ELSE
      LET ARR3.SPD = VFD.C.F
  ALWAYS
  ALWAYS
LET W.ARR.T(VEHICLE)=TIME.V-(PFD-BUFFER.L)/MAX.F(1.0,VFD)
ALWAYS
IF PFD>=B.BUFFER.L-VFD AND PFD<B.BUFFER.L+V.LENGTH AND KP>1
   " THIS VEHICLE IS ABOUT TO ENTER THE WEAVING SECTION

IF UP.TLC = 0
   " THIS VEHICLE HAS NOT INITIATED A LANE-CHANGING YET
   IF MOV.ST = 0
      " 2 SEC. HAVE ELAPSED SINCE LAST LANE-CHANGING
      IF LEAD.TLC = 0 AND NEW.LN(VEHICLE) = 0
         " THE LEADER OF THIS VEHICLE HAS NOT INITIATED
         " A LANE-CHANGING DURING PAST 2 SEC.
      CALL DESIRED.LANE(CUR.LANE.ORIGINP,DEST,VFD,DES.V,AFD,STATUSP)
      YIELDING NEW LANE
      LET NEW.LN(VEHICLE)=NEW.LANE
      ALWAYS
   ELSE
      " THIS VEHICLE HAS CHANGED LANE DURING LAST 2 SEC.
      SUBTRACT 1 FROM MOV.ST
      ALWAYS
   ELSE
      " THIS VEHICLE HAS ALREADY INITIATED A LANE-CHANGING
      ADD 1 TO UP.TLC
      ALWAYS
   ALWAYS
   IF PFD>B.BUFFER.L+V.LENGTH AND Y.EXT.T(VEHICLE)=0.
      " THIS VEHICLE HAS JUST PASSED THE WEAVING SECTION
      " THE EXIT TIME NEEDS TO BE CALCULATED
      LET W.EXT.T(VEHICLE)=TIME.V-(PFD-B.BUFFER.L+V.LENGTH)/MAX.F(1.0,VFD)
      LET UP.TLC = 0
      LET ADJUST(VEHICLE) = "O.K"
      ALWAYS
   LET VLD = VFD
   LET LP = LLP
   LET PLD = PFD
LET AID = AFD
IF PLD >= SIM LENGTH

' COLLECT DATA ON MEASURES OF PERFORMANCE
'
' LET TRAVEL TIME = W.EXT.T(VEHICLE) - W.ARR.T(VEHICLE)
IF STATUS = "VEAR"
    LET DELAY .NOW = MAX. F ((TRAVEL TIME - W. LENGTH / DES. V), 0.0) - 5280/W. LENGTH
    LET NOW.WV. SPD = (W. LENGTH / TRAVEL TIME) - 0.5
ELSE
    LET DLY . LCH = MAX. F ((TRAVEL TIME - W. LENGTH / DES. V), 0.0) - 5280/W. LENGTH
' PRINT 1 LINE WITH TIME, V, NUM, W. EXT.T(VEHICLE), W. ARR.T(VEHICLE), DES. V.
' TRAVEL TIME, DLY. LCH, DLY.
    LET WV. SPD = (W LENGTH / TRAVEL TIME) - 0.5

IF DEST NE CUR. LANE AND TIME. V > 0000
    ADD 1 TO FAIL.WV
ALWAYS

ALWAYS
ADD 1 TO T. EXIT.VOL
ADD 1 TO EXIT.VOL(LIN)
" LET P. DESTROY=PLD "
DESTROY THIS VEHICLE
GO TO SO
ALWAYS

' UPDATE ATTRIBUTES
'

LET ACCELERATION(VEHICLE) = AID
LET MOV. STATUS(VEHICLE) = MOV. ST
LET F BEFORE(VEHICLE) = PFT
LET S. BEFORE(VEHICLE) = VFT
LET P. AFTER(VEHICLE) = PLD
LET S. AFTER(VEHICLE) = VLD
LET T. L. C(VEHICLE) = UP. TLC
LET LEAD. TLC = UP. TLC
LET LEAD. ST = MOV. ST

IF ADJ NE "FASTER" OR ADJ NE "SLOWER"
    LET ADJUST(VEHICLE) = "O.K"
ALWAYS

FILE THIS VEHICLE IN WV(2)
' 30' LOOP
    LET KP=0
UNTIL WV(2) IS EMPTY, DO
    REMOVE THE FIRST VEHICLE FROM WV(2)
FILE THIS VEHICLE IN LIN(LIN)

LOOP
RETURN
END "" PROCESS
EVENT L CHANGE

```
"" THIS EVENT IS SCHEDULED RIGHT AFTER ALL VEHICLES
"" HAVE BEEN UPDATED BY EVENT PROCESS. IN THIS EVENT
"" THROUGH A COMPLETE SCAN OF THE SYSTEM, FOLLOWING
"" TASKS WILL BE ACCOMPLISHED:

"" 1. VEHICLES WHICH HAVE NOT CHANGED LANES DURING
"" PAST 2 SECONDS WILL BE CHECKED TO SEE WHETHER
"" OR NOT A NEED FOR LANE-CHANGING HAS BEEN EST-
"" TABLISHED. IF YES, ROUTINE INITIAL CHECK WILL
"" BE CALLED UPON TO SEARCH FOR POSSIBILITY OF
"" SUCH LANE-CHANGING. IF THE SEARCH IS SUCCESS-
"" FUL, THEN THE VEHICLE IS FLAGGED TO GO THROUGH
"" THE FINAL CHECK 2 SECONDS LATER.

"" 2. VEHICLES WHICH HAVE SUCCESSFULLY PASSED THE
"" INITIAL CHECK 2 SECONDS AGO, WILL NOW PERFORM
"" A FINAL CHECK. THESE VEHICLES WILL EITHER BE
"" MOVED TO A DESIGNATED NEW LANE OR REMAIN IN
"" THEIR CURRENT LANE, DEPENDING ON THE OUTPUT
"" OF THE FINAL CHECK.

"" 3. STATISTICS ON THE NUMBER OF LANE-CHANGING AND
"" MERGING POINTS WILL BE COLLECTED.

"" 4. APPROPRIATE ATTRIBUTES OF THE LANE-CHANGING
"" VEHICLES ARE ALSO UPDATED.
```

DEFINE L,L.INA.L,L.LL,CHECK AS INTEGER VARIABLES
DEFINE TYPL,STATL,ADJ.SAME AS TEXT VARIABLES
DEFINE VFDL,PFDL,AFDL,BRTL AS VARIABLES

FOR I = 1 TO 3. DO
UNTIL LN(I) IS EMPTY . DO
    REMOVE THE FIRST VEHICLE FROM LN(I)
    LET VFDL = S.AFTER(VEHICLE)
    LET PFDL = P.AFTER(VEHICLE)
    IF STATUS(VEHICLE) = "WEAVE"
```
```
    THIS VEHICLE IS A WEAVING VEHICLE
```
```
    IF PFDL>=B.BUFFER.L-VFDL AND PFDL<=B.BUFFER.L+V.V.LENGTH
    THIS VEHICLE IS NOW WITHIN THE WEAVING SECTION
```
```
    GO TO 10
```
ELSE
    FILE THIS VEHICLE IN \text{WV}(2)
    GO TO 20
ELSE
    '10' IF CURRENT LANE(VEHICLE) \& NEW LANE(VEHICLE) \& NEW LANE(VEHICLE) = 0
    AND (T.L.C(VEHICLE) = 0 OR T.L.C(VEHICLE) = 2)

    "" THIS VEHICLE HAS FLAGGED FOR LANE-CHANGING
    "" COPY ATTRIBUTE

    LET AFDL = ACCELERATION(VEHICLE)
    LET BRTL = BRAKT(VEHICLE)
    LET TYPL = TYPE(VEHICLE)
    LET LLL = LENGTH(VEHICLE)
    LET NEW L = NEW LANE(VEHICLE)
    LET STATL = STATUS(VEHICLE)

    IF T.L.C(VEHICLE) = 0
       FILE THIS VEHICLE IN \text{WV}(1)
       CALL INITIAL.CHECK(VFDL, PFDL, AFDL, BRTL, TYPL, LLL, NEW L, STATL, YIELDING CHECK, ADJ
       REMOVE THE FIRST VEHICLE FROM \text{WV}(1)
       IF CHECK = OKAY

       "" THE INITIAL CHECK HAS BEEN SUCCESSFUL

       LET T.L.C(VEHICLE) = 1
    ELSE
       ADD 1 TO REJ.LCH(1)
       IF ADJ = "SAME"
           LET ADJ = "SLOWER"
           ALWAYS
       IF STATL EQ "WEAVE"
           LET ADJUST(VEHICLE) = ADJ
       ELSE
           LET ADJUST(VEHICLE) = "O.K"
           ALWAYS
           ALWAYS
       FILE THIS VEHICLE IN \text{WV}(2)
    ELSE

        "" THIS VEHICLE HAS ALREADY PASSED THE INITIAL CHECK
        AND WILL NOW GO THROUGH THE FINAL CHECK

        FILE THIS VEHICLE IN \text{WV}(1)
        LET SEARCH=FINAL.CHECK(PFDL, LLL, NEW L, VFDL, STATL, TYPL, BRTL)
        REMOVE THE FIRST VEHICLE FROM \text{WV}(1)
        LET T.L.C(VEHICLE) = 0
        IF SEARCH = OKAY
THE FINAL CHECK HAS BEEN SUCCESSFUL

COLLECT LANE-CHANGING STATISTICS

IF NEW. LN(VEHICLE)=2
    IF CURRENT. LANE(VEHICLE)=1
        ADD 1 TO 1.2LCHG
        LET 1.2MGPT = P.AFTER(VEHICLE) - B.BUFFER.L
        LET H1.2MGPT = P.AFTER(VEHICLE)
    ELSE
        ADD 1 TO 3.2LCHG
        LET 3.2MGPT = P.AFTER(VEHICLE) - B.BUFFER.L
        LET H3.2MGPT = P.AFTER(VEHICLE)
    ALWAYS
ELSE
    IF NEW. LN(VEHICLE)=3
        ADD 1 TO 2.3LCHG
        LET 2.3MGPT = P.AFTER(VEHICLE) - B.BUFFER.L
        LET H2.3MGPT = P.AFTER(VEHICLE)
    ELSE
        ADD 1 TO 2.1LCHG
        LET 2.1MGPT = P.AFTER(VEHICLE)
        LET H2.1MGPT = P.AFTER(VEHICLE)
    ALWAYS
ALWAYS

UPDATE APPROPRIATE ATTRIBUTES OF THIS VEHICLE

LET CURRENT. LANE(VEHICLE)=NEW. LN(VEHICLE)
LET MOV. STATUS(VEHICLE) = 2
LET ADJUST(VEHICLE) = "O.K"
LET NEW. LN(VEHICLE) = 0
ADD 1 TO NO. LCH(VEHICLE)
ADD 1 TO L.C. VOLUME
FILE THIS VEHICLE IN LN(NEW. L)
ELSE

THE FINAL CHECK HAS FAILED FOR THIS VEHICLE

LET NEW. LN(VEHICLE)=0
FILE THIS VEHICLE IN VN(2)
ALWAYS
ALWAYS
ELSE

THIS VEHICLE HAS NOT FLAGGED FOR LANE-CHANGING
FILE THIS VEHICLE IN WV(2)
ALWAYS

'20' LOOP

UNTIL WV(2) IS EMPTY.DO
   REMOVE THE FIRST VEHICLE FROM WV(2)
   FILE THIS VEHICLE IN LV(1)
END LOOP
END LOOP

RETURN
END ' ' L CHANGE
EVENT STAT COLLECT

**
** THIS EVENT IS SCHEDULED AT USER SPECIFIED TIME
** INTERVALS. IT COLLECTS INTERMEDIATE STATISTICAL
** DATA ON LANE-CHANGING, SPEED, DELAY, HEADWAY,
** AND DENSITY AT EACH INTERVAL. IT RESCHEDULES
** ITSELF FOR THE NEXT INTERVAL.

DEFINE L, INT, II AS INTEGER VARIABLES
DEFINE SUM SPD, DISTANCE, HEADWAY, P LEAD, L LEAD AS VARIABLE

LET INT = TRUNC.F((TIME V - WARM UP)/INTERVAL)

LET I . MAX SPD (INT) = MAX. UV. SPD
LET SUM. CUR VOL (INT) = H. LN(1) + H. LN(2) + H. LN(3)
LET I. SUM LCH D (INT) = TOT. DEL. LCH
LET I. WV AV SPD (INT) = AV. WV. SPD
LET I. WV SD SPD (INT) = SD. WV. SPD
LET I. LCH AV SPD (INT) = AV. LCH. SPD
LET I. LCH SD SPD (INT) = SD. LCH. SPD
LET I. LCH AV D (INT) = AV. LCH. D
LET I. LCH MAX SPD (INT) = MAX. LCH. SPD
LET I. LCH TOT D (INT) = TOT. LCH. D
LET I. TOT TRT (INT) = TOTAL. TRT
LET I. AV TRT (INT) = AV. TRT
LET I. H. AV D (INT) = H. AV. DEL
LET I. SD TRT (INT) = SD. TRT
LET I. MAX TRT (INT) = MAX. TRT
LET I. H. MAX D (INT) = H. MAX. DEL
LET I. T. EXIT (INT) = T. EXIT VOLUME + SUM. CUR. VOL (INT)
LET SUM. VOL (INT) = T. EXIT VOLUME
LET SUM. LC (INT) = L. C. VOLUME

FOR L=1 TO 3 , DO

    LET IH. VOL (INT, L) = ENT. VOL (L)
    LET H. VOL (INT, L) = H. LN (L)
    LET OUT. VOL (INT, L) = ENT. VOL (L) - H. LN (L)

IF L = 1

    LET LCH.FR (INT, L) = RNG1.2
    LET LCH.TO (INT, L) = RNG2.1
    LET DENSITY (INT, L) = AV1 DENS
LET S.M.SPD(INT,L) = 1.AVSPD
LET I.AVHDY(INT,L) = AV.1.HDY
ELSE

IF L = 2  "" THIS VEHICLE IS IN LANE 2

LET LCH.FR(INT,L) = HMG2.3+HMG2.1
LET LCH.TO(INT,L) = HMG3.2+HMG1.2
LET DENSITY(INT,L) = AV2.DEIS
LET S.M.SPD(INT,L) = 2.AVSPD
LET I.AVHDY(INT,L) = AV.2.HDY
ELSE

"" THIS VEHICLE IS IN LANE 3

LET LCH.FR(INT,L) = HMG3.2
LET LCH.TO(INT,L) = HMG2.3
LET DENSITY(INT,L) = AV3.DEIS
LET S.M.SPD(INT,L) = 3.AVSPD
LET I.AVHDY(INT,L) = AV.3.HDY

ALWAYS

LOOP

PRINT 1 DOUBLE LINE WITH AV.NV.SPD,AV.NV.SPD,AV.DE.LCH,NOH.AV.DE,
LV.LENGTH,VR.2,VL(1),VL(3),AR.SPD-L.S.F(2)-AR.SPD-M.S.F(3),
TOT.VOL,AV.VOL.EV(PR/EAV(1),PR/EAV(2),PR/EAV(3)

SCHEDULE A RESTART NOW
SCHEDULE A STAT.COLLECT IN INTERVAL SECONDS
RETURN
END ""STAT.COLLECT
EVENT RESTART
```
RESET TOTALS OF DLY.LCH,DELY,DELY1,DELY2,DELY3,SPD1,SPD2,SPD3,
    SPD,NO.V,SPD,TRAVEL.TIME,HDVY1,HDVY2,HDVY3
RETURN
END
```

EVENT RESULT
```
```
THIS EVENT PRINTS SIMULATION RESULTS AT THE END
OF THE SIMULATION PERIOD BY CALLING ROUTINES:
INTERMEDIATE OUTPUT, MERG.DIST, DIST.HEADWAY
SPD.DIST, SPD.WV.DIST, AND GAP DISTRIBUTION.
IT ALSO GRAPHS SPEED, HEADWAY, AND ACCEPTED
GAP DISTRIBUTIONS BY CALLING APPROPRIATE
SUBROUTINES. THE USER HAS COMPLETE CONTROL OVER
THE TYPE OF OUTPUT HE DESIRES. A SIMPLE "NO"
ANSWER TO ANY OF THE QUESTIONS ASKED, DURING
THE INPUT PROCESS, WOULD ELIMINATE THE UNDESIRABLE
SET OF OUTPUTS.
```

