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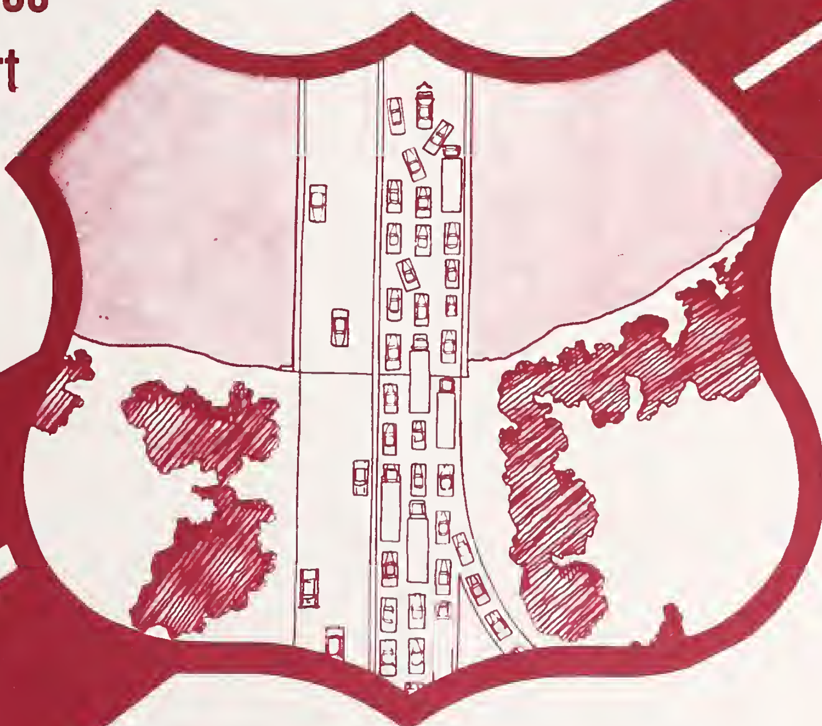
DEVELOPMENT AND TESTING OF INTRAS, A MICROSCOPIC FREEWAY SIMULATION MODEL

Vol. 1. Program Design, Parameter Calibration and Freeway Dynamics Component Development

October 1980

Final Report



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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Traffic Systems Division
Washington, D.C. 20590

FOREWORD

This report presents the concepts and algorithms used in the INTRAS program which is a microscopic freeway simulation model which can be used to evaluate alternative designs of and control systems for urban freeways. It may also be used to study related subjects such as detector station spacing and the efficacy of incident detection algorithms.

This report is the first volume in a four volume Final Report on the study, "Adaptation of a Freeway Simulation for Studying Incident Detection and Control."

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Charles F. Scheffey

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16. Abstract

This series of volumes documents the work performed to adapt a freeway simulation model for studying freeway incidents. The resulting program, INTRAS (INtegrated TRAffic Simulation), is a vehicle-specific time-stepping simulation designed to realistically represent traffic and traffic control in a freeway and surrounding surface street environment.

This volume describes the detailed capabilities of INTRAS and its structural and procedural attributes. The calibration of traffic descriptive parameters are presented herein. The development of the simulation components which model the car-following lane changing and vehicle generation aspects of freeway traffic are also included.

This volume is the first in a series. The others in the series are:

Vol. No.	FHWA No.	Short Title
2	80/107	User's Manual
3	80/108	Validation and Applications
4	80/109	Program Documentation

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TABLE OF CONTENTS

Section	Title	Page
1	INTRODUCTION	1
1.1	Background	1
1.2	Outline of Project Tasks	4
1.3	Organization of Report	6
2	CAPABILITIES OF THE INTRAS SIMULATION MODEL	7
2.1	Network Definitions and Limitations	7
2.2	Geometric Features of INTRAS	12
2.3	Signal and Sign Control	16
2.4	Traffic-Descriptive Features	17
2.5	Incident Simulation Capability	18
2.6	Surveillance System Simulation	19
2.7	Freeway Traffic Responsive Control	19
2.8	Detector Output Processing	24
2.9	INTRAS User Options	25
3	THE STRUCTURE AND METHODOLOGY OF INTRAS	28
3.1	Functional Structure of INTRAS	29
3.2	The User Interface	51
3.3	INTRAS Storage Array Methodology	86
3.4	INTRAS Error Procedures	98
4	INTRAS FREEWAY PARAMETER CALIBRATION	100
4.1	Vehicle Type Specific Calibration Parameters	100

TABLE OF CONTENTS (continued)

Section	Title	Page
4.2	Other INTRAS Calibration Parameters	115
5	LITERATURE REVIEW	124
5.1	Analytical Car-Following Models	124
5.2	Fail Safe Simulated Car Following	127
6	SIMULATION DEVELOPMENT	127
6.1	The Car Following Algorithm	127
6.2	Lane Changing Development	139
6.3	Vehicle Generation	145
7	COMPONENT MODEL TESTING	146
7.1	Calibration	146
7.2	Validation	155
8	SUMMARY	183
	APPENDIX A	185
	APPENDIX B	201
	APPENDIX C	208
	BIBLIOGRAPHY	220
	REFERENCES	228

LIST OF FIGURES

Number	Title	Page
1	Sample Physical Freeway-Frontage Road Network	8
2	Representation of Sample Network	9
3	Typical Freeway Link Configurations	11
4	Ramp-Freeway Interconnection Example	14
5	Typical Metered Ramp Geometry	22
6	Functional Structure and Information Transfer of INTRAS	31
7	Sample of INPLOT Program Vehicle Trajectory Plot Design	80
8	Sample of INPLOT Program Contour Plot Design	81
9	Freeway Passenger Car Zero Grade Acceleration	104
10	Non-Freeway Passenger Car Zero Grade Acceleration	105
11	Speed-Distance Profiles for Intercity Buses and Heavy Single Unit Trucks	110
12	Speed-Distance Profiles for Trailer Truck Vehicle Type	111
13	Lane-Specific Mean Speed Ratio	118
14	Cumulative Frequency of Speed to Mean Lane Speed Ratio	120
15	Percent of Commercial Vehicle Population to the Left of Lateral Position L	123

LIST OF FIGURES (continued)

Number	Title	Page
16	Platoon Behavior: PITT Algorithm-One Second Interval	132
17	Platoon Behavior: PITT Algorithm-Three Second Interval	133
18	Platoon Behavior: UTCS Algorithm-One Second Interval	134
19	Platoon Behavior: UTCS Algorithm-Three Second Interval	135
20	Platoon Behavior: Aerospace Algorithm-One Second Interval	136
21	The Lane Changing Vehicles	141
22	Driver Sensitivity ($\bar{k}$) vs. Average Lane Capacity	147
23	Intensity of Lane Changing as a Function of Volume for Two Lanes	149
24	Intensity of Lane Changing as a Function of Volume for Three Lanes	150
25	Intensity of Lane Changing as a Function of Volume for Four Lanes	151
26	Courtesy Factor Calibration Capacity Measured at Ramp Nose	154
27	Input Mean Spacing vs. Output Flow	156
28	Lane Configuration for PINY Experiments 2 & 6	157
29	Speed-Volume Relationships	158

LIST OF FIGURES (continued)

Number	Title	Page
30	Speed-Density Relationships	159
31	Volume-Density Relationships	160
32	Freeway Volume vs. Percent Trucks on Freeway	161
33	Lane Volume vs. Percent Trucks on Freeway Lane 1	162
34	Ramp Capacity as a Function of Acceleration Lane Length	163
35	Comparison of Lane Changes - Lanes 2-1, Experiment 2	171
36	Comparison of Lane Changes - All Movements, Experiment 2	172
37	Comparison of Lane Changes - Lanes 1-8, Experiment 6	173
38	Comparison of Lane Changes - All Movements, Experiment 6	174
39	Headway Distributions - Free and Congested Flow	175
40	Comparison of Headway for Long Island Data - Total Volume 2800 VPH	176
41	Los Angeles Headways - Detector #56 Shoulder Lane	178
42	Los Angeles Headways - Detector #55 Next to Shoulder Lane	179
43	Los Angeles Headways - Detector #54 Next to Median Lane	180

LIST OF FIGURES (continued)

Number	Title	Page
44	Los Angeles Headways - Detector #53 Median Lane	181
45	Ohio State Vehicle Trajectories Platoon of Twenty-Three Vehicles Showing Paths of Vehicle Numbers 1, 5, 10, 15, 20 and 23	182
46	INTRAS Supervisor Logic	186
47	PORGIS Module Logic	187
48	LIS Module Logic	190
49	SIFT Supervisor Logic	193
50	LOCON Suboverlay Logic	195
51	HICON Suboverlay Logic	196
52	POSPRO Module Logic	197
53	INPLOT Module Logic	198
54	INCES Module Logic	199
55	SAM Module Logical Flow	200

LIST OF TABLES

Number	Title	Page
1	Output of INTRAS Simulated Detectors	26
2	INTRAS Routines	32
3	PORGIS Routines	34
4	PORGIS and LIS Subroutine Correspondance	37
5	SIFT Routines	39
6	SAM Routines	47
7	INCES Routines	49
8	INPLOT Routines	50
9	INTRAS Data Categories	53
10	Description of Input Stream	55
11	Sample Freeway Link Definition Report	62
12	Definition of Column Headings in "Freeway Link Definition" Report	63
13	Sample Ramp and Surface Link Definition Report	64
14	Definition of Column Headings in "Ramp and Surface Link Identification Report"	65
15	Sample Sign and Signal Control Definition Report	66
16	Definition of Column Headings in "Sign and Signal Control Definitions" Report	67

LIST OF TABLES (continued)

Number	Title	Page
17	Sample Entering Traffic Definition Report	68
18	Definition of Column Headings in "Entering Traffic Definition" Report	69
19	Sample Surveillance System Definition Report	70
20	Definition of Column Headings in "Surveillance System Definition" Report	71
21	Sample Incident Definition Report	72
22	Definition of Column Headings in "Incident Definition" Report	73
23	Sample Freeway Statistical Report Design	74
24	Definition of Column Headings in "Sample Freeway Statistical Report"	75
25	Sample Ramp and Surface Statistical Report Design	76
26	Definition of Column Headings in "Sample Ramp and Surface Statistical Report"	77
27	Sample Freeway Station Headway and Speed Report Design	78
28	Definition of Column Headings in "Sample Freeway Station Headway and Speed Report"	79
29	Sample Point Processing Report Design	82
30	Sample MOE Estimation Report Design	83
31	Sample Incident Detection Report Design	84
32	Sample SAM Data Element Paired Comparisons	87

LIST OF TABLES (continued)

Number	Title	Page
33	Sample SAM Network Comparisons	88
34	Sample SAM Link Specific Statistical Test Report	89
35	Sample SAM Subinterval Specific Statistical Test Report	90
36	Sample SAM Network Statistical Test Report	91
37	INTRAS Calibration Normal Acceleration Rates for Low Performance Passenger Cars	106
38	INTRAS Calibration Normal Acceleration Rates for High Performance Passenger Cars	107
39	Multiplicative Factors Relating Passenger Car Acceleration on INTRAS Grades to Acceleration at 0% Grade	109
40	INTRAS Calibration Normal Acceleration Rates for Buses and Heavy Single Unit Trucks	112
41	INTRAS Calibration Normal Acceleration Rates for Trailer Trucks	113
42	Ratio of Lane Speed to Mean Speed for Los Angeles Detector Data	117
43	Ratio of Lane Volume to Overall per Lane Volume	121
44	Ranking of Car-Following Algorithm	140
45	Mean Frequency of Lane Changing vs. Probability of Lane Changing and Volume	152

LIST OF TABLES (continued)

Number	Title	Page
46	Comparison of Simulation Outputs and Field Data for Experiment 6	166
47	Comparison of Simulation Outputs and Field Data for Experiment 6	167
48	Correlation Analysis of PINY Data and Simulation Outputs	168
49	Comparison of Simulation with Given Data	170

1. INTRODUCTION

A program of major emphasis has been launched by the Federal Highway Administration (FHWA) to develop and implement incident detection strategies and to integrate these with surveillance and control policies to alleviate traffic congestion on the nation's freeways. A major element of this program is the development of a microscopic simulation model which can be utilized as a tool for evaluating alternate candidate solutions to this problem. Contract DOT-FH-11-8502 calls for the research agency to design, program, calibrate, validate, and demonstrate such a computer simulation model.