IF INT.OUTPUT EQ "YES"
    CALL INTERMEDIATE.OUTPUT
    ALWAYS

IF MERG.DIST EQ "YES"
    CALL MERG.DIST
    ALWAYS

IF HDY.DIST EQ "YES"
    CALL DIST.HEADWAY
    ALWAYS

IF HDY.GRAPH EQ "YES"
    CALL HDY.GRAPH
    ALWAYS

IF SPEED.DIST EQ "YES"
    CALL SPD.DIST
    ALWAYS

IF SPD.WV.DIST EQ "YES"
    CALL SPD.WV.GRAPH
    ALWAYS
IF GP.DIST EQ "YES"
    CALL GAP.DIST
    ALWAYS

IF GP.GRAPH EQ "YES"
    CALL GAP.GRAPH
    ALWAYS

CALL XOE

STOP
EIID ''RESULT
S. PROGRAM: SHAP.R

" " THIS SUBPROGRAM IS CALLED UPON IN CASE OF ANY
" " COLLISION OR ANY ERROR IN THE PROGRAM. IT
" " PRINTS THE CURRENT SIMULATION TIME AND LISTS
" " THE ATTRIBUTES OF ALL VEHICLES IN EACH LAUE
" " AS WELL AS THE ATTRIBUTES OF ALL VEHICLES (IF
" " ANY) IN ANY OF THE TWO DAMMY LANCES.

START NEW PAGE

PRINT 2 LINE WITH TIME.V THUS
A PROBLEM HAS BEEN ENCOUNTERED AT TIME * * * * * *
========================================================================

SKIP 2 LINES
LIST ATTRIBUTES OF EACH VEHICLE IN LH(1)
LIST ATTRIBUTES OF EACH VEHICLE IN LH(2)
LIST ATTRIBUTES OF EACH VEHICLE IN LH(3)
LIST ATTRIBUTES OF EACH VEHICLE IN WV(1)
LIST ATTRIBUTES OF EACH VEHICLE IN WV(2)

END ""SHAP.R
S. PROGRAM HDWY.ARRIVAL(V) YIELDING W

```
USING A SHIFTED NEGATIVE EXPONENTIAL DISTRIBUTION FUNCTION, THIS SUBPROGRAM COMPUTES THE INTERARRIVAL TIME FOR VEHICLES IN EACH LANE.
```

DEFINE K,VW AS VARIABLES
DEFINE V AS VARIABLE

LET K = RANDOM.F(3)
LET VW = 1.00-((3600/V)-1.0)-LOG.E.F(K)

RETURN WITH VW
END ** S.PROGRAM HDWY.ARRIVAL
THIS SUBPROGRAM IS ACTIVATED UPON ENTRANCE OF A NEW VEHICLE IN THE SYSTEM. IT DETERMINES THE BRAKE REACTION TIME AND THE MAXIMUM SPEED FOR EACH VEHICLE. IT ALSO COMPUTES AN ARRIVAL SPEED FOR EACH VEHICLE. APPROPRIATE ADJUSTMENTS ARE MADE BASED ON THE MINIMUM SAFE-FOLLOWING DISTANCE CRITERIA, TO BRAKE REACTION TIME AND ARRIVAL SPEED OF VEHICLES.

DEFINE NLL,P,L2 AS INTEGER VARIABLES
DEFINE BR, ARR.SPD, GAP, MAX.SPD, B, T1, T2, T3, VLD, VE2L, PLV, ACL, MX.SPD.X1, X2, T1, T2, T3, Y AS VARIABLES

COMPUTE BRAKE REACTION TIME

'1' LET B=GAUSS.F(B, MEAN.B, PARAM, 1)
IF B>1.5 OR B<=.25 Go TO 1
ALWAYS

COMPUTE VEHICLE MAXIMUM SPEED

'2' LET MAX.SPD = NORMAL.F(MX.SPD(NLL)/C.F, MX.SIGMA(NLL), 1)
IF MAX.SPD>UP.MX.SPD(NLL)/C.F OR MAX.SPD<LOW.MX.SPD(NLL)/C.F Go TO 2
ALWAYS

LET ARR.SPD = MAX.SPD

CHECK THE SPEED AND BRAKE REACTION TIME FOR MINIMUM SAFE-FOLLOWING DISTANCE CRITERIA

LET P=1/NLL(NLL)
IF P=0

THIS IS THE FIRST VEHICLE IN THIS LANE
LET BR = B
LET ARR.SPD = ARR.SPD
ELSE

THIS IS NOT THE FIRST VEHICLE IN THIS LANE

LET T11 = TIME.V-LST.UPD(NILL)
LET VLD = S.AFTER(L.LN(NILL))
LET LL2 = LENGTH(L.LN(NILL))
LET PLD = P.AFTER(L.LN(NILL))
LET ACL = ACCELERATION(L.LN(NILL))
LET PLV = VLD-T11+ACL*T11^2/2+PLD
LET VE2L = VLD+ACL*T11
LET X1 = (PLV-LL2)/2
LET T1 = (VE2L^2)/(2*ED)
LET T2 = PLV-LL2+T1
LET T3 = (T2^2)/2

IF B^2+T3<0.00

'' THIS VEHICLE SHOULD NOT ENTER THE SYSTEM (TOO
CLOSE TO ITS LEADER).

LET BR = 0.0
RETURN
ALWAYS

LET X2 = XED(-B-SQRT.F(B^2+CT3))
LET VE = MIN.F(L0V. AR.SPD*M.S.F(NILL)/C.F,VE2L)
LET IX.SP = MIN.F(X1,X2)

IF IX.SP>=AR.SP

IF AR.SP=68.00 AND B>=.745*(M.AR.SPD*M.S.F(NILL)/C.F)/AR.SP
LET BR=(.745*M.AR.SPD*M.S.F(NILL)/C.F)/AR.SP
ELSE
LET BR=B
ALWAYS
LET ARR.SP=AR.SP
ELSE

'' ACCORDING TO MINIMUM SAFE-FOLLOWING DISTANCE
'' CRITERIA THIS VEHICLE CANNOT MAINTAIN ITS
'' DESIRED SPEED. THE BRAKE REACTION TIME AND
'' SPEED OF THIS VEHICLE IS, THEREFORE,
'' ADJUSTED SUCH THAT THE VEHICLE COULD MAIN-
'' TAIN A SPEED EQUAL TO EITHER THE LANE
'' MINIMUM SPEED OR THAT OF ITS LEADER.