Volume I of this Final Report describes the work effort for Tasks A and B:

- Adaptation of the UTCS-1 Network Simulation Model Logic,
- Validate Simulation Components.

Volume II is a User's Manual for the resulting traffic simulation program, INTRAS. Program validation activities and the application of the validated model are described in Volume III. Detailed program documentation constitutes Volume IV.

1.1 Background

The two major subject areas which must be synthesized in this project are:

- Freeway Operations, Surveillance, Control and Incident Detection;
- Simulation of Traffic.

Brief overviews will be presented of each subject area.

1.1.1 Freeway Operations and Incident Detection

In recent years, increased attention has been focused on the need for developing effective freeway incident detection techniques. Moskowitz, in his review of research needs in traffic surveillance (Ref.1) stated that he believed the single most important problem in urban freeway traffic operations is the detection of stopped vehicles and the necessary steps required to remove the stoppage.

Flow-disruptive incidents are a substantial cause of congestion and considered by some to be even more of a problem than recurring daily congestion. In the Los Angeles area the California Division of Highways estimates that at least one-half of the delays to traffic can be attributed to incidents occurring along the freeway. This finding supports the earlier work done in Chicago by the Expressway Surveillance Project which also estimated the delay from incidents as at least one-half of the total delay to traffic.

Incidents occur predictably in frequency, but unpredictably by time and location. Often appearing during peak periods, these incidents severely reduce the level of service on the urban freeway. In most cases they significantly reduce the capacity of the freeway although in some cases the traffic demand may still be lower than the reduced capacity. Incidents which cause capacity reductions are a problem for demand volume either above or below capacity levels. Under conditions of light traffic demand the impact of the incident is to primarily slow traffic past the incident. Crane (Ref. 2) estimated that there are 6400 accident-related lane blockages each year on the 50-mile Detroit freeway network. These accidents only account for 7% of all lane blockages. He concludes that 14% of the time there are one or more lanes blocked by an incident in the system. The average time that a traffic lane is blocked by an incident tends to be short, in the range of four to six minutes.

The objective in managing traffic operations at the scene of an incident is to minimize the hazard and delay caused to both the motorist involved and those passing through the affected area. The treatment of an incident is considered in four steps:

a) Detection of the incident
b) Identification of location and type of incident
c) Service response to the incident
d) Restoration of traffic operations.

The first two steps are addressed by this project.

1.1.2 Simulation of Traffic

Digital computer programs to simulate traffic flow have been developed over a period of three decades. The great appeal of the simulation approach is that this technique offers the user an opportunity to evaluate alternative strategies before implementing them in the field. Thus the optimal strategy may be identified prior to the commitment of substantial funds for implementation of large systems.

Despite the intense interest in this field, it is only recently that a very limited number of such models have been applied productively to solve real-world problems in traffic engineering. The reasons for the limited number of successful models can be traced to the complexities of the physical problem of traffic dynamics and the resulting sophistication of program logic required to replicate these real-world events properly. While these difficulties apply to the smallest traffic element--the isolated intersection--they are greatly amplified when the scope of the problem is enlarged to encompass a network representation of a roadway system.

Simulation models may be classified as microscopic or macroscopic. The term "microscopic," as used here, denotes a model which simulates the movements of individual vehicles. "Macroscopic" denotes a grouping of vehicles and the application of flow relationships to determine successive traffic states.

- A <u>microscopic</u> model generally requires a larger programming and debugging effort, exhibits more stringent storage requirements and consumes more computing time, while providing greater resolution and potentially more accuracy, relative to the alternative.

- A <u>macroscopic</u> model, on the other hand, while being more economical in every way, may be unable to describe a complex process adequately, yielding inaccurate or misleading results which are wholly unacceptable.

It is seen that a careful tradeoff between level of detail and economy of operation is an essential ingredient in a successful, large-scale simulation model. Clearly, the degree of simulation microscopy must be tailored to the nature of the process it is describing. This requirement implies that the designer must possess a keen understanding both of the dynamics of the process and of efficient simulation methodology.

1.2 Outline of Project Tasks

The project defined by the subject contract is segmented into the following tasks:

Task A - Adapt the UTCS-1 Network Simulation Model for Freeway Applications

The UTCS-1 simulation model (Ref. 3,4) has been developed under FHWA sponsorship over the last five years as a vehicle for evaluating urban traffic systems. This program is a stochastic, microscopic simulation model that traces the trajectory of each vehicle along the streets (links) of a specified network. The control devices accommodated included pre-timed and actuated traffic signals, stop signs and yield signs. Other features include surveillance systems (detector deployments), bus traffic and random blockages (events).

The simulation procedures of the UTCS-1 model are to be adapted to the simulation of traffic on a freeway and parallel service facility. The resulting model, INTRAS, (INtegrated TRAffic Simulation), will retain the stochastic microscopic nature and traffic operation and control simulation capabilities of UTCS-1. The scope of the program will be expanded and will include specially designed, calibrated and validated component models representing the dynamics of freeway flow.

Task B - Validate Candidate Components

The candidate component models, representing freeway traffic dynamics, will be subjected to statistical tests to ascertain their validity. Comparable field data bases will be used to represent the "real" freeway environment. Output of the component models, for demand levels present in the field data bases, will be compared with the corresponding field statistics.

Task C - Program the Simulation Model

The INTRAS simulation model will be programmed so as to run effectively in a 240K byte partition of the FHWA IBM 360/65 computer. The model will be thoroughly debugged by exercising all logical paths.

Task D - Validate and Refine the Simulation Model

The debugged simulation model will be exercised, over a wide range of traffic demand, to determine whether the integrated components combine to produce a valid overall model. Comparisons of a simulation output with field data will be performed for at least the following traffic measures of effectiveness (MOE):

- Total travel time and vehicle miles for each subinterval (period of constant demand volume) and roadway section (subsystem)
- Spot speed and headway distribution at one point in each subsystem for each subinterval
- Frequency of lane changes in each subsystem for each subinterval
- The lane distribution of traffic at selected points for each subinterval to determine the effect of distance from on-ramps and off-ramps

If the model proves to be invalid, it will be appropriately modified and retested until validation can be demonstrated.

Task E - Validate Incident Detection Algorithms

Incident detection algorithms supplied by FHWA will be programmed as an integral part of the INTRAS model. These algorithms will act on output of the INTRAS simulation to detect simulated incidents. For each incident detection algorithm, situations from a range of traffic conditions will be simulated and, for each condition, the following three parameters will be calculated for both the beginning and ending of incidents:

- Percent successful detection

- Percent false alarm

- Distribution of time to detection.

The criteria of Task D and existing traffic stream data will be used to determine the validity of the detection algorithms within the structure of the INTRAS simulation model.

Task F - Apply the Simulation Model

Two simulation application studies will be performed. First, each of the FHWA-supplied incident detection algorithms will be applied in a parametric evaluation. The three parameters of Task E will be evaluated over a range of two independent variables: volume and detector spacing.

Second, the most promising incident detection algorithm and detector configuration will be applied in conjunction with a ramp control policy. The ability for the ramp control policy to ameliorate the disturbance caused by the incident will be evaluated for a range of volumes. Incident removal will also be studied.

1.3 Organization of Report

The subject of Sections 2 through 4 of this Final Report consists of the design, development and component calibration and validation activities accomplished prior to the actual simulation model programming (Task C). These sections describe the computer program design and the calibration of parameters and arrays, needed by the model to represent various traffic characteristics. Sections 5 through 7 describe the development, calibration and validation of the various components which model the dynamics of freeway traffic (car-following, lane-changing, and vehicle-generation). The conclusion, Section 8, summarizes the computer program design activities.

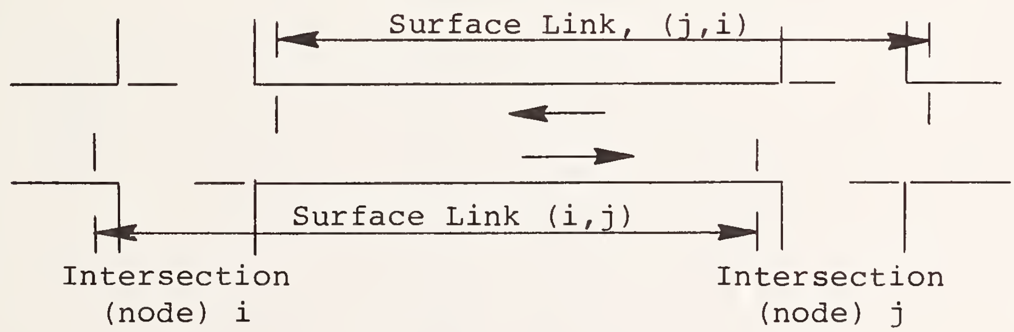
2. CAPABILITIES OF THE INTRAS SIMULATION MODEL

Those design characteristics which define the INTRAS model capabilities are described in this section. Specific features required by the Task A work statement, as well as others which augment the performance or usefulness of the simulation, are included.

2.1 Network Definitions and Limitations

The geometric representation of a roadway system in the INTRAS simulation model is accomplished by constructing a network analog of links (roadway segments) and nodes (intersections or geometric discontinuities). Figures 1 and 2 illustrate a typical road system and its network representation, respectively. To realize economy of storage, and to permit appropriate logical treatment for roadway sections of diverse characteristics, three link types are defined for INTRAS.

A <u>Surface</u> link is defined as a roadway segment servicing one direction of traffic. The nodes at each end represent grade intersections. Each "surface" link extends from the upstream stopline to the downstream stopline as in the following sketch:



As indicated (in the sketch) a link is normally identified by the upstream and downstream node numbers. Each "surface" link may consist of up to 5 lanes in width. Two of these lanes may be turning pockets (one left and one right) which do not extend for the full link length.

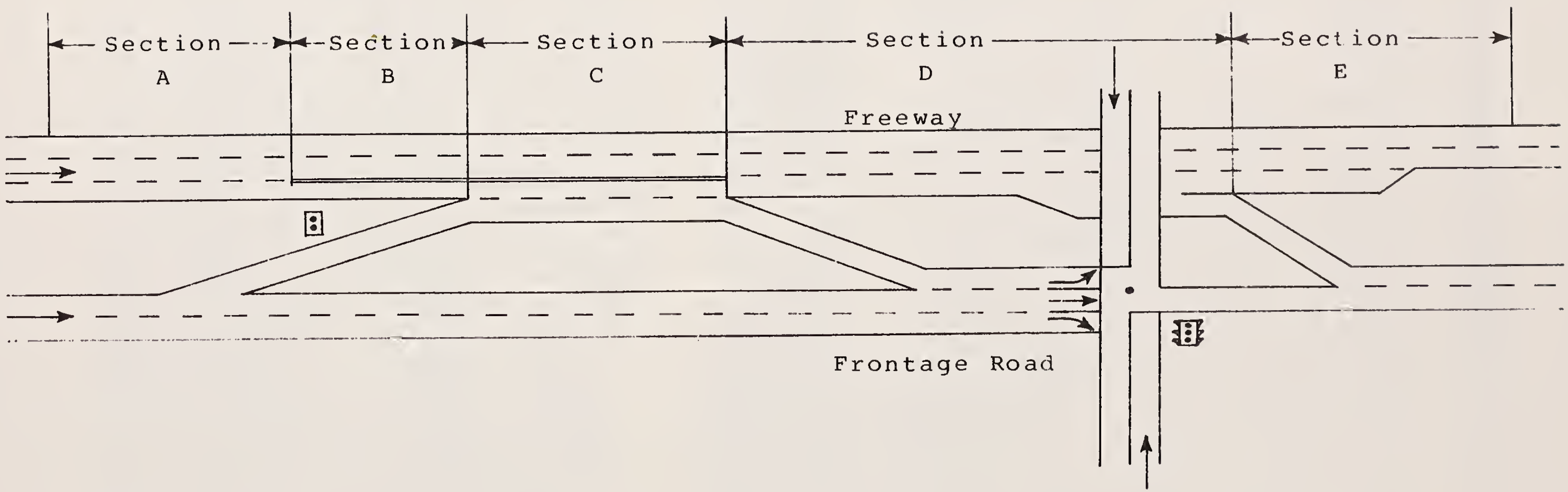


Figure 1: Sample Physical Freeway-Frontage Road Network

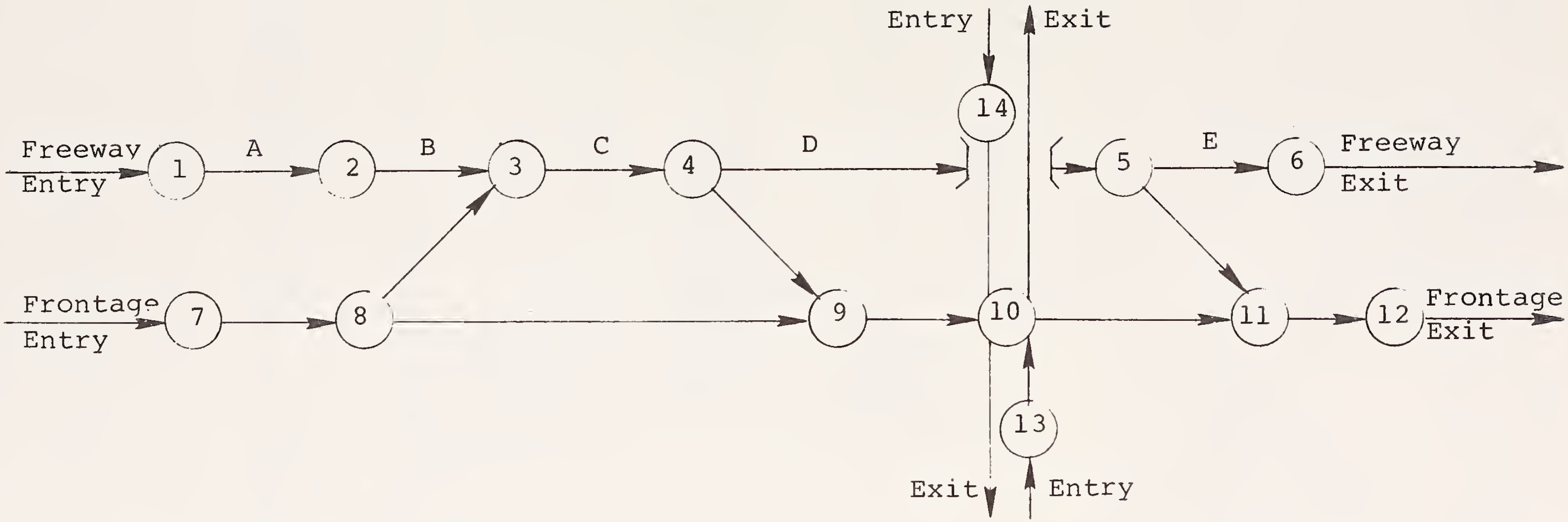


Figure 2: Representation of Sample Network

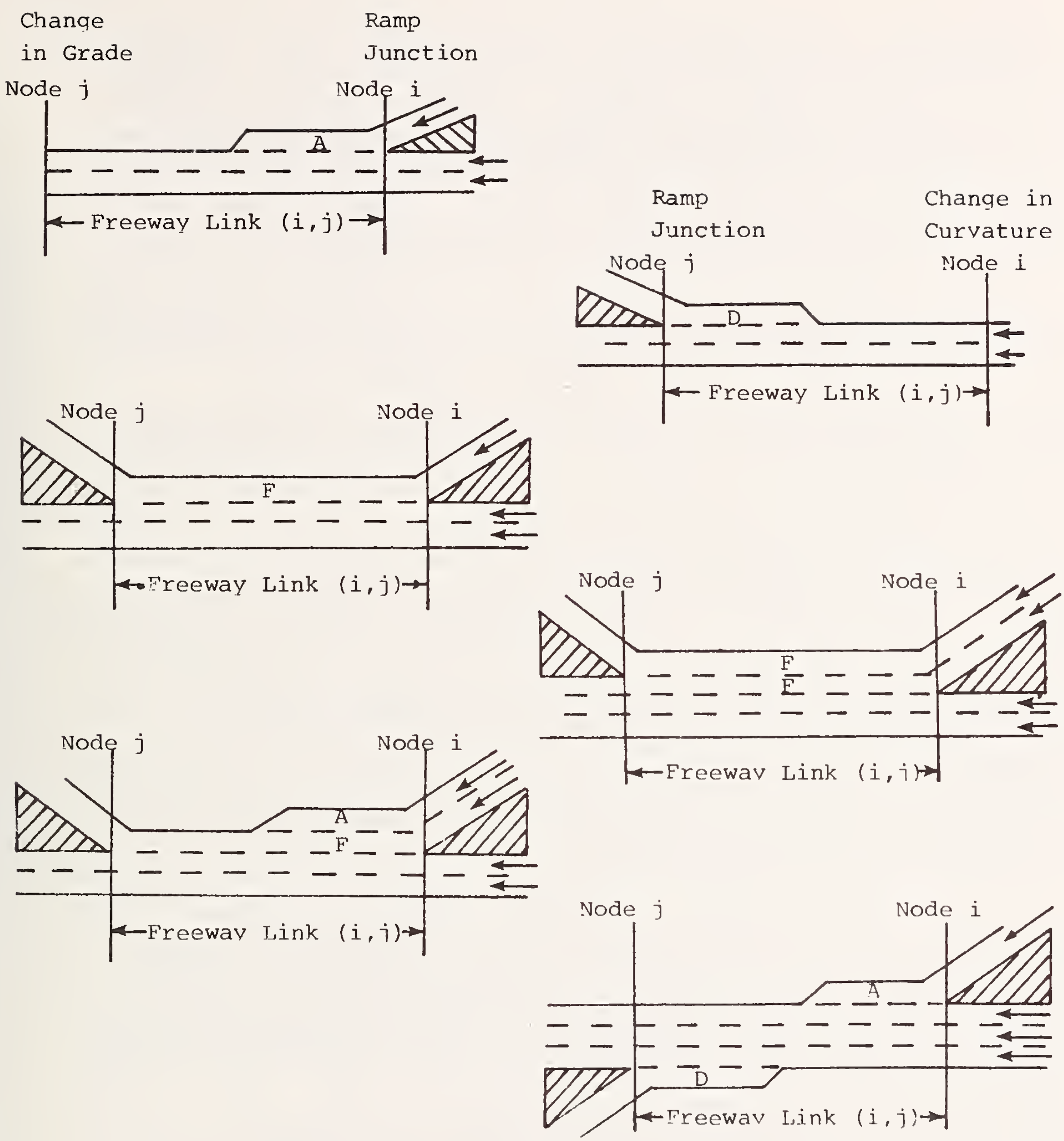
Vehicles traversing an INTRAS "surface" link will be moved at one-second intervals utilizing the logic established in the UTCS-1 urban traffic simulation model. This resolution properly replicates (Ref. 4) the dynamics of traffic on urban networks.

A Freeway link is defined as a one-way roadway segment, of a controlled-access highway, characterized by generally constant geometric characteristics (grade, curvature, number of through lanes). The extremities of a "freeway" link correspond to either ramp junctions or significant geometric changes. Each "freeway" link may contain up to five through lanes and two auxiliary lanes. Each auxiliary lane may be described as "acceleration", "deceleration" or "full", as defined below:

Auxiliary Lane Type	Definition
Acceleration	A lane which extends from the upstream extremity of a freeway link to some mid-link position
Deceleration	A lane which extends from a mid-link position to the downstream extremity of a freeway link
Full	A lane which extends for the full length of a freeway link with at least one end connecting to an on or off-ramp

Auxiliary lanes may occur on either the left or right-hand side of the roadway. Typical "freeway" links are illustrated in Figure 3.

Vehicles traversing "freeway" links move in accordance with the logic of component models specially designed for INTRAS (see Sections 5-7).



Key:

A Acceleration Lane

D Deceleration Lane

F Full Auxiliary Lane

Figure 3: Typical Freeway Link Configurations

A Ramp link is defined as a one-way non-freeway roadway segment which connects directly to a freeway link. Ramps may be one or two lanes in width. "Ramp" links are further characterized as either on or off-ramps indicating that end of the link that connects to the freeway.

The same logic is applied to move vehicles on "ramp" links as for "surface" links.

Absolute restrictions on the network size and traffic density, which may be accommodated by INTRAS, exist by virtue of the node, link and vehicle identification structure. Thus, links are identified by a 3-digit number (within link type) so that there may be no more than 999 links of each type.

Similarly, the maximum number of vehicles permitted on each link type (freeway, ramp, surface), is 9999. Node numbers in the interior of the network may take on values from 1 through 699. Nodes which describe the outer extremities of entry and exit links are limited to values from 700 → 799 and 800 → 899, for freeway and surface extremities, respectively. There is an absolute link length limitation of 3265 feet for surface and ramp links and 9800 feet for freeway links. None of the above limits should pose any significant problem to the user.

Relative restrictions on network size and traffic volume exist and vary directly with the available computer memory. Dynamic allocation of storage to link and vehicle arrays (Section 3) is performed, internal to the INTRAS program, to assure full utilization of the available memory.

2.2 Geometric Features of INTRAS

To model a roadway system in sufficient detail to replicate "real world" traffic statistics, it is necessary to accommodate those geometric features which significantly affect traffic performance. Geometric features (lanes, lengths, number of links) which represent numeric limits on the size of roadway systems which may be simulated were treated in the previous section. Other significant geometric features of the INTRAS design are described below.

Intersections - The junction of surface links with either other surface links or ramp links are modeled as in the UTCS-1 program. Each intersection is identified by a unique node number. Links are identified by the ordered pair of node numbers which identify their upstream and downstream extremities. There may be up to four links approaching, and four links departing, a given intersection (node).