IF IX.SP=VE
LET ARR.SP=IX.SP
LET BR=B
ELSE
LET ARR.SP=VE
LET BR=(IX.SP/VE)^B
ALWAYS
ALWAYS
ALWAYS
RETURN!
END 'SPEED.BAT
S. PROGRAM DESIRED.LANE(CUR.LANE, ORGL, DEST, VFD, DES.V, AFD, STAT)
YIELDING NEW.LANE

```
THIS SUBPROGRAM DETERMINES THE LANE-CHANGING
NEED FOR WEAVING AND NON-WEAVING VEHICLES. IT
FINDS AND ASSIGNS NEW LANES TO ALL CHANGING
VEHICLES BASED ON THEIR CURRENT LANE AND DEST-
INATION.
```

DEFINE VFD, DES.V, AFD AS VARIABLES
DEFINE NEW.LANE, CUR.LANE, ORGL, DEST, M.ELC AS INTEGER VARIABLES
DEFINE STAT AS TEXT VARIABLES

IF STAT EQ "NON.WEAVE" AND CUR.LANE NE 3

```
THIS VEHICLE IS A NON-WEAVING VEHICLE AND IS
NOT CURRENTLY IN LANE 3
```

LET M.ELC = HOME ESSENTIAL.LC(VFD, DES.V, AFD)
IF M.ELC EQ OKAY

```
THE NON-ESSENTIAL LANE-CHANGING DESIRE HAS
BEEN ESTABLISHED FOR THIS VEHICLE
```

IF ORGL = 1
   LET NEW.LANE = 2
ELSE
   LET NEW.LANE = 1
ALWAYS

ALWAYS
ELSE
IF CUR.LANE NE DEST
   IF CUR.LANE = 3 OR CUR.LANE = 1
      LET NEW.LANE = 2
   ELSE
      LET NEW.LANE = DEST
   ALWAYS
ELSE
   LET NEW.LANE = 0
   ALWAYS
ALWAYS

RETURN
END ** DESIRED.LANE
THIS SUBPROGRAM DETERMINES THE NONE-ESSENTIAL CHANGING NEED FOR NON-WEAVING VEHICLES. THE LANE CHANGING DESIRE IS GENERATED RANDOMLY FROM A BINOMIAL PROBABILITY DISTRIBUTION FOR ALL VEHICLES TRAVELLING BELOW THEIR DESIRED SPEED AND ACCELERATING BY LESS THAN 1.0 FPS DURING THE LAST UPDATE INTERVAL.

DEFINE HE.VFD, HE.DES.V, HE.AFD AS VARIABLES
DEFINE K AS INTEGER VARIABLE

IF HE.VFD < HE.DES.V AND HE.AFD <= 1.0 AND VL(1) > 0.0
LET K = BINOMIAL.F(1, PLC, 4)
RETURN WITH K
ELSE
RETURN WITH 0

END '' NONE.ESSENTIAL
S. PROGRAM CRITICAL. GAP(IL, SPD, TYP)

```
'' THIS SUBPROGRAM COMPUTES THE CRITICAL GAP FOR A
'' GIVEN SPEED AND VEHICLE TYPE.

DEFINE GAP, VAR AS VARIABLE
DEFINE TYP AS TEXT VARIABLE
DEFINE IL AS INTEGER VARIABLE

LET VAR = (UP. MX. SPD(IL)/C.F - SPD)/(UP. MX. SPD(IL)/C.F - LOW. MX. SPD(IL)/C.F)
IF VAR <= .005
    LET VAR = .005
    ALWAYS
IF VAR > .995
    LET VAR = .995
    ALWAYS

'' COMPUTE THE CRITICAL GAP
'' =========================

LET C.GAP = (11.325 + LOG.E(1-VAR)/VAR)/.1188

IF TYP NE "PASGR"
    LET GAP = C.GAP + 20
ELSE
    LET GAP = C.GAP
    ALWAYS

RETURN WITH GAP
END '' S. PROGRAM CRITICAL. GAP
S. PROGRAM: INITIAL.CHECK(VFDG,PFDG,AFDG,BRTG,TYPG,LLLG, H,LG,STATG) YIELDING CHK,ADJ

```
""
""
""
""
""
""
""
""
""
""
""
""
""
```

```
IN THIS SUBPROGRAM: VEHICLES FLAGGED FOR LANE-
CHANGING WILL BE CHECKED TO SEE IF SUCH A
CHANGE IS POSSIBLE. IF THE VEHICLE IS A WEAVING
VEHICLE A LANE-CHANGING FACTOR WILL BE COMPUTED
BASED ON THE CURRENT POSITION OF THE VEHICLE
WITH RESPECT TO THE WEAVING SECTION EXIT GORE.
THE FOLLOWING CHECKS WILL BE PERFORMED ON EACH
VEHICLE:

A. THE LEAD HEADWAY CHECK
B. THE LAG HEADWAY CHECK
C. THE CRITICAL GAP CHECK

IF ALL THREE CHECKS ARE POSITIVE THE SUBPROGRAM
RETURNS A "1" AND A "0" OTHERWISE. IF EITHER
THE LEAD HEADWAY OR THE LAG HEADWAY CHECK IS
UNSUCCESSFUL APPROPRIATE SUBPROGRAMS WILL BE
CALLED UPON TO ADJUST VEHICLE SPEED IN ORDER TO
MAKE THE LANE-CHANGING POSSIBLE.

INFORMATION ON SIZE AND NUMBER OF ACCEPTED GAPS
ARE COLLECTED AND WHEN NEEDED THE NUMBER OF
REJECTED GAPS ARE INCREASED.

DEFINE VFDG,PFDG,D.SP,G,AFDG,L.H.G,LPOS1,LV1,LACL,BRTG,FV1,
PPGS1, FACL, FBRT, AV.GAP, T.GAP AS VARIABLES
DEFINE LLLG,H,LG,NEW.LEADER,CUR.LEADER,FOLLOWER,N.LEADER,
LG.HD/Y, LD.HD/Y, H.FOLLOWER, LLGT, CUR.FOLLOWER,
CHK, LD.S.ADJ, LG.S.ADJ AS INTEGER VARIABLES
DEFINE TYPG, FTYP, STATG, LTYPG, ADJ,SAME AS TEXT VARIABLES

IF STATG EQ "WEAVE"
```

```
""
""
""
```

```
● THIS VEHICLE IS A WEAVING VEHICLE

● COMPUTE THE LANE-CHANGING FACTOR

-----------------------------

LET POSITION = PFDG-B.BUFFER.L
LET FACTOR = MAX.F(EXP.F(LOG.F(1+VW.FACT(N.L.G)/TOT.WV)
*POSITION/VW.LENGTH),1.0)
```

```
ELSE

""
```

```
● THIS VEHICLE IS A NON-WEAVING VEHICLE
```

LET FACTOR = 1
ALWAYS

```
** FIND THE LEADER AND THE FOLLOWER IN THE
** THE NEW LANE

IF N.LI(N.L.G) < 1
** THE NEW LANE IS EMPTY

LET CHK = 1
LET ADJ = "O.K"
RETURN
ALWAYS

FOR EACH VEHICLE IN H.LI(N.L.G) WITH P.AFTER <= PFDG
FIND FOLLOWER = THE FIRST VEHICLE
IF NONE
** THIS VEHICLE DOESN'T HAVE A FOLLOWER IN THE
** DESIRED NEW LANE.

LET NEW.LEADER = L.LI(N.L.G)
LET NEW.FOLLOWER = NONE
ELSE

IF FOLLOWER = F.LI(N.L.G)
LET NEW.LEADER = NONE
** THIS VEHICLE DOESN'T HAVE A LEADER IN THE
** DESIRED NEW LANE.
ELSE
LET NEW.LEADER = P.LI(FOLLOWER)
ALWAYS
ALWAYS
IF NEW.LEADER = NONE
LET LD.HDVY = OKAY
ELSE
** COPY ATTRIBUTES OF NEW LEADER
** -------------------------------------