Vehicles on each approach link to an intersection may have up to three destinations (receiving links) upon passing through that intersection. Each of these receiving links is entered by performing the associated traffic maneuvers: left turns, through movement or right turns. Left turners will seek gaps in opposing traffic; right turners will slow before turning, etc.

Freeway-Freeway and Freeway-Ramp Interconnections - The lane alignment of freeway links and on-ramp links with the next downstream freeway link is defined by two input specifications. First, the number and type (through, auxiliary) of lanes which comprise each link is specified. Second, the lane in the downstream link which receives traffic from the right-most through lane of the upstream link must be identified.

Lanes are labeled for identification via the following convention. The through lanes of each freeway link (and all lanes of ramp links) are numbered sequentially from right to left (i.e., the right-most through lane is always labeled "1"). The left-hand auxiliary lanes are numbered 6 and 7, respectively, with lane 6 adjacent to the freeway lane. Right-hand auxiliary lanes are numbered 8 and 9, respectively, with lane 8 adjacent to the freeway lane.

Freeway links are logically connected to downstream off-ramps by specifying the number of ramp lanes and whether it is a right-hand or left-hand off-ramp. The outside lanes on the designated side of the freeway are then internally assigned as connecting to the off-ramp.

As clarification of this convention, the following example is provided:

Figure 4a illustrates a roadway section containing four

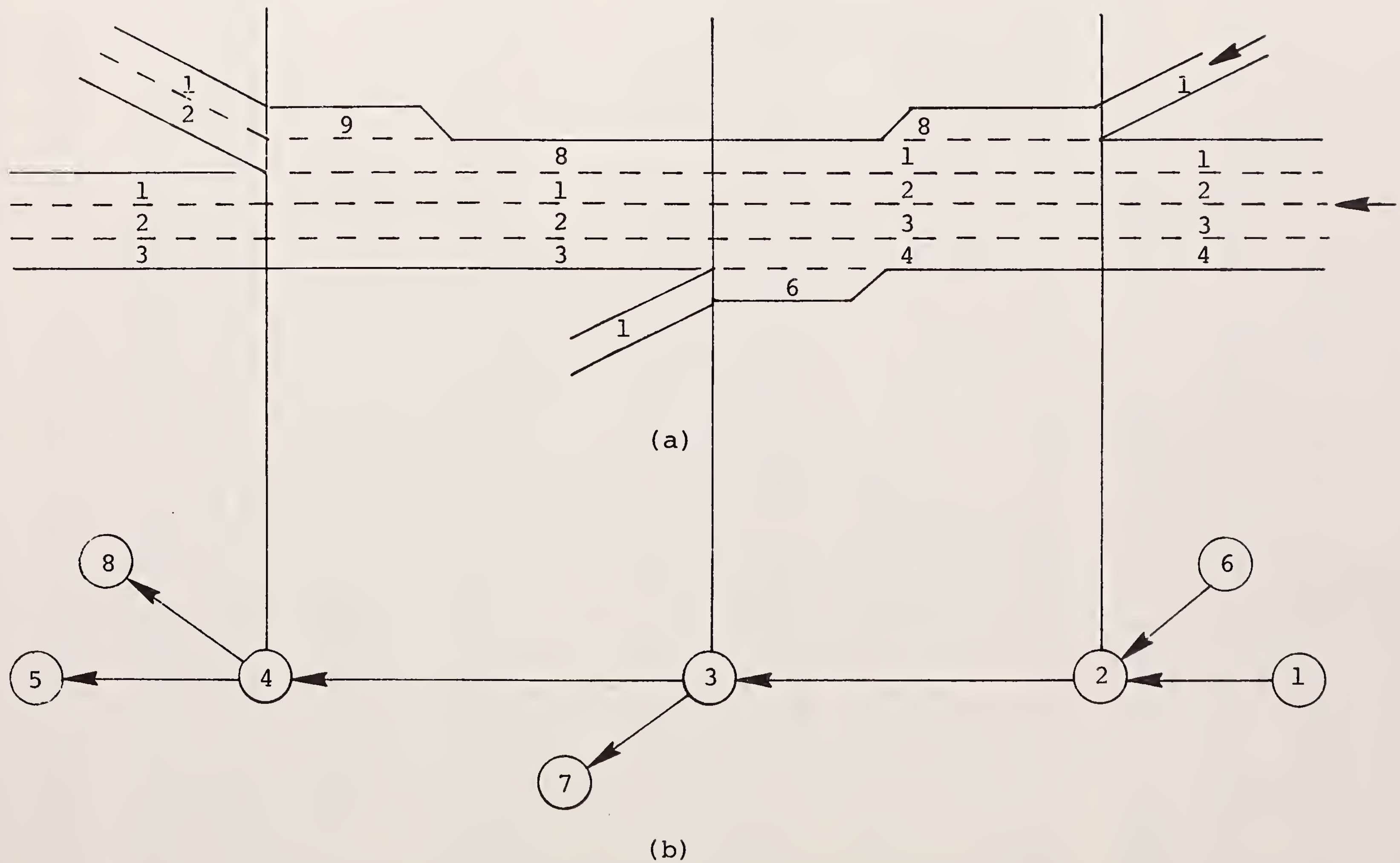


Figure 4: Ramp-Freeway Interconnection Example

freeway links, one on-ramp, and two off-ramps. Figure 4b contains the network idealization for the same roadway section. In this example, the alignment of freeway links and on-ramps is given in the following table:

Feeding Link	Receiving Link	Receiving Lane for Lane 1 Traffic
1,2	2,3	1
2,3	3,4	8
3,4	4,5	1
6,2 (on-ramp)	2,3	8

The off-ramp alignment is implicitly determined in INTRAS by the specification that left exiting vehicles from 2,3 enter 3,7 and right exiting vehicles from 3,4 enter 4,8. This specification, coupled with the number and definition of lanes in the four links, is sufficient to define alignment.

Grade Specification INTRAS has been designed to accept link-specific grade as input. Thus, it is proper to define a continuous section of roadway (containing a significant change in gradient) as two contiguous links, with a node defined at the point where the grade changes. The INTRAS logic examines the link-specific grade specification to modify several operating parameters (see Section 4).

Curvature As for grade, a change in horizontal curvature is sufficient reason to segment a roadway section into two links. Two methods of limiting vehicle performance on horizontal curves are available in the INTRAS design. First, a lowered value of desired free-flow speed may be defined for an affected link. Although easy to apply, this method presumes some pre-analysis on the part of the user.

Second, radius of curvature, super elevation and pavement condition may be defined. An internal table is referenced to determine friction coefficient from pavement condition. The basic equation for vehicle operation on a curve (Ref. 5), is then used to generate an upper bound for desired free-flow.

$$V = \sqrt{15R(e+f)}$$

where, e = rate of roadway superelevation, foot per foot
f = Friction coefficient for given pavement condition
R = Radius of curve in feet
V = Vehicle speed, miles per hour.

The simulation model applies the minimum of the input free-flow speed, and the curvature dictated upper bound, to traffic on the subject link.

Lane Separation - The typical freeway often contains sections where lane changing is physically prohibited by virtue of barrier curbs or traffic islands. These restrictions are designed to segregate through traffic from weaving traffic, or, to guide vehicles around some obstruction (bridge abutments, etc.). INTRAS is designed to accept physical barriers of this nature on a link-specific basis.

2.3 Signal and Sign Control

Each intersection in a simulated study network requires a control policy to establish the right-of-way for approaching vehicles. Similar to the UTCS-1 program, INTRAS has the ability to simulate both fixed-time signal control and sign control. Provision has been made for the modular inclusion and referencing of specially coded subroutines to model traffic responsive signal control.

Fixed Time Signal Control - Intersections of an INTRAS simulated network may be controlled by fixed time signals of up to six control intervals each. During each interval, one of the following standard signal configurations is applied to control each of the approach links:

Amber
Green
Red
Red with Green Right Arrow
Red with Green Left Arrow
No Turns - Green Through Arrow
Red with Left and Right Green Arrows
No Left Turn - Green Through and Right

The duration of each control interval is user-specified.

Sign Control - Each intersection not controlled by a fixed-time signal is controlled by either stop or yield signs. The user must specify which approaches face such signs. For the common situation, where no control of any kind is present, the INTRAS user will need to specify yield signs for one approach direction to indicate the minor street.

Ramp Metering - Four algorithm modules have been coded for controlling vehicles entering a freeway from on-ramps (see Section 2.7.1).

Freeway Traffic Diversion - Two algorithm modules have been coded for diverting freeway vehicles to alternate routes (see Section 2.7.2).

Traffic Responsive Intersection Control - A control module containing procedures similar to those in the UTCS-1 simulation have been implemented conforming to the NEMA standard.

An additional control has been designed for freeway link application. Advisory Signs will be simulated which inform freeway drivers of the presence of a downstream exit. Vehicles passing the acquisition point for these signs will alter their desired lane if they are assigned to exit the freeway at the indicated ramp.

2.4 Traffic Descriptive Features

Each driver-vehicle pair in a traffic stream behaves as an individual entity having different motivations and standards of performance from those around it. This quality must be modelled in INTRAS to achieve the proper stochastic variation in individual vehicle performance. To accomplish this, the INTRAS design provides for five vehicle types, each possessing its own family of vehicle characteristics (length, speed, acceleration profile, etc.). These characteristics may be revised as an option, so that the particular vehicle types chosen for the basic INTRAS model do not constitute a limitation on the user. The vehicle types chosen for the initial development of INTRAS are:

High Performance Passenger Car
Low Performance Passenger Car
Intercity Buses
Single Unit Trucks
Trailer Truck Combinations.

Further discussion of vehicle-type specific characteristics appears in Sections 3.1.9 and 4.

Variations within vehicle type are attributed to differences in driver performance. Decile distributions of these characteristics (variation about mean free-flow speed, queue discharge headway, etc.) are implemented in the INTRAS model as in the UTCS-1 program.

The two most important elements describing the traffic assignment on a given network are entering volume and routing. The INTRAS design allows specification of entering volumes, by vehicle type. The volume for each entry link is held constant over a period of simulated time referred to as a subinterval. At the end of each subinterval any number of these entering demand volumes may be revised. The duration of each subinterval is a user specification, thereby providing complete freedom in the variation of traffic loading with time.

Routing is normally performed by specifying the percentage (or count) of vehicles negotiating each possible turn movement on a link-specific basis. Turn movements may also be varied by the user from subinterval to subinterval. See Section 2.7 for a discussion of other routing techniques.

2.5 Incident Simulation Capability

A comprehensive freeway incident simulation procedure has been designed for INTRAS. The user may specify either blockages or "rubbernecking" to occur on a lane-specific basis. Each incident may occur at any longitudinal position on a freeway link and extend for any desired length of time.

The character of an incident may be changed with time. It is possible to specify, for example, a two-lane blockage which, after some specified duration, becomes only a one-lane blockage. The lane from which the blockage is removed may then become unrestricted or subject to "rubbernecking".

"Rubbernecking" may be applied, without a corresponding blockage, to simulate a shoulder incident. The user will input a factor indicating the percentage reduction in speed for vehicles traversing the affected lane segment.

2.6 Surveillance System Simulation

To render the INTRAS model an effective tool for evaluating a "real world" traffic performance evaluation and control techniques, it is necessary to simulate "real world" information gathering (surveillance) systems. Three types of traffic detectors are to be simulated by INTRAS.

Doppler radar detectors are characterized in the model by the lane and longitudinal location at which vehicles are detected. Each simulated vehicle crossing this location will cause the surveillance logic to output speed and time of actuation.