LET LPOS1 = P.AFTER(NEW.LEADER)
LET LV1 = S.AFTER(NEW.LEADER)
LET LLGT = LENGTH(NEW.LEADER)
LET LACL = ACCELERATION(NEW.LEADER)
LET LTYP = TYPE(NEW.LEADER)
LET L.HH = HEAD.VY(NEW.LEADER)
** CHECK THE LEAD HEADWAY
** ------------------------
```
LET LD.HDWY = LD.CHECK(VFDG, AFDG, PFDG, LPOS1, LV1, LACL, LLGT,
                     BRTG, TYPG, LTYP, FACTOR, STATG)

ALWAYS

IF LD.HDWY NE OKAY

** THE LEAD HEADWAY CHECK HAS BEEN UNSUCCESSFUL
** DETERMINE TYPE OF THE SPEED ADJUSTMENT
** REQUIRED

LET CHK = 0
LET MDL = CONF.DECEL(VFDG, TYPG)
LET LD.S.ADJ = LD.SPD.ADJ(LPOS1, LV1, LACL, PFDG, VFDG, MDL, L.HH)

IF LD.S.ADJ = 0

LET ADJ = "SLOWER"  ** THE VEHICLE SHOULD SLOW DOWN
ELSE

LET ADJ = "FASTER"  ** THE VEHICLE SHOULD SPEED UP

ALWAYS
RETURN
ELSE

** THE LEAD HEADWAY HAS BEEN SUCCESSFUL. CHECK THE
** LAG HEADWAY

IF II.FOLLOWER = NOON

LET LG.HDWY = OKAY
ELSE

** COPY ATTRIBUTES OF FOLLOWER
** ================

LET FPOS1 = P.AFTER(FOLLOWER)
LET FV1 = S.AFTER(FOLLOWER)
LET FBRT = BRAKT(FOLLOWER)
LET FTYP = TYPE(FOLLOWER)
LET FACL = ACCELERATION(FOLLOWER)

LET LG.HDWY = LG.CHECK(VFDG, AFDG, PFDG, FPOS1, FV1, FACL,
                       LLGT, FBRT, FTYP, LTYP, FACTOR, STATG)

ALWAYS

IF LG.HDWY NE OKAY

** THE LEAD HEADWAY CHECK HAS BEEN UNSUCCESSFUL
** DETERMINE TYPE OF THE SPEED ADJUSTMENT
** REQUIRED
LET CHK = 0
LET H.AL = MAX.ACCEL(VFDG, TYPG)
LET LG.S.ADJ = LG.SPD.ADJ(PFDG, VFDG, H.AL, FPDS1, FV1, FACL)
IF LG.S.ADJ = 0
  LET ADJ = "SLOWER" "THE VEHICLE SHOULD SLOW DOWN"
ELSE
  LET ADJ = "FASTER" "THE VEHICLE SHOULD SPEED UP"
ALWAYS
RETURN
ELSE

; THE LAG HEAdWAY HAS BEEN SUCCESSFUL. CHECK THE
; CRITICAL GAP.

LET AV.GAP = LPDS1 - FPDS1 - LLGT
LET C.GAP = CRITICAL_GAP(H.L.G, VFDG, TYPG)
IF AV.GAP >= C.GAP/FACTOR
  LET CHK = 1 "THE GAP HAS BEEN ACCEPTED"
  LET ADJ = "O.K"
ELSE
  LET C.H.K = 0 "THIS GAP HAS BEEN REJECTED"
  LET ADJ = "SAME"
RETURN
END "S.PROGRAM INITIAL.CHECK"
PROGRAM LD.CHECK(VFDG, AFDG, PFDG, LPOS1, LV1, LAACL, LLNG,
                        BRTG, TYPG, TYPL, FACT, STAT)

' ' THIS SUBPROGRAM PERFORMS ALL NECESSARY CHECKS
' ' FOR A LEAD HEADWAY CHECK. IF THE CHECK IS
' ' POSITIVE, IT RETURNS A "1" AND A "0" OTHERWISE.

DEFINE TYPG, TYPL, STAT AS TEXT VARIABLE
DEFINE CAR.F.CHECK, LLNG AS INTEGER VARIABLES
DEFINE VFD2, PFD2, LPOS2, LV2 AS VARIABLES

' ' PREDICT SPEED AND POSITION FOR THE NEXT
' ' INTERVAL

' ' LEADER
' ' ==========

            LET VFD2 = VFDG+AFDG
            LET PFD2 = PFDG+VFDG+AFDG/2.

' ' LEADER
' ' ==========

            LET LPOS2= LPOS1+LV1+LAACL/2.
            LET LV2 = LV1+LAACL

IF LV2 > VFD2 AND LPOS2 > PFD2+10+LLNG

' ' THE SPEED OF THE NEW LEADER IS GREATER THAN THE
' ' LANE-CHANGING VEHICLE AND THEY ARE MORE THAN
' ' 10 FEET APART.

            RETURN WITH 1
ELSE

            LET CAR.F.CHECK = SAFE(LPOS2, PFD2, LV2, VFD2, LLNG,
                                   TYPG, TYPL, BRTG, FACT, STAT)

            IF CAR.F.CHECK = OKAY
                RETURN WITH 1
            ELSE
                RETURN WITH 0

END ' 'S.PROGRAM LD.CHECK
THIS SUBPROGRAM PERFORMS ALL NECESSARY CHECKS
FOR A LAG HEADWAY CHECK. IF THE CHECK IS
POSITIVE, IT RETURNS A "1" AND A "0" OTHERWISE.

DEFINE FTYP,LTYP,STAT AS TEXT VARIABLE
DEFINE LLLG,CAR.F.CHECK AS INTEGER VARIABLES
DEFINE VFD2,PFD2,FV2,FPOS2 AS VARIABLES

PREDICT SPEED AND POSITION FOR THE NEXT
INTERVAL

=======

LET VFD2 = VFDG+AFDG
LET PFD2 = PFDG+VFDG+AFDG/2.

FOLLOWER

=======

LET FV2 = FV1+FACL
LET FPOS2 = FPOS1+FV1+FACL/2

IF VFD2 > FV2 AND PFD2 >= FPOS2+LLLG+15

THE LANE-CHANGING VEHICLE HAS SPEED GREATER
THAN THAT OF ITS NEW FOLLOWER AND THE TWO
VEHICLES WILL BE MORE THAN 15 FEET APART IN
THE DESIRED NEW LANE.

RETURN WITH 1

ELSE

LET CAR.F.CHECK = SAFE(PFD2,FPOS2,VFD2,FV2,
LLLG,FTYP,LTYP,FBRT,FACT,STAT)

IF CAR.F.CHECK = OKAY
    RETURN WITH 1
ELSE
    RETURN WITH 0

END ""S.PROGRAM LG.CHECK
S PROGRAM SAFE(PL, PF, VLL, VLF, LL, TYPF, TYPL, BRTF, FACT, STAT)

** THIS SUBPROGRAM IS CALLED UPON BY SUBPROGRAMS
** LD.CHECK AND LG.CHECK AS PART OF THEIR CHECK
** FOR A SUCCESSFUL LANE-CHANGING MANEUVER. IT
** COMPUTES THE ACCELERATION THAT A LANE-CHANGING
** VEHICLE MUST UNDERGO SO THAT IT WILL BE SAFELY
** BEHIND THE NEW LEADER OR THE ACCELERATION THAT
** THE POTENTIAL NEW FOLLOWER MUST UNDERGO IN
** ORDER FOR THE LANE-CHANGING VEHICLE TO MOVE
** IN FRONT OF IT SAFELY. THIS ACCELERATION IS THEN
** COMPARED WITH THE VEHICLE'S ACCEPTABLE DECELER-
** RATION RATE. WHEN THE COMPUTED ACCELERATION IS
** GREATER THAN THE ACCEPTABLE DECELERATION, THE
** SUBPROGRAM RETURNS A "1", INDICATING THAT THE
** MERGING IS SAFE. OTHERWISE A "0" WILL BE
** RETURNED, INDICATING DENIAL OF MERGING DUE TO
** UNSAFE POSITIONING OF THE VEHICLES.

DEFINE LL AS INTEGER VARIABLE
DEFINE TYPF, TYPL, STAT AS TEXT VARIABLE

IF PL-PF-LL <=0.0
    RETURN WITH 0
ALWAYS

** COMPUTE THE ACCELERATION!
** --------------------------

LET C.DL = CONF.DECEL(VLL, TYPL)
LET DENOMINATOR = PL-PF-VLF-(BRTF)+VLL^-2/(-2*C.DL)-10-LL
LET NUMERATOR = VLF^-2
LET AF = ABS(F(NUMERATOR/(2*DENOMINATOR)))

IF STAT HE "WEAVE"

** THIS VEHICLE IS A NON-WEAVING VEHICLE

    LET ACPT.DECEL = CONF.DECEL(VLF, TYPF)
ELSE

** THIS VEHICLE IS A WEAVING VEHICLE

    LET ACPT.DECEL = -MED-FACT
ALWAYS

** COMPARE THE COMPUTED ACCELERATION WITH THE
"ACCEPTABLE ACCELERATION"

IF -AF >= ACCEPT.DECEL
    RETURN WITH 1 "MERGING IS SAFE"
ELSE
    RETURN WITH 0 "MERGING IS UNSAFE"
END "SAFE"
S. PROGRAM LD.SPD.ADJ(PL, VL, AL, PCH, VCH, MDL, L. HEAD)

** THIS SUBPROGRAM DETERMINES THE TYPE OF THE **
** SPEED ADJUSTMENT REQUIRED IN ORDER TO FIND AN **
** ACCEPTABLE LEAD HEADWAY FOR THE LANE CHANGING **
** VEHICLE. **

DEFINE I, K, LL AS INTEGER VARIABLES
DEFINE TYPCH, TYPL AS TEXT VARIABLES

IF PCH <= BUFFER.L + 2*V.V. LENGTH/3

** DETERMINE THE TIME REQUIRED TO FIND AN ACCEPTABLE **
** TABLE LEAD HEADWAY IF THE CHANGER INCREASES ITS **
** SPEED. **

LET DIST1 = PL - PCH

LET PPCH = PCH + VCH + MDL/2.0
LET PPL = PL + VL + AL/2.0
LET DIST2 = PPL - PPCH
IF DIST2 <= DIST1 AND VL <= VCH - 10.0 AND L. HEAD >= 75.0

RETURN WITH 1 ' 'FASTER
ELSE
RETURN WITH 0 ' 'SLOWER
ELSE
RETURN WITH 0 ' 'SLOWER

END ' 'SUBPROGRAM LD.SPD.ADJ
S.PROGRAJ! LG.SPD.ADJ(PCH, VCH, HAL, PF, VF, AF)

'' THIS SUBPROGRAM DETERMINES THE TYPE OF THE
'' SPEED ADJUSTMENT REQUIRED IN ORDER TO FIND AN
'' ACCEPTABLE LAG HEADWAY FOR THE LANE CHANGING
'' VEHICLE

DEFINE I,K, ICH AS INTEGER VARIABLES
DEFINE TYPCH, TYPF AS TEXT VARIABLES

IF PCH <= B.BUFFER.L + 2*V.V.LENGTH/3

'' DETERMINE THE TIME REQUIRED TO FIND AN ACCEPTABLE LAG HEADWAY IF THE CHANGER DECREASES ITS SPEED

LET DIST1 = PCH - PF

''

LET PPCH = PCH + VCH + HAL/2.0
LET PPF = PF + VF + AF/2.0
LET DIST2 = PPCH - PPF

IF DIST2 >= DIST1 OR VCH >= VF + 10.0
   RETURN WITH 1 'FASTER
ELSE
   RETURN WITH 0 'SLOWER
ELSE
   RETURN WITH 0 'SLOWER

END ''SUBPROGRAM LG.SPD.ADJ
S. PROGRAM FINAL.CHECK(PFDF, LL, H.L, VFDF, STAT, TYP, BRT)

** IN THIS SUBPROGRAM VEHICLES THAT HAVE ALREADY
** PASSED THE INITIAL CHECK FOR LANE-CHANGING WILL
** GO THROUGH THE FINAL CHECK. IF CURRENT POSITION
** OF THE LEADER/FOLLOWER AND THE LANE-CHANGING
** VEHICLE ALLOW A SAFE LANE-CHANGING MANEUVER,
** THEN THE VEHICLE WILL CHANGE LANE (SUBPROGRAM
** RETURNS A "1").

DEFINE LL, H.L, LLNG, LEADER, FOLLOWER, H.LEADER, H.FOLLOWER,
LG.LOOK, LD LOOK AS INTEGER VARIABLES
DEFINE FPOS, LPOS, VFDF, BRT, PFDF, LSPD, FSPD AS VARIABLES
DEFINE TYP, TYPL, TYPF, STAT AS TEXT VARIABLES

** FIND THE LEADER AND FOLLOWER IN THE DESIRED
** NEW LANE

LET FACT = 1.0

FOR EACH VEHICLE IN LN(H.L) WITH P.AFTER <= PFDF
FIND FOLLOWER = THE FIRST VEHICLE
IF NONE

** THIS VEHICLE DOES NOT HAVE A FOLLOWER IN THE
** DESIRED NEW LANE

LET LEADER = L.LN(H.L)
LET H.FOLLOWER = NONN
LET LPOS = P.AFTER(LEADER)
ELSE
IF FOLLOWER = F.LN(H.L)

** THIS VEHICLE DOES NOT HAVE A LEADER IN
** THE NEW LANE

LET H.LEADER = NONN
ELSE
LET LEADER = P.LN(FOLLOWER)
LET LPOS = P.AFTER(LEADER)
LET LLNG = LENGTH(LEADER)
ALWAYS
LET FPOS = P.AFTER(FOLLOWER)
ALWAYS
IF H.LEADER = NONN
IF PFDF <= FPOS + LL + 10
RETURN WITH 0
ELSE
RETURN WITH 1
ELSE
IF MOV.STATUS(LEADER) NE 0

' THIS GAP HAS JUST BEEN ACCEPTED BY ANOTHER
' VEHICLE. DOUBLE CHECK THE MINIMUM SAFE-FOLLOWING
' DISTANCE CRITERIA.

LET LSPD = S.AFTER(LEADER)
LET TYPL = TYPE(LEADER)
LET LD.LOOK = SAFE(LPOS, PFDF, LSPD, VFDF, LLHG,
                     TYP, TYPL, BRT, FACT, STAT)

IF LD.LOOK NE OKAY
RETURN WITH 0
ALWAYS
ALWAYS
IF H.FOLLOWER = DOOK
GO TO 20
ELSE
IF MOV.STATUS(FOLLOWER) NE 0

' THIS GAP HAS JUST BEEN ACCEPTED BY ANOTHER
' VEHICLE. DOUBLE CHECK THE MINIMUM SAFE-FOLLOWING
' DISTANCE CRITERIA.

LET FSPD = S.AFTER(FOLLOWER)
LET TYPF = TYPE(FOLLOWER)
LET BRTF = BRAKT(FOLLOWER)
LET LG.LOOK = SAFE(PFDF, FPOS, VFDF, FSPD, LL,
                    TYPF, TYPL, BRTF, FACT, STAT)

IF LG.LOOK NE OKAY
RETURN WITH 0
ELSE
GO TO 10
ELSE

' LEAD AND LAG CHECK
' ================

'10' LET FPOS = P.AFTER(FOLLOWER)
     LET FSPD = S.AFTER(FOLLOWER)
     LET FACL = ACCELERATION(FOLLOWER)

'20' LET LPOS = P.AFTER(LEADER)
     LET LSPPD = S.AFTER(LEADER)
     LET LAACL = ACCELERATION(LEADER)
IF LPOS >= MAX.F(PFDF+LLMG+10-LACL,PFDF+LLMG-LACL+VFDF-LSPD-MED-10) AND
PFDF >= MAX.F(FPOS+LL+FACL+FSPD-TDF-MED-10,FPDS+LL+FACL)
RETURN WITH 1
ELSE
RETURN WITH 0
END "S.PROGRAM FINAL.CHECK
S PROGRAM CAR FOLLOWING(LINF, VFTF, PFTF, D S F, BRTF, LLF,
VLD, PLDF, TF, KC, TYPF, STAT, L, ADJ,
AF, LEAD ST, MOV ST, SD)
YIELDING VDF, PFD, ADF

"" IN THIS SUBPROGRAM ALL WEAVING VEHICLES WILL BE
"" CHECKED TO SEE IF SPEED ADJUSTMENTS ARE REQUIRED
"" FOR LANE-CHANGING MANEUVERS. IF YES, SUBPROGRAM
"" ADJ.CAR.FOLLOWING WILL BE CALLED UPON TO COMPUTE
"" THE NEW ACCELERATION RATE. OTHERWISE THE MAXIMUM
"" RATE OF ACCELERATION WILL BE COMPUTED BASED ON
"" THE SAFE-FOLLOWING DISTANCE CRITERIA, INHIBITED
"" BY THE VEHICLES DESIRED SPEED AND ITS
"" ACCELERATION/DECELERATION CAPABILITIES.
"" BASED ON THE COMPUTED ACCELERATION/DECELERATION
"" RATE, THE POSITION AND SPEED OF THE VEHICLES
"" WILL BE UPDATED.

DEFINE VFTF, PFTF, D S F, BRTF, VLD, PLDF, TF, VDF, PFD,
AFDF, DENOM INATOR, AFDC1, AFDC2, AFDC3, AFDC4, F,
F1, F2, P, VFDU, F9, AF AS VARIABLES
DEFINE LINF, LLF, KC, L, LEAD ST, MOV ST AS INTEGER VARIABLES
DEFINE TYPF, STAT, ADJ AS TEXT VARIABLES

"" CHECK IF ADJUSTMENT NEEDS TO BE MADE TO THE SPEED
"" OF THE WEAVING VEHICLES IN ORDER TO MAKE THE
"" LANE-CHANGING POSSIBLE

LET CDF. D = CONF. DECEL(VFTF, TYPF)
LET LEAD. H = PLDF - LLF - (PFTF + VFTF* TF + AF*(TF-2)/2.0)

IF STAT = "WEAVE" AND (ADJ = "FASTER" OR ADJ = "SLOWER")
AND LEAD ST < 1 AND AF > CDF. D - 2.0
AND LEAD. H > LLF + 15 AND MOV ST < 1

"" 1. THIS VEHICLE IS A WEAVING VEHICLE
"" 2. SPEED ADJUSTMENT IS REQUIRED FOR THIS VEHICLE
"" IN ORDER TO COMPLETE THE LANE-CHANGING PROCESS
"" 3. THIS VEHICLE IS NOT THE FOLLOWER OF A VEHICLE
"" WHICH HAS JUST CHANGED LANE
"" 4. THIS VEHICLE IS NOT DECELERATING 2.0 FTPS
"" BELOW ITS COMFORTABLE DECELERATION RATE
"" 5. THIS VEHICLE HAS NOT CHANGED LANE DURING LAST
"" TWO INTERVALS

CALL ADJ.CAR.FOLLOWING(PFTF, VFTF, AF, TYPF, ADJ,)
PLDF,LLF,LT) YIELDING AFDF

GO TO 1
ELSE
    IF KC=1

      ** FIRST VEHICLE IN LANE 1, 2 OR 3

      IF VFTF < D.S.F

      ** THIS VEHICLE IS TRAVELLING BELOW ITS DESIRED SPEED

          IF PFTF = B.BUFFER.L
            LET AFDC3 = (D.S.F - VFTF)/TF
          ELSE
            LET AFDC3 = (D.S.F - (M.MAX.SPD(1ILF) - M.AR.SPD - M.S.F(1ILF)) / C.F - VFTF) / TF
          ALWAYS
            LET MAX.PASS.ACCEL = MAX.PASS.ACCEL(VFTF,TYPF)
          LET AFDC4 = MAX.PASS.ACCEL
          LET AFDF = MIN.F(AFDC4,AFDC3)
        ELSE
          LET AFDF = 0.00
          ALWAYS
          GO TO 1
ELSE

      ** THIS VEHICLE HAS A LEADER

      IF ABS.F(VFTF - VLDF) <= 0.01

      ** BOTH LEADER AND FOLLOWER HAVE ALMOST THE SAME SPEED.

          LET AFDF = (VLDF - VFTF)/TF

      ** LET VDF = MAX.F(VLDF,0.0)

      ** LET PFDF = MAX.F(PFTF,PFTF + VFDF*TF)
      GO TO 1
ELSE
    IF TF<1.00 AND VFTF>VLDF AND VFTF<D.S.F

      ** THIS VEHICLE HAS JUST ARRIVED TO THE SYSTEM

          LET F3 = 0.5*(VFTF-2-VLDF-2)/MED
          IF TF> = (PLDF-PFTF-LLF-SD-BRTF-VFTF-F3)/VFTF
          GO TO 6
        ELSE
          LET AFDC2=0.00
          GO TO 7
ELSE

      ** COMPUTE THE ACCELERATION FOR THE SAFE-FOLLOWING DISTANCE CRITERIA WHEN THE LEADER HAS SPEED GREATER THAN THE FOLLOWER
LET NUMERATOR = -LLF*PLDF-VFTF*(TF+BRTF)-PFTF-SD
LET DENOMINATOR = 2*BRTF*TF + TF*2
LET AFDC1 = 2*NUMERATOR/DENOMINATOR

** ENSURE CONSTRAINT: COMPUTE THE ACCELERATION FOR THE CONDITION WHEN THE LEADER IS DECELERATING AT ITS MAXIMUM EMERGENCY DECELERATION RATE.

LET F = 0.6*(VFTF*2 - VLDF*2)
LET F1 = (2*MED/TF) * (TF/2*BRTF*VFTF/ME)
LET F9 = PLDF-PFTF-VFTF*TF-LLF*BRTF*VFTF-MED-F/ME
LET F2 = (2*MED/(TF*2)) * (F9)
LET AFDC2 = -0.5*F1 + 0.5*SQR.T.F(F1*2 + 4*F2)

** COMPUTE THE ACCELERATION TO REACH THE DESIRED SPEED.

'7' IF PPTF >= B.BUFFER.L
    LET AFDC3 = (D.S.F-VFTF)/TF
ELSE
    LET AFDC3 = (D.S.F-(M. MAX.SPD(LEFT)-M. AR.SPD-M. S.F(LEFT))/C.F-VFTF)/TF
ALWAYS

** DETERMINE THE MAXIMUM RATE OF ACCELERATION FOR A GIVEN VEHICLE AT A GIVEN SPEED.

LET AFDC4 = MAX.ACCEL(VFTF,TYPF)

IF VLDF >= VFTF

** THE LEADER HAS SPEED GREATER THAN THAT OF THE FOLLOWER

ELSE
    LET AFDF = MIN.F(AFDC1,AFDC2,AFDC3,AFDC4)
ELSE
    LET AFDF = MIN.F(AFDC2,AFDC3,AFDC4)
ALWAYS

** THIS VEHICLE HAS JUST CHANGED LANE

LET AFDF = MIN.F(AFDF,0.0)
ALWAYS

** COMPUTE THE UPDATED POSITION AND SPEED OF THE VEHICLE
LET $V_{DF} = \max(F(V_{TF} + T - A_{DF}, 0), 0)$
LET $P_{DF} = \max(F(P_{TF}, P_{TF} + V_{TF} - T + A_{DF} - (T - 4) / 2), 0)$

RETURN

END " CAR-FOLLOWING
THIS SUBPROGRAM COMPUTES THE ACCELERATION/DECELERATION RATE FOR THOSE VEHICLES WHICH REQUIRE A SPEED ADJUSTMENT IN ORDER TO MAKE THE LANE-CHANGING POSSIBLE.

DEFINE STATF, ADJF, TYPF AS TEXT VARIABLES
DEFINE LL, L AS INTEGER VARIABLES

IF ADJF = "FASTER"

UPWARD SPEED ADJUSTMENT IS REQUIRED IN ORDER TO MAKE THE LANE-CHANGING POSSIBLE

LET AUX = MAX ACCEL(VF, TYPF)
LET AD = MAX F(AUX, AF)

MAXIMUM SPEED CONSTRAINT

LET ASPD = UP. MAX. SPD(L)/C.F-VF

FOLLOWING DISTANCE CONSTRAINT

LET ADIST = 2*(PL-LL-PF-VF-T)/(T-2)
LET ACL = MIN F(ASPD, ADIST, AUX)
LET ACL = MAX F(ACL, 0.0)

COMPARE CURRENT AND UPDATED ACCELERATION RATES

IF ACL-AF >= AUX
LET ACL = MAX F(0.0, AF + ACL)
ALWAYS RETURN
ELSE

DOWNWARD SPEED ADJUSTMENT IS REQUIRED IN ORDER TO MAKE THE LANE-CHANGING POSSIBLE

LET DMX = CONF. DECEL(VF, TYPF)
LET DM = MIN F(DMX, AF)

MINIMUM SPEED CONSTRAINT

LET DSPD = (LOW. MAX. SPD(L)-15.0)/C.F-VF
LET ACL = MAX F(DSPD, DM)
LET ACL = MIN.F(ACL, 0.0)

```
FOLLOWING DISTANCE CONSTRAINT
```

\\[\text{LET UP\_POS = PF + VF\_T + ACL\_\cdot(T\_\cdot 2)}/2.~\]

IF PL\_UP\_POS < LL

\\[\text{LET DDIST = 2\cdot(PL\_PF\_VF\_T\_LL)/(T\_\cdot 2)}~\]

\\[\text{LET ACL = MIN.F(ACL, DDIST, 0.0)}~\]

ALWAYS

RETURN!

END "ADJ\_CAR\_FOLLOWING"
S.PROGRAM MAX.ACCEL(VFTM,TYPH)

```

** THIS SUBPROGRAM GIVES MAXIMUM RATE OF ACCELERATION FOR A GIVEN SPEED AND VEHICLE TYPE. **

DEFINE VFTM,MX.ACCEL AS VARIABLES
DEFINE TYPH AS TEXT VARIABLE

IF TYPH EQ "PASGR"
    LET MX.ACCEL = -0.1296082·VFTM+13.86120219
ELSE
    IF TYPH EQ "TRUCK"
        LET MX.ACCEL = -0.04442623·VFTM-3.65684999
    ELSE
        LET MX.ACCEL = -0.04311476·VFTM+3.46349727
    ALWAYS
    ALWAYS
RETURN WITH MX.ACCEL
END '' MAX.ACCEL
```
FOR A GIVEN SPEED AND VEHICLE TYPE, THIS
SUBPROGRAM YIELDS A COMFORTABLE DECELERATION
RATE.

DEFINE VFTCD, COMFORT.D AS VARIABLES
DEFINE TYPCD AS TEXT VARIABLES

IF VFTCD <= 22.00
    LET COMFORT.D = -7.773
    GO TO 1
ELSE
    IF VFTCD > 22.00 AND VFTCD <= 44.00
        LET COMFORT.D = -6.746
        GO TO 1
    ELSE
        LET COMFORT.D = -4.84
    "1" IF TYPCD EQ "TRUCK"
        LET COMFORT.D = COMFORT.D * 0.75
    ELSE
        IF TYPCD EQ "TRAILER"
            LET COMFORT.D = COMFORT.D * 0.66
        ALWAYS
        ALWAYS
RETURN WITH COMFORT.D
END 'CONF.DECEL'
S. PROGRAM COAST.DECEL(SPD,TYP) YIELDING ACL.COAST

' ' FOR A GIVEN SPEED AND VEHICLE TYPE, THIS
' ' SUBPROGRAM YIELDS A FREEWAY COASTAL DECELERATION RATE.

DEFINE SPD,ACL.COAST AS VARIABLES
DEFINE TYP AS TEXT VARIABLE

IF TYP EQ "PASGR"
  IF SPD < = 40.00
    LET ACL.COAST = -1.00
  ELSE
    IF SPD < = 60.00
      LET ACL.COAST = -2.00
    ELSE
      LET ACL.COAST = -3.00
    ALWAYS
  ALWAYS
ELSE
  LET ACL.COAST = -1.00
ALWAYS
RETURN
END '' COAST.DECEL''
S.PROGRAM L.O.S(V.SPD,H.SPD) YIELDING W.LOS,H.W.LOS

...BASED ON AVERAGE RUNNING WEAVING AND NON-WEAVING SPEEDS. THIS SUBPROGRAM RETURNS A LEVEL OF SERVICE (A THROUGH E) FOR WEAVING AND NON-WEAVING TRAFFIC.

DEFINE LOS,W.LOS,H.W.LOS AS TEXT VARIABLE
DEFINE I AS INTEGER VARIABLE

LEVEL OF SERVICE FOR WEAVING TRAFFIC
==================================

LET SPD=V.SPD

IF SPD >= 65.
   LET LOS = "A"
ELSE
   IF SPD >= 60.
      LET LOS = "B"
   ELSE
      IF SPD >= 45.
         LET LOS = "C"
      ELSE
         IF SPD >= 40.
            LET LOS = "D"
         ELSE
            IF SPD >= 35.
               LET LOS = "E"
            ELSE
               LET LOS = "F"
            ALWAYS
         ALWAYS
      ALWAYS
   ALWAYS

LET W.LOS = LOS

LEVEL OF SERVICE FOR NON-WEAVING TRAFFIC
=====================================

LET SPD=H.SPD

IF SPD >= 60.
   LET LOS = "A"
ELSE
   IF SPD >= 54.
      LET LOS = "B"
   ELSE
      IF SPD >= 49.
         LET LOS = "C"
      ELSE
         IF SPD >= 44.
            LET LOS = "D"
         ELSE
            IF SPD >= 39.
               LET LOS = "E"
            ELSE
               LET LOS = "F"
            ALWAYS
         ALWAYS
      ALWAYS
   ALWAYS

LET H.W.LOS = LOS
LET LOS = "B"
ELSE
  IF SPD >= 48.
    LET LOS = "C"
  ELSE
    IF SPD >= 42.
      LET LOS = "D"
    ELSE
      IF SPD >= 35.
        LET LOS = "E"
      ELSE
        LET LOS = "F"
      ALWAYS
    ALWAYS
  ALWAYS
ELSE
  ALWAYS
ALWAYS
ALWAYS
ALWAYS

LET NW. LOS = LOS

RETURN
END "S.PROGRAM LOS"
S. PROGRAM VEH.ATTRIBUTE(ROA, TYPA, PFDA, VFDA, AFDA, LDHA,
H.LCHA, ORIGINA, DESTA, LINA, KPA, ADJA, STATA)

```
\* THIS SUBPROGRAM PRINTS VEHICLE ATTRIBUTES FOR
\* EACH LANE AT ANY USER SPECIFIED TIME INTERVAL.