Short inductance loops are characterized by lane and longitudinal position, and loop length. Either of two output methods may be chosen by the user. A digital output form may be selected to simulate the time interval scanning method prevalent in many control systems. The output for this method consists of an (occupied, not occupied) status indication. Normally the detector scanning interval will be of shorter duration than the simulation time step. The on, off status of each detector for each scanning interval is obtained by interpolating vehicle position across the simulation time step, assuming constant acceleration.

An analog output form may be chosen which outputs the time and duration of actuation for each vehicle.

Coupled short inductance loops are described to INTRAS as two single short loops of equal length. The downstream loop is located by lane and longitudinal position. The upstream loop is implicitly located by defining the separation distance between the pair. The output for coupled pairs may either be analog or digital as for single loops.

All surveillance system output is made available for subsequent treatment by point processing (detector specific) and system evaluation (measure of effectiveness--MOE) estimation and incident detection modules. Internal arrays are maintained to service the dynamic control logic (see the following section).

2.7 Freeway Traffic Responsive Control

Vehicles entering the freeway via on-ramps may be subjected (as a user option) to a variety of control techniques. In parallel to, or independent of on-ramp control, diversion of freeway vehicles to a parallel service facility may be simulated. Both metering of ramp vehicles and diversion of freeway traffic are accomplished on a node-specific basis via specially coded subroutines. This subroutine structure permits a modular replacement of control policies. Control parameters are entered through the normal input stream for each affected node, in a general format acceptable to all control policies.

2.7.1 On-Ramp Controls

Four methods of on-ramp control are to be implemented in the INTRAS model. A typical geometric configuration of a metered on-ramp site is shown in Figure 5. The ramp signal (at C in the figure) is assumed to be upstream of the ramp-freeway interface at B. The downstream section of the physical ramp, link (C,B) is represented as a <u>ramp link</u>. The upstream portion (D,C) is represented as a <u>surface link</u>, subject to the normal queue discharge logic applied at all signalzied intersections. Optionally, node C may be removed, and the ramp control may be applied at node D. In this event (D,B) is represented as <u>ramp link</u>. The signal indication at D then specifies the ramp metering rate, as well as the control to through traffic.

<u>Clock Time Metering</u> - To simulate clock-time control of on-ramps, one fixed metering rate (vehicles per minute) is specified at each such node. A count-down clock is assigned to each associated on-ramp and the signal is set to "green" each time the clock returns to zero. The signal is maintained at "green" until a vehicle is discharged, and is then set to "red". A non-compliance percentage (user specified) is applied to vehicles arriving during the "red" signal. The indicated percentage of vehicles will be discharged through the "red" signal.

<u>Demand/Capacity Metering</u> - An evaluation of current excess capacity, immediately downstream of the metered on-ramp, is performed at user specified intervals. A maximum metering rate is calculated such that capacity of this freeway section is not violated. This metering rate is

applied as for clock-time metering. A minimum metering rate of 1 vehicle/20 seconds is applied to ensure that waiting vehicles are not "trapped" (i.e., as in Section D, C of Figure 5).

In addition to the evaluation period, the user must specify the following parameters for each on-ramp operating under demand/capacity metering control:

- Capacity at downstream freeway station
- Freeway link to which capacity applies
- Identify detectors on that link which provide input to the metering algorithms

Speed Control Metering - The procedure for this form of ramp metering is rather similar to the demand/capacity description above. A freeway link detector station must be established and identified at which speed evaluations are to be made to establish a metering rate. Generally, this location will be upstream of the on-ramp, although the logic will not preclude other placements. The user must specify a table of speeds, and metering rates, for each speed controlled on-ramp. As each evaluation period concludes, the prevalent speed, at the datum freeway station, will be compared to the tabular speed minimums to determine the proper metering rate.

Gap Acceptance Merge Control - This method of ramp control employs the ramp signal control to release ramp vehicles so as to merge smoothly into gaps* detected in the outside freeway lane traffic. The input required to implement this procedure is simplified in that no evaluation period nor metering rate criteria is required. A coupled pair of loop detectors must have been defined (via surveillance system specifications) in the outside lane of the upstream freeway link. The link identification and detector position must be identified to the gap acceptance algorithm, for each ramp, as well as the minimum acceptable gap size.

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* Gaps are expressed in units of time.

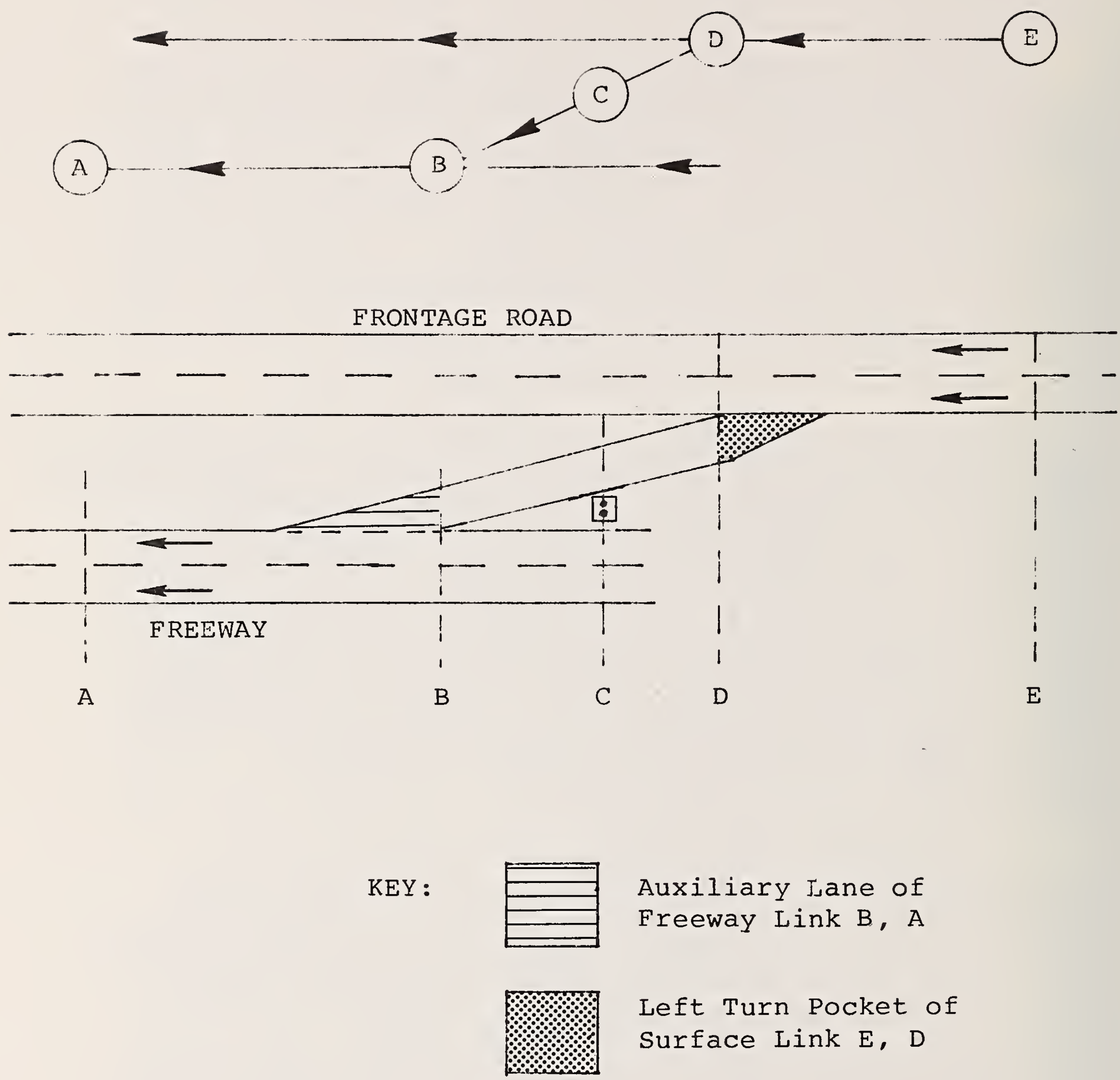


Figure 5: Typical Metered Ramp Geometry

Gaps detected in the traffic stream are projected downstream to the merge point. The merge point gap size will be adjusted to reflect the relative speeds of the leading and following vehicles. As in the design of a physical system, the user will have to excercise care that one of the following two logical absurdities does not occur:

- The detector is so close to the merge point that vehicles at the ramp signal can not be released in time to enter an acceptable gap

- The detector is so far upstream as to significantly affect the accuracy of the projected gap size

All of the above ramp control methods are subjected to built-in distributions reflecting (by driver-type), maximum tolerable queue delay for queue leader, and willingness to join a queue. These distributions are imbedded in the modular ramp control subroutines.

2.7.2 On-Freeway Diversion

Two procedures for diverting freeway vehicles to a parallel service facility will be programmed as subroutines of INTRAS. Both procedures will involve assignment of some portion of the through vehicles (at each freeway-off ramp junction) to the off-ramp. Each diverted vehicle will be assigned to a user specified path, eventually leading either out of the network or back to the freeway.

Clock Time Diversion. This diversion method will apply a user specified percent of through vehicles to be diverted to each affected off-ramp. The time at which diversion begins must also be specified as well as the subsequent routing for each vehicle.

Least Time Path Diversion. For this procedure, travel time will be monitored for freeway paths and user-specified alternate paths which rejoin the freeway at some downstream node. When, and if, an all-freeway path is more time consuming than its alternate, vehicles will be diverted at the appropriate off-ramp. The number of vehicles diverted will be calculated such that the total ramp loading does not exceed ramp capacity.

2.8 Detector Output Processing

The simulated surveillance system produces output analagous to that generated by an on-line system. This output is stored on a peripheral device as a sequential file. At the conclusion of the simulation, this file may be saved for subsequent processing or analyzed immediately. The following procedures for analyzing detector data are included in the INTRAS design.

- Point processing procedures process each individual detector's output to generate local estimates of traffic flow parameters

- Measure of Effectiveness (MOE) estimation procedures, provided by FHWA, generate system wide or subsystem (link)-specific parameters

- Incident detection procedures, provided by FHWA, analyze the detector data to identify the occurence of capacity reducing incidents.

All evaluations aggregate data over time intervals of user specified duration.

The following subsections describe the functions of these procedures in more detail.

2.8.1 Point Processing

Each detector on a roadway emits basic information as "raw" data. This "raw" data takes on different characteristics depending on the nature of the detector and the communications method. In "digital" mode each detector is polled at fixed intervals to determine current status (on-off, occupied-not occupied, etc.). In analog mode each detector sends a signal whose amplitude is proportional to the current measurement. INTRAS may operate in either digital or analog mode in simulating loop detectors. Simulated doppler radar detectors only operate as analog.

Table 1 describes the output of the detector types. Also shown are the parameters evaluated via point processing procedures. Each evaluation is detector specific. An assumed value of vehicle length is embedded in the point processing procedures to permit calculation of speed for single loops.

2.8.2 MOE Estimation

Procedures specified by FHWA will be implemented in INTRAS to estimate traffic performance parameters for freeway sections between detector stations. These procedures will operate on the data generated by detectors at the upstream and downstream stations. Estimates of area-related parameters (travel time, density, delay, etc.) will be generated to characterize traffic performance in the study sections.

2.8.3 Incident Detection

The primary goal of the subject project is to develop a simulation model to be used for the study of freeway incident detection and control. As described earlier, the INTRAS design includes comprehensive incident and surveillance system simulation capabilities. The INTRAS model will contain algorithms (to be provided by FHWA) to analyze the detector data and determine whether or not an incident has occurred on the simulated freeway. Either "raw" detector data or the results of the point processing procedures may be used as input to the incident detection algorithms.

The output of these procedures will be the time of detection of both the onset and end of each incident. When all detector data for the full simulation run has been processed, a comparison of the performance of the detection algorithms with the actual simulated history will be generated. The MOE of interest will include: time till detection (both onset and end of incident), percent of real incidents detected, and percent false alarms.

2.9 INTRAS User Options

Numerous peripheral functions are designed into the INTRAS model to enhance its usefulness in the study of

Table 1: Output of INTRAS Simulated Detectors

Detector Type	Analog Output	Digital Output	Point Processing Output
Single Loop	Time and Duration of actuation	Occupied-not occupied Status	Volume Time Mean Speed Mean Time Headway Mean Occupancy
Coupled Loops	Time and Duration of actuation for each loop	Occupied-not occupied status for each loop	Volume Time Mean Speed Mean Time Headway Mean Occupancy
Doppler Radar	Speed and Time of Actuation	————	Volume Time Mean Speed

freeway traffic systems. To service these peripheral functions and to provide the user with the output information best suited to describe each subject traffic situation, a variety of options are made available:

- The standard output (consisting of such MOE as vehicle-miles, vehicle-minutes, volume, density, speed, delay per-vehicle, lane-changes, etc.) will normally be reported at the end of each simulation subinterval, on both a link-specific and network-wide basis. The user may also elect to generate these reports at specified time intervals within each subinterval. These statistics are cumulative either from the start of simulation or, optionally, from the beginning of each subinterval.

- The output of surveillance detector data may be restricted to individual links or inhibited altogether. This option permits more economical use of the simulation model without major revision to a working data deck. Detector data output by INTRAS may either be analyzed immediately or retained and analyzed at a later time. This procedure permits re-analysis with modified point processing or system analysis algorithms without costly repetition of the simulation process.

- Data may be output to tape or disc file for later processing by a plotting module. Through this option, vehicle trajectory and/or MOE contour plots may be created for selected freeway links or groups of links.

- The MOE data in the standard output reports may be saved for processing by the statistical analysis procedures. It will be possible to compare pairs of simulation runs, performed to study the effect of parametric variations, for statistical agreement by use of these procedures.

- It is possible to specify one station, on each freeway or ramp link, at which lane-specific mean values and distributions of headway and speed will be reported. These statistics, plus lane-specific volume, will be output in addition to the standard report at the end of each simulation subinterval.

- Values of embedded calibration parameters (i.e. grade dependent speed or acceleration, lane distribution of desired free-flow speed, etc.) may be varied via card input. Thus, as an example, it is possible to revise all characteristics of a particular vehicle type without recompiling any portion of the computer program.

- The user may choose to execute only the data diagnostic procedures in order to check a new or revised data deck. This option provides for rapid data "check out." The more time consuming simulation may then be run under a lower priority to realize cost savings.

The above user options ensure that INTRAS is capable of efficiently satisfying the requirements of a wide variety of research studies.

3. THE STRUCTURE AND METHODOLOGY OF INTRAS

The INTRAS simulation model is designed so as to satisfy a set of criteria which reflect the project goals and prior experience in designing and using traffic simulation models. These criteria may be stated as follows:

- The INTRAS program design must include provision for all functional capabilities specified in the project work statement and described in Section 2.

- INTRAS must be capable of realistically and accurately representing the dynamic and stochastic nature of traffic in a freeway-ramp-service road system.

- The program must be designed for maximum utility. The user must be able to input data and exercise program control options via clear, concise input and program execution procedures.

- Programming and internal data must be designed so as to minimize the total core storage required.

- To the extent possible, after consideration of the preceding criteria, execution time must be minimized.

The following sections describe the structure and methodology incorporated into the INTRAS design to achieve the above objectives.

3.1 Functional Structure of INTRAS

The INTRAS model is a highly complex system containing procedures for multi-purpose input processing, diagnostic testing, microscopic traffic simulation, output reporting, statistical analysis, detector output processing and digital plotting. Reliable and efficient use of such a system depends on the system structure and organization. Early in the development of INTRAS, the time ordering of the above procedures was determined. The independent portions of each procedure were identified and isolated. This planning function provided a basis for the structural design of INTRAS.

One danger encountered in the implementation of large complex programming systems is that, when they are completed, storage restrictions may limit their usage to trivial applications. To achieve meaningful results it may then be necessary to segment the system. This unplanned segmentation often leads to loss of efficiency and debilitates certain features of the original plan. It is of utmost importance to design a system functionally, so that segmentation is planned and the logical flow between segments occurs in the most efficient way, consistent with project goals.

INTRAS is designed with these factors in mind. The functional segments are overlayed so as to provide maximum computer storage for arrays and scalars. The maximization of data storage assures the greatest utility from the standpoint of treating large traffic networks. Major portions of the data storage are optimized to increase network size capabilities to the maximum. This optimization is discussed in Section 3.3.

The overlay structure and information transfer of INTRAS is illustrated in Figure 6. The functions associated with each module are described in detail in the following subsections.

3.1.1 The INTRAS Supervisor Module

The INTRAS system will exercise its various functions by performing transfers (CALLs) to the functional modules in the order dictated by input Run Control specifications. The logical entity performing these transfers is referred to as the INTRAS Supervisor. A flow chart of the Supervisor logic is included as Figure 46 in Appendix A. To ascertain the first module transfer of each case, parameters on the Run Control card (for that case) are interpreted. Thereafter, before returning to the Supervisor, each module determines the next necessary transfer and communicates this choice via a control variable (NEXCAL).

There are a number of service subroutines in the Supervisor overlay module which are referenced from many locations in several of the overlay modules. Since they must reside in storage at all times, these routines must be included in the Supervisor.

Identification of the INTRAS Supervisor module subroutines, and a brief description of each, is presented in Table 2. In addition to the routines identified in Table 2, the following service routines which perform packing and unpacking of individual data array elements are included in the INTRAS Supervisor:

Array	Unpacking Routine	Packing Routine
LNKR	ULNKR	PLNKR
LNKS	ULNKS	PLNKS
VR	UVR	PVR
VS	UVS	PVS

3.1.2 The PORGIS Module

The PORGIS (Program to ORGanize the Input Stream) module is a pre-processor which reads all simulation oriented input data and performs an exhaustive series of diagnostic tests thereon. Errors uncovered by these testing procedures are reported and tables of input data are output.

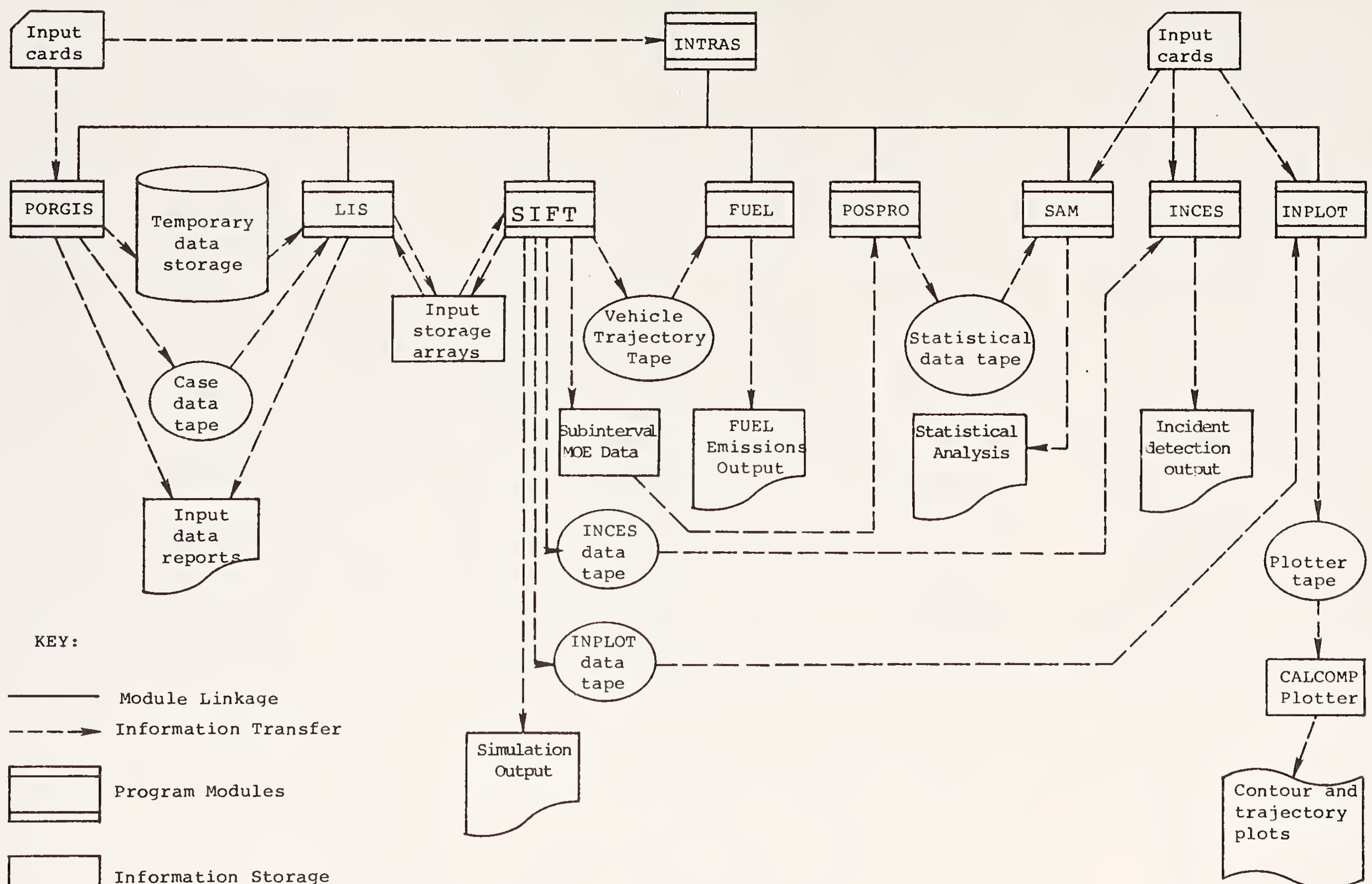


Figure 6: Functional Structure and Information Transfer of INTRAS

Table 2: INTRAS Routines

Routine	Function
INTRAS	Main supervisor program. Reads Type 99 card and performs routing for each case by calling the appropriate overlay modules.
EROT	Generalized error message generator. This routine reports each error condition by number and prints the associated parameters (See Section 3.6).
DRWS	Disc read/write subroutine. This subroutine performs most of the I/O processing required by the other subroutines. Error messages and standard reports are <u>not</u> generated by DRWS.
UNPAK	This subroutine unpacks one entire parameter vector for any of the arrays LNKR, LNKS, VR, VS (see Section 3.3).
PAK	This subroutine packs one entire parameter vector for any of the arrays LNKR, LNKS, VR, VS (See Section 3.3).
FINDL	This subroutine locates the link number and type of a link described by its upstream and downstream nodes.
BLOCK DATA	Defines variables and arrays related to the INTRAS model structure.
FINDLN	Determines lane alignment of two freeway links or a ramp and a freeway link.
NEXTLN	Determines the downstream link, link type and lane for a given freeway or on-ramp link.
LRANK	Order freeway links, downstream to upstream, so that downstream links may be processed first.