DEFINE ROA, H.LCHA, ORIGINA, DESTA, LINA, KPA AS INTEGER
VARIABLES
DEFINE PFDA, VFDA, AFDA, LDHA AS VARIABLES
DEFINE TYPA, ADJA, STATA AS TEXT VARIABLES

IF KPA=1
START NEW PAGE
SKIP 5 LINES
PRINT 2 LINES WITH LINA, TIME. V THUS
  ATTRIBUTES OF ALL VEHICLES IN LANE (•)
  AT TIME ————.

  VEHICLE ID, TYPE, POSITION, SPEED, ACCELERATION, LEAD HDWY # OF L.CHANGE
  ORIGIN, DESTINATION, STATUS, SPEED, ADJ

  ---------  ----  --------  -----  -------------  ---------  ----------  

  ---------  ----  --------  -----  -------------  ---------  ----------  

ALWAYS
SKIP 1 LINE
PRINT 1 DOUBLE LINE WITH ROA, TYPA, PFDA, VFDA, AFDA, LDHA, H.LCHA,
ORIGINA, DESTA, STATA, ADJA THUS

RETURN
END ''VEH.ATTRIBUTE''
```
S. PROGRAM: INTERMEDIATE OUTPUT

```
' THIS SUBPROGRAM PRINTS STATISTICS ON MEASURES ' OF PERFORMANCE FOR EACH LANE AND LEVEL OF ' SERVICE FOR WEAVING AND NON-WEAVING TRAFFIC AT ' USER SPECIFIED TIME INTERVALS.

DEFINE I,L AS INTEGER VARIABLES
DEFINE W. LOS, M. LOS AS TEXT VARIABLES

FOR I = 1 TO H. INT .DO
START NEW PAGE
SKIP 2 LINES
PRINT 3 DOUBLE LINES WITH I. I-INTERVAL THUS

STATISTICS ON MEASURES OF PERF
DURING INTERVAL •
PRESENT TIME IS •

SKIP 8 LINES
PRINT 4 DOUBLE LINES LIKE THIS

GINING AVERAGE DENSITY AVERAGE TOTAL NO. OF VEHICLE EXIT LANE CHAIN
SPEED HEADWAY VOLUME CURRENTLY IN THE VOLUME VOLUME SYSTEM FROM
TO (MPH) (VEH/C) (SEC.) ===== = = = = = = = = = = = =

SKIP 2 LINES
FOR L = 1 TO 3 .DO
PRINT 1 DOUBLE LINES WITH L. IN VOL(I,L), NOW VOL(I,L), OUT VOL(I,L),
LCH.FR(I,L), LCH.TO(I,L), S. M. SPD(I,L),
DENSITY(I,L), I. AHEADY(I,L) THUS

LANE •

SKIP 1 LINE
LOOP
PRINT 3 DOUBLE LINES WITH SUM VOL(I), SUM CUR VOL(I), I. T. EXIT(I),
SUM LC(I) THUS

TOTAL •

SKIP 5 LINES
```
PRINT 14 DOUBLE LINES WITH I.LCH.AV.D(I), I.H.AV.D(I), I.AV.TRT(I),
I.W.AV.SPD(I), I.NW.AV.SPD(I),
I.LH.SD.D(I), I.HG.SD.D(I), I.SD.TRT(I),
I.VV.SD.SPD(I), I.HH.SD.SPD(I),
I.LN.X.D(I), I.NW.X.D(I), I.X.X.TRT(I),
I.W.NX.SPD(I), I.NAX.NX.SPD(I),
I.SUM.LCH.D(I), I.H.TOT.D(I), I.TOT.TRT(I) THUS
DELAY - TRAV

<table>
<thead>
<tr>
<th>EL TIME</th>
<th>SPEED</th>
<th>DELAY</th>
<th>- TRAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME</th>
<th>SPEED</th>
<th>DELAY</th>
<th>- TRAV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WEAVING</th>
<th>NON-WEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC.</td>
<td>(MPH)</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AVERAGE</th>
<th>(SEC.)</th>
<th>(SEC.)</th>
<th>(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STD. DEV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAXIMUM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>(SEC.)</th>
<th>(SEC.)</th>
<th>(S)</th>
</tr>
</thead>
</table>

CALL L.0.S(I.W.AV.SPD(I), I.NW.AV.SPD(I)) YIELDING W.LOS, NW.LOS
SKIP 3 LINES
PRINT 4 LINES WITH W.LOS, NW.LOS THUS
LEVEL OF SERVICE FOR WEAVING TRAFFIC IS
LEVEL OF SERVICE FOR NON-WEAVING TRAFFIC IS

LOOP
RETURN
END 'S PROGRAM INTERMEDIATE OUTPUTS
S. PROGRAM: SPD,HDWAY,DATA(SPD,HDWAY,LINe)

' THIS SUBPROGRAM IS ACTIVATED AT EACH 1-SECOND TIME INTERVAL BY EACH VEHICLE. IT COLLECTS SPEED AND HEADWAY DATA FOR EACH VEHICLE.

DEFINE LINE AS INTEGER VARIABLES
DEFINE SPD,HDWAY AS VARIABLES

LET HDWAY = MAX.F(HDWAY,0.0)
IF LINE = 1

' THIS VEHICLE IS IN LANE 1
' ===============
LET SPD1 = SPD.C.F
LET HDWAY1 = HDWAY
ELSE
IF LINE = 2

' THIS VEHICLE IS IN LANE 2
' ===============
LET SPD2 = SPD.C.F
LET HDWAY2 = HDWAY
ELSE

' THIS VEHICLE IS IN LANE 3
' ===============
LET SPD3 = SPD.C.F
LET HDWAY3 = HDWAY
ALWAYS
ALWAYS
RETURN
END "SPD,HDWAY DATA"
S PROGRAM MOE

```
** THIS SUBPROGRAM PRINTS STATISTICS ON SOME
** MEASURES OF EFFECTIVENESS AS WELL AS THE NUMBER
** OF REJECTED GAPS AND REJECTED ARRIVALS.

DEFINE M AS INTEGER VARIABLE

START NEW PAGE
SKIP 5 LINES
PRINT 12 LINES WITH HMG1.2, HMG2.1, HMG2.3, HMG3.2, L.C.VOLUME. THUS
NO. OF LANE CHANGINGS

FROM LANE 1 TO LANE 2
FROM LANE 2 TO LANE 1
FROM LANE 2 TO LANE 3
FROM LANE 3 TO LANE 2
TOTAL

_skip 8 lines
PRINT 12 DOUBLE LINES WITH VL(1), ENT.VOL(1), N.LN(1), ENT.VOL(1)-N.LN(1),
HMG1.2, HMG2.1, VL(2), ENT.VOL(2), N.LN(2), ENT.VOL(2)-N.LN(2),
HMG2.3+HMG2.1, HMG1.2+HMG3.2, VL(3), ENT.VOL(3), N.LN(3), ENT.VOL(3)-N.LN(3),
HMG3.2, HMG2.3, TOT.VOL, T.ENT.VOL, N.LN(1)+N.LN(2)+N.LN(3),
I.T.EXIT(N.INT), L.C.VOLUME. THUS
TOTAL VOLUME    TOTAL    NO. OF VEHICLE    EXIT    LANE CHANGING
PER HOUR        VOLUME    CURRENTLY IN THE VOLUME VOLUME
SYSTEM    FROM TO

📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣📣annonce

LANE 1

LANE 2
```
### Statistics on Measures of Effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Std. Dev</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delay (seconds)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weaving Veh.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Weaving Veh.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Travel Time (sec.)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Arrival Speed (mph)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weaving Arr. Spd LANE 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANE 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANE 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Miscellaneous Data

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NO. OF REJECTED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO. OF REJECTED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For \( M = 1 \) to 3, do

```
FOR M = 1 TO 3, DO
PRINT 1 LINE WITH M, REJ.VEH(M), REJ.LCH(M) THUS
    LANE :
LOOP
PRINT 4 LINES WITH REJ.VEH(1) + REJ.VEH(2) + REJ.VEH(3),
```
REJ LCH(1)+REJ LCH(2)+REJ LCH(3), NO. ACCIDENT THUS

TOTAL

NUMBER OF ACCIDENT = 

RETURN

END ' 'S. PROGRAM NOE
PROGRAM DIST.HEADWAY

** THIS SUBPROGRAM PRINTS HEADWAY FREQUENCY DISTRIBUTION, STANDARD DEVIATION, MINIMUM, AND AVERAGE HEADWAY FOR EACH LANE. THE CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAYS IS ALSO PRINTED. **

DEFINE I AS INTEGER VARIABLE

START NEW PAGE
SKIP 3 LINES
PRINT 10 LINES WITH H1.HDWY(1),H2.HDWY(1),H3.HDWY(1) THUS

LANE 1 LANE 2 LANE 3

| HDWY < 1.0 | *** | *** | *** |

FOR I=2 TO 16 DO
PRINT 1 LINE WITH I-1,I,H1.HDWY(I),H2.HDWY(I),H3.HDWY(I) THUS
*** < HDWY < ***
***
***
***
***
***
***
***
***
***

LANE 1 LANE 2 LANE 3

| 15.0 < HDWY | *** | *** | *** |

PRINT 8 LINES WITH H1.HDWY, H2.HDWY, H3.HDWY,
MIN.1.HDWY,MIN.2.HDWY, MIN.3.HDWY,
AV.1.HDWY, AV.2.HDWY, AV.3.HDWY,
SD.1.HDWY,SD.2.HDWY,SD.3.HDWY THUS

TOTAL # OF OBS.

| *** | *** | *** |

MIN. HEADWAY

| *** | *** | *** |

AVE. HEADWAY

| *** | *** | *** |

STD.DEV HEADWAY

**
**

START NEW PAGE
SKIP 3 LINES
PRINT 7 LINES LIKE THIS

CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAY

Lane 1         Lane 2         Lane 3

LET CF.H1 = 100·H1·HDWY(1)/MAX·F(1,H1·HDWY)
LET CF.H2 = 100·H2·HDWY(1)/MAX·F(1,H2·HDWY)
LET CF.H3 = 100·H3·HDWY(1)/MAX·F(1,H3·HDWY)
PRINT 1 LINE WITH CF.H1,CF.H2,CF.H3 THUS

HDWY <  1

FOR I = 2 TO 15, DO
LET CF.H1 = CF.H1+100·H1·HDWY(I)/MAX·F(1,H1·HDWY)
LET CF.H2 = CF.H2+100·H2·HDWY(I)/MAX·F(1,H2·HDWY)
LET CF.H3 = CF.H3+100·H3·HDWY(I)/MAX·F(1,H3·HDWY)
SKIP 1 LINE
PRINT 1 LINE WITH I,CF.H1,CF.H2,CF.H3 THUS

HDWY >  1

LOOP
SKIP 1 LINE
PRINT 1 LINE WITH CF.H1+100·H1·HDWY(16)/MAX·F(1,H1·HDWY),
CF.H2+100·H2·HDWY(16)/MAX·F(1,H2·HDWY),
CF.H3+100·H3·HDWY(16)/MAX·F(1,H3·HDWY) THUS

HDWY >= 16

RETURN

END "S.PROGRAM DIST.HEADWAY
S.PROGRAM MERG.DIST

**This subprogram prints merging points for weaving vehicles in each lane and merging points frequency distributions as well as average and standard deviation of the distance from beginning of the weaving section to the merging point.**

DEFINE L,I AS INTEGER VARIABLE

START NEW PAGE
PRINT 3 LINES LIKE THIS

```
########################################
#* LANE CHANGING STATISTICS *
########################################
```

SKIP 4 LINES
PRINT 7 LINES WITH MG1.2(1),MG2.1(1),MG3.2(1),MG2.3(1) THUS

```
MERGING POINT DISTRIBUTION

<table>
<thead>
<tr>
<th>1 TO 2</th>
<th>2 TO 1</th>
<th>3 TO 2</th>
<th>2 TO 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

FOR L=2 TO 15 ,DO
PRINT 2 LINES WITH 100-(L-1),100-L,MG1.2(L),MG2.1(L),MG3.2(L),MG2.3(L) THUS

```
LOOP
```

PRINT 2 LINES WITH MG1.2(16),MG2.1(16),MG3.2(16),MG2.3(16) THUS

```
1600<=L
```

SKIP 2 LINES
PRINT 9 LINES WITH N12,MGPT, N21,MGPT, N22,MGPT, N23,MGPT, N112,MGPT, N121,MGPT, N122,MGPT, N123,MGPT, MAX12,MGPT, MAX21,MGPT, MAX22,MGPT, MAX23,MGPT, AV12,MGPT, AV21,MGPT, AV22,MGPT, AV23,MGPT, SD12,MGPT, SD21,MGPT, SD22,MGPT, SD23,MGPT THUS

```
# OF OBS.
```

```
MIN. MGPT ***.* ***.* ***.* ***.* ***.*
MAX. MGPT **.* **.* **.* **.* **.*
AVE. MGPT ***.* ***.* ***.* ***.* ***.*
STD. MGPT **.* **.* **.* **.* **.*
```
CUMULATIVE DISTRIBUTION FUNCTION OF MERGING POINTS

<table>
<thead>
<tr>
<th>1 TO 2</th>
<th>2 TO 1</th>
<th>3 TO 2</th>
<th>2 TO 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
</tbody>
</table>

LET CF.MG12 = \( \frac{100 - MG1.2(1)}{\text{MAX}.F(1, HHG1.2)} \)
LET CF.MG21 = \( \frac{100 - MG2.1(1)}{\text{MAX}.F(1, HHG2.1)} \)
LET CF.MG32 = \( \frac{100 - MG3.2(1)}{\text{MAX}.F(1, HHG3.2)} \)
LET CF.MG23 = \( \frac{100 - MG2.3(1)}{\text{MAX}.F(1, HHG2.3)} \)

PRINT 1 LINE WITH CF.MG12, CF.MG21, CF.MG32, CF.MG23 THUS
MERG-POINT < 100

FOR I = 2 TO 16, DO
LET CF.MG12 = CF.MG12 + 100 - MG1.2(I)/\text{MAX}.F(1, HHG1.2)
LET CF.MG21 = CF.MG21 + 100 - MG2.1(I)/\text{MAX}.F(1, HHG2.1)
LET CF.MG32 = CF.MG32 + 100 - MG3.2(I)/\text{MAX}.F(1, HHG3.2)
LET CF.MG23 = CF.MG23 + 100 - MG2.3(I)/\text{MAX}.F(1, HHG2.3)

PRINT 1 LINE WITH I - 100, CF.MG12, CF.MG21, CF.MG32, CF.MG23 THUS
MERG-POINT < 1000

LOOP

RETURN

END "S PROGRAM MERG DIST
S. PROGRAM SPD.DIST

' THIS SUBPROGRAM GENERATES AND PRINTER SPEED DISTRIBUTION FOR WEAVING AND NON-WEAVING VEHICLES. IT ALSO PRINTS THE CUMULATIVE DISTRIBUTION FUNCTION, MINIMUM, MAXIMUM, AVERAGE, AND STANDARD DEVIATION OF SPEED FOR WEAVING AND NON-WEAVING VEHICLES.

DEFINE J AS AN INTEGER VARIABLE

START NEW PAGE
SKIP 3 LINES
PRINT 6 LINES LIKE THIS

SPEED DISTRIBUTION WITHIN THE WEAVING SECTION

<table>
<thead>
<tr>
<th>WEAVING</th>
<th>NON-WEAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>......</td>
<td>......</td>
</tr>
</tbody>
</table>

SKIP 2 LINES
PRINT 1 LINE WITH H.Y.V SPD(1),HNW.SPD(1) THUS
SPEED < 5 MPH 

SKIP 1 LINE
FOR J = 2 TO 12, DO
PRINT 1 LINE WITH (J-1)*5, J-5, H.Y.V SPD(J), HNW.SPD(J) THUS
. . . <= SPEED < . . . MPH

SKIP 1 LINE
LOOP
PRINT 1 LINE WITH H.Y.V SPD(13), HNW.SPD(13) THUS
SPEED >= 60 MPH

SKIP 3 LINES

# OF OBS. ...... ...... ...... 
MIN. SPEED ...... ...... ...... 
MAX. SPEED ...... ...... ...... 
AVE. SPEED ...... ...... ...... 
STD. SPEED ...... ...... ...... 

START NEW PAGE
SKIP 3 LINES
PRINT 5 LINES LIKE THIS
CUMULATIVE DISTRIBUTION FUNCTION OF SPEED

---

SKIP 2 LINES
PRINT 1 LINE WITH 100-HNV.SPD(1)/MAX.F(1,N,NV.SPD),
100-HNV.SPD(1)/MAX.F(1,N,NV.SPD) THUS

SPEED < 5 MPH

SKIP 1 LINE
LET HV = HVV.SPD(1)
LET HW = HVV.SPD(1)
FOR J = 2 TO 12, DO

LET CUM.WW = CUM.WW+100-(HV+HVV.SPD(J))/MAX.F(1,N,WV.SPD)
LET CUM.HW = CUM.HW+100-(HW+HVV.SPD(J))/MAX.F(1,N,NW.SPD)
LET HW = 0.0
LET HV = 0.0

PRINT 1 LINE WITH J+6,CUM.WW,CUM.HW THUS
SPEED < ...

SKIP 1 LINE
LOOP

PRINT 1 LINE WITH CUM.WW+100-HNV.SPD(13)/MAX.F(1,N,WV.SPD),
CUM.HW+100-HNV.SPD(13)/MAX.F(1,N,NW.SPD) THUS

SPEED >= 60 MPH

CALL SPD.L.DIST
RETURN
END 'S PROGRAM SPD.DIST

S.PROGRAM SPD.L.DIST

'' THIS SUBPROGRAM GENERATES AND PRINTS SPEED
'' DISTRIBUTION FOR EACH LANE. IT ALSO PRINTS
'' THE CUMULATIVE DISTRIBUTION FUNCTION, MINI-
'' MAX, MAXIMUM, AVERAGE, AND STANDARD DEVIATION OF
'' OF SPEED FOR ALL VEHICLES IN EACH LANE.

DEFINE L AS INTEGER VARIABLE

START NEW PAGE
SKIP 5 LINES
PRINT 9 LINES WITH H1.SPD(1),H2.SPD(1),H3.SPD(1) THUS
DISTRIBUTION OF SPEEDS

---
SPEED (MPH)  LANE 1  LANE 2  LANE 3

SPEED < 25

FOR L = 2 TO 10, DO
    PRINT 1 LINE WITH 20*U(L-1)-5, 20*U-5, H1.SPD(L), H2.SPD(L), H3.SPD(L)
    THUS
    *** < SPEED < ***
    SKIP 1 LINE
LOOP
PRINT 1 LINE WITH H1.SPD(11), H2.SPD(11), H3.SPD(11)
    THUS
    70 < SPEED
    *** > *** > ***
    SKIP 4 LINES
PRINT 7 LINES WITH 1.MINSPD, 2.MINSPD, 3.MINSPD,
    1.AVSPD, 2.AVSPD, 3.AVSPD,
    1.SDSPD, 2.SDSPD, 3.SDSPD
THUS
    TOTAL # OF OBS.
    *** *** ***
    MIN. SPEED
    *** *** *** ***
    AVE. SPEED
    *** *** *** ***
    STD. DEVI.
    *** *** *** ***
RETURN
END **SPD.L.DIST
S.PROGRAM GAP.DIST

' THIS SUBPROGRAM GENERATES AND PRINTS FREQUENCY
' AND CUMULATIVE DISTRIBUTION FUNCTION AS WELL
' AS THE STANDARD DEVIATION, MINIMUM, MAXIMUM,
' AND THE AVERAGE OF THE ACCEPTED GAPS IN EACH
' LANE.

DEFINE L, I AS INTEGER VARIABLE

START NEW PAGE
SKIP 5 LINES
PRINT 9 LINES WITH H1.GAP(1), H2.GAP(1), H3.GAP(1) THUS
DISTRIBUTION OF ACCEPTED GAPS

<table>
<thead>
<tr>
<th>GAP SIZE (SEC.)</th>
<th>LANE 1</th>
<th>LANE 2</th>
<th>LANE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAP &lt; 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FOR L = 2 TO 10, DO
PRINT 1 LINE WITH (L-1), L, H1.GAP(L), H2.GAP(L), H3.GAP(L) THUS
... < GAP < ...
SKIP 1 LINE
LOOP
PRINT 1 LINE WITH H1.GAP(11), H2.GAP(11), H3.GAP(11) THUS
10 < GAP
SKIP 4 LINES
PRINT 7 LINES WITH 1.NGAP, 2.NGAP, 3.NGAP,
1.MINGAP, 2.MINGAP, 3.MINGAP,
1.AVGAP, 2.AVGAP, 3.AVGAP,
1.SD GAP, 2.SD GAP, 3.SD GAP
TOTAL # OF OBS.

MIN. ACCEPT GAP

AVE. ACCEPT GAP

STD. DEV.

START NEW PAGE
SKIP 3 LINES
PRINT 7 LINES LIKE THIS

CUMULATIVE DISTRIBUTION FUNCTION OF ACCEPTED GAPS

====================================================================
LET CF.G1 = 100*H1.GAP(1)/MAX.F(1,1.HGAP)
LET CF.G2 = 100*H2.GAP(1)/MAX.F(1,2.HGAP)
LET CF.G3 = 100*H3.GAP(1)/MAX.F(1,3.HGAP)
PRINT 1 LINE WITH CF.G1,CF.G2,CF.G3 THUS
   GAP < 1 SEC.
    *  *  *
   FOR I = 2 TO 10, DO
LET CF.G1 = CF.G1+100*H1.GAP(I)/MAX.F(1,1.HGAP)
LET CF.G2 = CF.G2+100*H2.GAP(I)/MAX.F(1,2.HGAP)
LET CF.G3 = CF.G3+100*H3.GAP(I)/MAX.F(1,3.HGAP)
SKIP 1 LINE
PRINT 1 LINE WITH I,CF.G1,CF.G2,CF.G3 THUS
   GAP <    SEC.    *  *  *
LOOP
SKIP 1 LINE
PRINT 1 LINE WITH CF.G1+100*H1.GAP(I)/MAX.F(1,1.HGAP),
   CF.G2+100*H2.GAP(I)/2.HGAP,
   CF.G3+100*H3.GAP(I)/3.HGAP THUS
   GAP >= 10 SEC.
    *  *  *
RETURN
END "GAP.DIST"
S.PROGRAM: HDWAY.GRAPH

\[
\text{THIS SUBPROGRAM GRAPHS THE CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAYS FOR EACH LANE}
\]

DEFINE L,HDWAY AS INTEGER VARIABLES
DEFINE CDF.1,CDF.2,CDF.3,DH1,DH2,DH3 AS REAL VARIABLES

FOR L = 1 TO 15, DO
LET CDF.1 = CDF.1+HDWAY(L)/MAX.F(1,H1.HDWAY)
LET CDF.2 = CDF.2+HDWAY(L)/MAX.F(1,H2.HDWAY)
LET CDF.3 = CDF.3+HDWAY(L)/MAX.F(1,H3.HDWAY)

LET DH1 = H1.HDWAY(L)
LET DH2 = H2.HDWAY(L)
LET DH3 = H3.HDWAY(L)
LET HDWAY = L

\text{WRITE HDWAY,CDF.1,CDF.2,CDF.3,DH1,DH2,DH3 AS BINARY USING 3}
\text{WRITE AS / USING 3}

LOOP
RETURN
END "SUBPROGRAM HDWAY.GRAPH"
S. PROGRAM SPD.GRAPH

* * *
THIS SUBPROGRAM GRAPHS THE CUMULATIVE DISTRIBUTION FUNCTION OF SPEEDS FOR EACH LANE.