PORGIS also performs some data service functions. Simulation case data which is error free may be stored on a Case Data Tape for future execution. A table of contents for this tape, displaying identification for each case, may be generated as a user option.

Identification of the PORGIS module subroutines, and a brief description of each, is presented in Table 3. The logical flow of PORGIS is illustrated as Figure 47 in Appendix A.

3.1.3 The LIS Moduel

The function of the LIS (Load Input Stream) Module is to read and load simulation case data into the model data arrays and scalars, to perpare for execution of each simulation subinterval. The diagnostic tests of PORGIS are not performed, as LIS is not referenced unless the data deck has been shown to be error free. Such is the case for case data, previously checked by PORGIS, in a previous computer run, and stored on the "Case Data Tape" (see Figure 6). The logical flow of LIS is illustrated as Figure 48 in Appendix A. All subroutines of the LIS module are directly analogous to those of PORGIS with the diagnostic tests removed. Table 4 presents the correspondence between the subroutine names of LIS and of PORGIS. The simulation module, SIFT, is always specified as the next overlay to be called by the Supervisor, upon completion of processing by LIS.

3.1.4 The SIFT Module

SIFT (SImualtion of Freeway Traffic) is the overlay module of the INTRAS system which performs all simulation activities. Reflecting the scope and complexity of the simulation model, it was necessary to segment this module into two lower level overlays in order to satisfy the specified storage constraints. To avoid excessive computer time expenditures, for "spooling" these segments in-and-out of core storage, those routines which perform frequent processing activities (at least once per time step) are grouped into one segment. The other segment is comprised of those routines which perform relatively infrequent processing activities (i.e., output, fill time equilibrium testing). The SIFT module subroutines are described briefly in Table 5. Logical flow diagrams for the SIFT

Table 3: PORGIS Routines

Routine	Function
PORGIS Supervisor	This main program of the overlay reads and checks the type 00, 01, 50, 51, 56 57 and 60 cards. Subroutines are called to read the other card types and print input tables
TABCON	Prints a "table of contents" for the "Case Data Tape".
LPAK	Performs the function of compressing or expanding the LNKF, LNKR or LNKS arrays to either economize on storage or provide for a larger network (see Section 3.3).
LINKIN	Reads and diagnostically checks the link geometry, name and operation cards (Types 02, 03, 04, 05 and 06). The appropriate arrays and scalars are primed. LPAK is called to compact the storage arrays.
INT1	Performs system wide geometric checking and primes certain system geometric dependent variables.
TURNIN	Reads and diagnostically checks the turning movement cards (Type 08).
PRSIG	Reads and diagnostically tests the signal and sign control cards (Type 10).
PRMSND	Reads and diagnostically tests the input demand volumes (Card types 20 and 21).

Table 3: PORGIS Routines (continued)

SURVIN	Reads and diagnostically tests the surveillance detector specifications on card type 25. The DTCTR array is primed.
INCIN	Reads and diagnostically tests the incident specifications on card type 30. The INCID array is primed.
IMBED	Reads and diagnostically tests revisions to imbedded calibration data (Card Types 35-49).
PRACT	Determines if intersection actuated traffic control input cards (types 15, 16 and 17) are present and calls appropriate subroutines to process them.
CTPFF	Reads and diagnostically checks the actuated controller cards (type 15).
CTPSX	Reads and diagnostically checks the phase cards (type 16).
CTPSV	Reads and diagnostically checks the phase operations cards (type 17).
CLRALL	Initializes COMMON variables and arrays before processing each case.
INACT	Prints a table of intersection actuated traffic control parameters for each traffic actuated intersection.
DETGEN	Generates synthetic detector stations required to output plotting parameters.
LINOUT	Prepares output tables describing the link specific geometrics and operation parameters.

Table 3: PORGIS Routines (continued)

SIGOUT	Prints a tabulation of the signal and sign control at each network node.
FLOOUT	Prints a table of demand volumes at each entry link.
SUROUT	Prints a table of user defined surveillance detector specifications.
INCOUT	Prints a table of incident specifications.
IMBEDO	Prints a table containing the current values of the imbedded calibration parameters if any values have been revised via input.
MATCH	Tests for equality in the last two digits of 700 and 800 series node numbers.
CHKNOD	Performs validity tests on node numbers.

Table 4: PORGIS and LIS Subroutine Correspondence

PORGIS Subroutine	Corresponding LIS Subroutine
PORGIS	LIS
LPAK	LLPAK
LINKIN	LLINKI
INT1	LINT1
TURNIN	LTURNI
PRSIG	LPRSIG
PRMSND	LPRMSN
SURVIN	LSURVI
INCIN	LINCIN
IMBED	LIMBED
DETGEN	LDETGE
LINOUT	LLINOU
SIGOUT	LSIGOU
FLOOUT	LFLOOU
SUROUT	LSUROU
INCOUT	LINCOU
IMBEDO	LIMBDO
CLRALL	LCLRAL
PRACT	LPRACT

Table 4: PORGIS and LIS Subroutine Correspondence
(continued)

PORGIS Subroutine	Corresponding LIS Subroutine
CTPFF	LCTPFF
CTPSX	LCTPSX
CTPSV	LCTPSV
INACT	LINACT

Table 5: SIFT Routines

Routine	Function	Supervisor or Low or High Overlay
SIFT Supervisor	Executive which contains a simulation control loop and calls low and high frequency overlays as required	S
VPAK	Reallocates unused vehicle array storage	S
LASTLK	Determines the previous link, link type and lane for a given freeway lane	S
FRSTV	Determines the most downstream vehicle in lane of link specified	S
LASTV	Determines the most upstream vehicle in lane of link specified	S
FINDFV	Locates an empty slot in freeway vehicle array	S
FINDRV	Locates an empty slot in ramp vehicle array	S
FINDSV	Locates an empty slot in surface vehicle array	S
RANDOM	Pseudo-random number generator	S
HICON	Executive of high frequency overlay segment	H
UPSIG	Revises fixed time signal timing and calls appropriate routines to link with traffic responsive control algorithms. Also flags end of queue and cycle failures when necessary	H
SIGACT	Performs intersection actuated traffic control processing	H
PDAFZ	Subroutine to poll all detectors for intersection actuated traffic control processing during an active phase	H

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
PDNAFZ	Subroutine to poll all detectors for intersection actuated traffic control processing during an inactive phase	H
UPACT	Controls updating of signal settings for intersection actuated traffic control processing	H
GRNSIG	Updates green signal settings for intersection actuated traffic control	H
REDSIG	Updates red signal settings for intersection actuated traffic control	H
TERMFZ	Terminates old phases and activates new phases during intersection actuated traffic control processing	H
DECACT	Determines whether any phase now in green should enter clearance interval (amber) during intersection actuated traffic control processing	H
TERM	Terminates phases during intersection actuated traffic control processing	H
ACTFZ	Activates phases, calculates interval durations and sets status codes during intersection actuated traffic control processing	H
ASIG	Sets signal codes facing entry links under intersection actuated traffic control processing	H
DETSW	Implements detector switching, if appropriate, during intersection actuated traffic control processing	H

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
FZCL	Determines if there is a call to a phase for a specified controller during intersection actuated traffic control processing	H
CAL1	Performs clock time ramp metering	H
CAL2	Performs demand/capacity ramp metering	H
CAL3	Performs speed control metering	H
CAL4	Performs gap acceptance merge control	H
CAL5	Performs clock time diversion	H
CAL6	Performs least time path diversion	H
CAL8 CAL9	Two dummy subroutines included so that additional traffic responsive control algorithms may be integrated	H
MOEV	Loops over all lanes of surface and ramp links calling appropriate subroutines to process non-freeway vehicles	H
MOOV	Processes all vehicles in a designated lane of a non-freeway link for the current time step	H
SVEH	Generates vehicles on surface entry links	H
GOQ	Processes vehicles eligible to discharge from surface or ramp links	H
OFFRMP	Interface between freeway and off ramps	H
HDWY	Calculation of queue discharge headways (non-freeway)	H

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
GETCD	Generates turn codes for vehicles entering new links	H
LSWCH	Performs non-freeway lane switching	H
LANES	Assigns discharging vehicles to lanes on new non-freeway links	H
TSTSAT	Tests for saturation on links receiving discharging non-freeway vehicles	H
DETECT	Revised detector array to provide current status each time step	H
TSIG	Examines signal code and decides whether it is permissive or prohibitive for a given vehicle	H
NORM	Computes normal trajectory for given vehicle for current time step	H
CLNUP	Performs bookkeeping and statistical updates at end of each time step	H
INCDAT	Outputs data to "INCES Data Tape" at each vehicle actuation of a surveillance detector	H
TPTOUT	Outputs data on vehicle trajectories to "INPLOT Data Tape" at user specified intervals	H
QSTATE	Determines if a particular non-freeway vehicle is in queue at end of time step	H
TYPE	Generates vehicle type or driver type	H
SELEN	Determines environment of non-freeway link being processed	H
FILL	Fills non-freeway link environment arrays	H

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
RELEN	Updates link array parameters for receiving and approach links in environment of subject link	H
SEVEN	Creates environment of vehicle being processed	H
GETUNV	Determines which vehicle unpacking routine to call by testing type of link being processed	H
REVEN	Updates vehicle array parameters, after subject vehicle has been processed, for vehicles in environment of subject vehicle	H
ONRMP	Interface between on-ramps and freeway links	H
FMAIN	Loops over freeway links to process vehicles for freeway time step	H
CLOSE	Determines points at which a lane will be closed due to incidents or lane-end	H
BLOK	Determines whether a vehicle can stop before reaching nearest blockage and adjusts new speed if necessary	H
CONSOL	Consolidates a sequence of CALLS to other lower level freeway processing routines so that they may be referenced from multiple locations	H
FMOVE	Moves all vehicles in one lane of a specified freeway link	H
EMGNCY	Calculates accelerations for collision avoidance of freeway vehicles	H

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
FGNRAT	Generates vehicles on freeway entry links	H
CHANGE	Determines target lane for freeway vehicles desiring to change lanes	H
CHECK	Determines if change to freeway target lane is currently possible	H
CHOOZ	Determines exit lane, or desire of lane change or yielding-way on freeway	H
FRESET	Updates the identification of the last vehicle in the specified lane of the specified freeway link	H
RISK	Determines the maximum deceleration acceptable to a freeway vehicle changing lanes or of its new follower	H
LCROSS	Updates parameters after freeway vehicle crosses link boundary	H
ALANE	Identifies the origin lane of a freeway lane-change maneuver	H
CANCEL	Modifies the tracing (leader-follower) linkage for freeway vehicles	H
COLECT	Updates detector and freeway data station arrays to reflect current status	H
ADVANC	Implements "Advanced Warning" sign logic	H
LOCON	Executive of low frequency overlay segment	L
INIT	Initialization of parameters outside time step control loop	L
RESET	Resets statistics at end of network priming period (fill time)	L

Table 5: SIFT Routines (continued)

Routine	Function	Supervisor or Low or High Overlay
FILTST	Determines whether equilibrium has been attained during fill time	L
FTSC	Calculates appropriate current freeway time step	L
CPTOUT	Outputs MOE data for contour plotting to "INPLOT Data Tape"	L
CYCP	Prints reports of cumulative or interval specific MOEs	L
INTST	Prints intermediate (detailed) data reports	L
SINCES	Implements incident detection algorithms for feedback control applications	L
SPOINT	Performs point processing of individual detector data for feedback control applications	L
SINC1 SINC2 SINC3	Performs incident detection algorithm processing for feedback control applications	L

Supervisor, HICON and LOCON are included as Figures 49, 50 and 51 in Appendix A.