DEFINE L,VEL AS INTEGER VARIABLES
DEFINE CDF.1,CDF.2,CDF.3 AS REAL VARIABLES

FOR L = 1 TO 11, DO
   LET CDF.1 = CDF.1+H1.SPD(L)/MAX.F(1,1,NSPD)
   LET CDF.2 = CDF.2+H2.SPD(L)/MAX.F(1,2,NSPD)
   LET CDF.3 = CDF.3+H3.SPD(L)/MAX.F(1,3,NSPD)
   LET VEL = L*5+20

* * *
WRITE VEL,CDF.1,CDF.2,CDF.3 AS BINARY USING 1
* * *
WRITE AS / USING 1
LOOP

RETURN

END ""SUB_PROGRAM SPD.GRAPH""
PROGRAM SPD.VV.GRAPH

"" THIS SUBPROGRAM GRAPHS THE CUMULATIVE DISTRIBUTION FUNCTION OF SPEEDS FOR WEAVING AND NON-WEAVING VEHICLES.

DEFINE L,VEL AS INTEGER VARIABLES
DEFINE CDF.VV,CDF.WW AS REAL VARIABLES

FOR L = 1 TO 13, DO
   LET CDF.VV = CDF.VV+VF.VV.SPD(L)/MAX.F(1,H.VV.SPD)
   LET CDF.WW = CDF.WW+VF.WW.SPD(L)/MAX.F(1,H.WW.SPD)
   LET VEL = L+6

""WRITE VEL,CDF.VV,CDF.WW AS BINARY USING 1
""WRITE AS / USING 1
LOOP
RETURN
END ''SUBPROGRAM SPD.VV.GRAPH''
S PROGRAM GAP GRAPH

"" THIS SUBPROGRAM GRAPHS THE CUMULATIVE DISTRIBUTION FUNCTION OF ACCEPTED GAPS FOR EACH LANE.

DEFINE L,GAP AS INTEGER VARIABLES
DEFINE CDF.1,CDF.2,CDF.3 AS VARIABLES

FOR L = 1 TO 11 DO
    LET CDF.1 = CDF.1 + H1.GAP(L)/MAX.F(1,1.NGAP)
    LET CDF.2 = CDF.2 + H2.GAP(L)/2.NGAP
    LET CDF.3 = CDF.3 + H3.GAP(L)/3.NGAP
    LET GAP = L

""WRITE GAP,CDF.1,CDF.2,CDF.3 AS BINARY USING 2
""WRITE AS / USING 2
LOOP
RETURN
END "" SUBPROGRAM GAP.GRAPH""
SIMULATION RUN PARAMETERS

SIMULATION TIME
2200.00 SECONDS

WARM UP PERIOD
400.00 SECONDS

RANDOM SEED #

STREAM 1
21388690
1165804615
1804951546
369470775
780159578

WEAVING SECTION PARAMETERS

WEAVING SECTION LENGTH
1000.0 0.30 FEET
600.0 FEET

DOWN STREAM BUFFER LENGTH
600.0 FEET

UP STREAM BUFFER LENGTH

TRAFFIC PARAMETERS

VOLUME (VPH) %WEAVING LANE

1000.0 1
1000.0 2
800.0 3

PERCENT TRUCK
0.08

PERCENT TRAILER
0.04

SPEED DATA
MAXIMUM SPEED

\[
\begin{array}{cccc}
\text{AVE.} & \text{STD. DEV} & \text{MAX.} & \text{MIN.} \\
5.00 & 10.00 & 65.00 & 40.00 \\
5.00 & 10.00 & 65.00 & 40.00 \\
6.00 & 100.00 & 60.00 & 40.00 \\
\end{array}
\]

ARRIVAL SPEED

\[
\begin{array}{cccc}
\text{M.S.F} \\
1.1458 \\
1.000000 \\
1.000000 \\
48.00 & 10.00 & 58.00 & 38.00 \\
0.04 & \text{PROBABILITY OF NON-ESSENTIAL LANE-CHANGING}
\end{array}
\]

VEHICLE PARAMETERS

\[
\begin{array}{cccc}
16 & \text{FEET} & \text{AVERAGE LENGTH OF A PASSENGER CAR} \\
32 & \text{FEET} & \text{AVERAGE LENGTH OF A TRUCK} \\
40 & \text{FEET} & \text{AVERAGE LENGTH OF A TRAILER} \\
18.0 & \text{FPSS} & \text{MAXIMUM EMERGENCY DECELERATION RATE}
\end{array}
\]

DRIVER CHARACTERISTICS

\[
\begin{array}{cc}
0.746 \text{ SECOND} & \text{MEAN BRAKE REACTION TIME} \\
7.60 \text{ SECONDS} & \text{BRAKE REACTION TIME PARAMETER FOR GAUSSIAN DISTRIBUTION}
\end{array}
\]

LIST OF DESIRED OUTPUTS

\[
\begin{array}{ll}
\text{IS A LIST OF ATTRIBUTES OF ALL VEHICLES DESIRED?} & \text{NO} \\
\text{ARE INTERMEDIATE OUTPUTS DESIRED?} & \text{YES} \\
\text{IF YES, HOW MANY INTERVALS?} & 4 \\
\text{IS THE DISTRIBUTION OF MERGING POINTS DESIRED?} & \text{NO}
\end{array}
\]
IS THE DISTRIBUTION OF ACCEPTED GAPS DESIRED? NO
IS A GRAPH OF C.D.F OF ACCEPTED GAPS DESIRED? NO
IS DISTRIBUTION OF SPEEDS FOR EACH LANE DESIRED? NO
IS DISTRIBUTION OF WEAVING AND NON-WEAVING SPEEDS DESIRED? NO
IS A GRAPH OF C.D.F OF WEAVING AND NON-WEAVING SPEEDS DESIRED? NO
IS DISTRIBUTION OF HEADWAYS DESIRED? NO
IS A GRAPH C.D.F OF HEADWAYS DESIRED? NO
ARE VEHICLE TRAJECTORIES FOR EACH LANE DESIRED? NO
IF YES, FROM WHEN TO WHEN 1700.0 900.0

END OF INPUT DATA
==========
/*
//SAS EXEC PROC=SAS
//SASDATA1 DD DSNAME=.SIM.GO.SIMU01,DISP=(OLD,DELETE)
//SASDATA2 DD DSNAME=.SIM.GO.SIMU02,DISP=(OLD,DELETE)
//SASDATA3 DD DSNAME=.SIM.GO.SIMU03,DISP=(OLD,DELETE)
//SASDATA4 DD DSNAME=.SIM.GO.SIMU04,DISP=(OLD,DELETE)
//SYSIII DD
GOPTIONS DEVICE=VERSATEC IODSYMBOL;
DATA SIMOUT;
INFILE SSASDATA1;
INPUT (SPD CDF1 CDF2 ) (IB4..RB4..RB4.);
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF WEAVING SPEEDS V.EAVSIM;
LABEL SPD='SPEED (MPH.)' CDF1='CUMULATIVE PROBABILITY';
PLOT CDF1 SPD;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF NON-WEAVING SPEED V.EAVSIM;
LABEL SPD='SPEED (MPH.)' CDF2='CUMULATIVE PROBABILITY';
PLOT CDF2 SPD;
SYMBOL1 C=BLACK L=1 I=JOIN;
DATA SIMOUT;
INFILE SSASDATA2;
INPUT (GAP CDF1 CDF2 CDF3 ) (IB4..RB4..RB4..RB4.);
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF ACCEPTED GAPS V.EAVSIM;
TITLE2 'LANE 1';
LABEL GAP='ACCEPTED GAP (SEC.)' CDF1='CUMULATIVE PROBABILITY';
PLOT CDF1 GAP;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF ACCEPTED GAPS V.EAVSIM;
TITLE2 'LANE 2';
LABEL GAP='ACCEPTED GAP (SEC.)' CDF2='CUMULATIVE PROBABILITY';
PLOT CDF2 GAP;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF ACCEPTED GAPS V.EAVSIM;
TITLE2 'LANE 3';
LABEL GAP='ACCEPTED GAP (SEC.)' CDF3='CUMULATIVE PROBABILITY';
PLOT CDF3 GAP;
SYMBOL1 C=BLACK L=1 I=JOIN;
DATA SIMOUT;
INFILE SSASDATA3;
INPUT (HDWAY CDF1 CDF2 CDF3 H1 H2 H3 ) (IB4..RB4..RB4.);
PROC GPLOT DATA=SIMOUT;
PLOT H1 HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
TITLE1 HEADWAY DISTRIBUTION V.EAVSIM;
TITLE2 'LANE 1';
LABEL HDWAY='HEADWAY (SEC.)' H1='PROBABILITY';
PROC GPLOT DATA=SIMOUT;
TITLE1 HEADWAY DISTRIBUTION WEAVSIM;
TITLE2 ' (LANE 2)';
LABEL HDWAY='HEADWAY (SEC.)' H2='PROBABILITY';
PLOT H2-HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 HEADWAY DISTRIBUTION WEAVSIM;
TITLE2 ' (LANE 3)';
LABEL HDWAY='HEADWAY (SEC.)' H3='PROBABILITY';
PLOT H3-HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAY WEAVSIM;
TITLE2 ' (LANE 1)';
LABEL HDWAY='HEADWAY (SEC.)' CDF1='CUMULATIVE PROBABILITY';
PLOT CDF1-HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAY WEAVSIM;
TITLE2 ' (LANE 2)';
LABEL HDWAY='HEADWAY (SEC.)' CDF2='CUMULATIVE PROBABILITY';
PLOT CDF2-HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
PROC GPLOT DATA=SIMOUT;
TITLE1 CUMULATIVE DISTRIBUTION FUNCTION OF HEADWAY WEAVSIM;
TITLE2 ' (LANE 3)';
LABEL HDWAY='HEADWAY (SEC.)' CDF3='CUMULATIVE PROBABILITY';
PLOT CDF3-HDWAY;
SYMBOL1 C=BLACK L=1 I=JOIN;
DATA SIMOUT;
INFILE SSASDATA4;
INPUT (LANE TIME ID PQS) (IB4. RB4. IB4. RB4.);
PROC SORT; BY LANE;
PROC GPLOT DATA=SIMOUT; BY LANE;
TITLE1 VEHICLE TRAJECTORIES (WEAVSIM);
LABEL TIME='SIMULATION TIME (SEC.)' POS='POSITION (FT.)';
PLOT POS-TIME=ID/NOLEGEND;
SYMBOL1 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL2 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL3 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL4 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL5 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL6 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL7 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL8 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL9 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL10 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL11 C=BLACK L=1 I=JOIN REPEAT=10;
SYMBOL12 C=BLACK L=1 I=JOIN REPEAT=10;
/.
//