The high frequency activity overlay is called from only one location in the SIFT Supervisor (at the beginning of each new time step). This overlay is only reloaded if the low frequency activity overlay is in core. The low frequency overlay is called from several locations, depending upon the options requested; a flag, ISSEQ, indicates the logical path to be followed in LOCON.

3.1.5 The POSPRO Module

The POSPRO Module (POSt PROcessor) is designed to act as an interface between the SIFT simulation and the statistical testing procedures of the SAM module. The task performed by POSPRO is to create a file of simulation statistics on the Statistical Data Tape. This module, consisting of a single routine, is entered at the end of each simulation subinterval to add the subinterval link-specific and network statistics to a temporary file. When the total simulation run is completed, the contents of this file are added to the Statistical Data Tape.

A flow chart of the POSPRO logic is included as Figure 52 in Appendix A.

3.1.6 The SAM Module

The SAM (Statistical Analysis Module) module is designed to perform statistical comparisons between pairs of simulation runs. The purpose of such comparisons might be to determine if a particular parametric variation results in a significant change in key MOEs. Since it is likely that the user may use INTRAS to resolve just such questions, SAM is included as part of INTRAS to satisfy this need in the most efficient manner.

In addition to comparing the results of a pair of simulation runs, SAM may be used to compare simulation results with externally supplied MOE (i.e. field data). Data formats are provided for input of such external data to create the equivalent of a simulation run statistical file on the Statistical Data Tape. A logical flow chart of SAM is included as Figure 55 in Appendix A. Table 6 presents a listing of the SAM module subroutines and a brief description of each.

Table 6: SAM Routines

Routine	Function
SAM Supervisor	This main program of the SAM module reads the SAM data cards, performs file creation or management activities, and calls subroutines to accomplish a statistical comparison between files.
READCL	Reads statistical data from statistical Data Tape and primes arrays.
PRINT	Prints contents of arrays for cases to be compared.
STAT	Performs statistical analyses by calling individual test algorithm subroutines.
TTEST	Calculates paired T-test statistics and determines significance.
CALC	Calculates arithmetic means and variances.
ANOVA	Performs one-way analysis of variance tests.
WILCOX	Performs the Wilcoxon matched pairs signed-ranks test.
UTEST	Performs the Mann-Whitney U-test.
RANK	Algebraically ranks vector elements.

3.1.7 The INCES Module

The purpose of the INCES (INCident Detection and EStimation) Module is to perform all processing of detector data output. In addition to implementation of incident detection and parameter estimation procedures, this module includes point processing and MOE evaluation algorithms. INCES may be employed as an integral part of a simulation run or as a separate run to process previously stored data. In either case, detector data is taken from the INCES Data Tape, as primed by SIFT.

A flow chart of the INCES logic is included as Figure 54. Brief descriptions of the INCES subroutines appear in Table 7.

3.1.8 The INPLOT Module

The INPLOT Module prepares vehicle trajectory and MOE contour plots based upon data, stored by SIFT, on the INPLOT Data Tape. Both plot types are generated in the time-space plane. The space axis may represent one or a group of contiguous freeway links. The user may request vehicle trajectory plots, in a single lane, or for all lanes, in a specified section of freeway. The available MOE's considered in the contour plots are: spot speed, volume, density, delay/vehicle-mile, headway, and travel time/vehicle-mile, as specified by the user.

Contours are plotted, for each MOE, at a standard set of values embedded in INPLOT arrays. These standard values may be revised via the INPLOT parameter card. In addition to this option, an index may be created which details the current contents of the INPLOT Data Tape.

A flow chart illustrating the INPLOT logic is included as Figure 53 in Appendix A. The identification and a brief description of the INPLOT subroutines appear in Table 8.

3.1.9 The FUEL Module

Recently, a new overlay module was designed, for the UTCS-1 model, which calculates fuel consumption and vehicle emissions data based upon the dynamics of indivi-

Table 7: INCES Routines

Routine	Function
INCES	This main program of the INCES Module reads the INCES Parameter cards and selects the proper subroutines to call to execute the prescribed procedures.
READET	Reads the detector data from the INCES Data Tape
POINT	Performs detector specific (point processing) parameter evaluations
POUT	Prints a report containing the results of the point processing evaluations.
INC1 INC2 INC3	Performs the incident detection algorithm processing
PINC	Prints a report containing the results of the incident detection algorithms
MOE1 MOE2 MOE3	Perform the measure of effectiveness evaluation processing
MOUT	Prints a report containing the results of the MOE evaluation algorithms
TTIME	Implements the travel time algorithm for a number of MOE algorithms

Table 8: INPLOT Routines

Routine	Function
INPLOT Supervisor	This main program of the INPLOT module reads the INPLOT request card and calls the appropriate subroutines to perform the requested activity.
AXPLOT	Determines the extent of and plots the axes required for each plot.
COMPCT	Manages the trajectory data buffer. As the data is plotted COMPCT retains enough of the previous buffer to ensure continuity with the new buffers data.
CONTR	Reads MOE data, computes MOE values to be plotted and then calls CPLOT to plot.
CPLOT	Determines scaled time and space coordinates, at which MOE contour is to be plotted and then calls the CALCOMP software routines to perform plotting operation.
IOPROC	Reads data from INPLOT Data Tape and splits it into two temporary files for contour MOE and vehicle trajectories.
PATH	Identifies and sequences those links and lanes from which data is required for a particular plot.
SEARCH	Searches trajectory data to find matching vehicles for successive time steps.
SPTAL	Identifies each contiguous lane segment in a freeway section and calls TRAJEC to plot trajectories for each segment.
TPLOT	Scales trajectory time and space coordinates and calls CALCOMP software to perform plots.
TRAJEC	Reads trajectory data and calls appropriate subroutines to plot vehicle trajectories.
PAGE	Draws page outline, writes plot heading and roadway section indicators.
FILEX	Prints tape file index.
LEGEND	Draws a legend of contour plot symbols.

dual vehicles at each time step. This overlay module, FUEL, is included in the INTRAS design, as a user option, to provide link-specific evaluations throughout the course of a simulation run. Calculations of fuel consumption and emissions (for carbon monoxide, hydrocarbons, and oxides of nitrogen) are based upon vehicle type and trajectory data: acceleration/deceleration and speed. These data are stored by SIFT on the Vehicle Trajectory Tape, each time step, for all network vehicles. MOE's values are reported at the end of each simulation subinterval by the FUEL Module. Fuel consumption and emission rates are specified internally as default data table which may be over-ridden by the user. The default data tables are representative of the following assumed characteristics for the INTRAS vehicle types:

- High Performance Passenger Car - 8 cylinder
- Low Performance Passenger Car - 4 and 6 cylinder composite
- Intercity Bus - Diesel powered
- Single Unit Trucks - Gasoline powered
- Trailer Truck Combinations - Diesel powered.

Tables defining the response surfaces of emission rates and of fuel consumption rates, in the speed-acceleration plane, for each vehicle type, will be supplied by FHWA. These tables are a part of the FUEL module, but may be over-riddern by user supplied card input, as for the modified UTCS-1 program. This module consists of a single main program plus a series of BLOCK DATA routines defining the tables.

3.2 The User Interface

The most obvious, and therefore most sensitive, characteristics of any program are contained in the user interface. The utility of a computer program is often judged on ease of use, and quality and clarity of output. Because of the comprehensive nature of the INTRAS simulation and the wide range of run control and output options available, it is particularly important that the user is provided with orderly and unambiguous utilization procedures.

3.2.1 Data Input and Run Control Procedures

The INTRAS input is patterned after its

forerunner, the UTCS-1 model (Ref. 4). To organize the input design process, functional data categories are defined. Within each category data elements are identified and then further subdivided so as to group those elements which pertain to particular subject areas (i.e. signal control, geometry, output specification, etc.). Table 9 presents the hierarchy of data categories.

A generalized card format is adopted to avoid proliferation of FORMAT statements throughout the input routines. For the standard 80-column data card, this format consists of twenty-six three-column data fields followed by a two-column field for card type identification. All alphanumeric data is grouped on the first few card types to permit unrestricted use of the generalized input format for the majority of the data deck.

Data elements are assigned to card types by data category. Card type numbers (other than card type 99) are assigned to conform to the required order, in the input stream, of each data category. Table 10 identifies all frequency (i.e. number of cards for each application of the program) for each card type is also indicated.

3.2.2 INTRAS Model Output

The INTRAS Model produces many standard and optional output formats. The following subsections identify, describe and illustrate each major variety.

3.2.2.1 Input Parameter Reports

Tables of input parameters are provided, by the PORGIS and LIS modules, for each simulation case run. These tables fully identify the geometric, control and traffic input descriptors which characterize the current study. The values of parameters which may change with time are output each subinterval.

Tables 11, 13, 15, 17, 19 and 21 illustrate the Input Parameter Reports for the traffic network of Figure 1 and 2. Nodes 1, 2, 4 through 8, 13 and 14 have been excluded from Table 15 for brevity. The format of their sign control output would be similar to that of node 12. Tables 12, 14, 16, 18, 20 and 22 contain definitions of the column

Table 9: INTRAS Data Categories

Data Category	Subcategories
Run Control	Run Oriented Control Simulation Oriented Control Subinterval Oriented Control
Network Descriptors	Geometry Traffic Control Surveillance
Traffic Descriptors	Volume Routing Incidents
Output Control	Printed Reports Detector Output Raw Data for Plotting Storage of Statistics for Comparisons
Calibration Revisions	Imbedded Parameters and Arrays FUEL Data Tables
Parameters of Peripheral Function Algorithms	Detector Data Processing Statistical Analysis Plot Generation

headings on the corresponding Input Parameter Reports.

3.2.2.2 Standard SIFT Output

The standard output report formats of the SIFT Module are illustrated in Tables 23, 25 and 27. These reports may be either cumulative or subinterval specific. The latter form is shown. The samples represent the statistical results from one five-minute simulation subinterval for the network of Figures 1 and 2. Definitions of the column headings for these three output reports are presented in Tables 24, 26 and 28.

3.2.2.3 INPLOT Module Output

The INPLOT Module creates CALCOMP digital plots of vehicle time space trajectories, and contour maps of MOE values in the time-space plane, as requested. Figure 7 is an idealization of the vehicle trajectory plot design. The actual INPLOT output would contain the trajectories of all vehicles traversing the designated roadway section. To assist the user in correlating the plot with the roadway geometry, the position of nodes within the designated roadway section is displayed along the horizontal (distance) axis of the plot.

Figure 8 illustrates the contour map output capability of INPLOT. This output form may be produced for several different Measures of Effectiveness including: spot speed, volume, density, delay, headway and travel time. Contours are produced which represent constant values of these MOE's. The default family of speed contour values are displayed in Figure 8. A unique symbol is associated with each value and is used to label the plotted contours. The MOE contour values may be updated, as a user option, by card input. It would, for example, be possible for the user to specify a family of speed values of 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61 and 62 MPH in order to obtain a much finer contour map than that shown in Figure 8.

As for the trajectory plots, node numbers are displayed along the distance axis for reference.

3.2.2.4 INCES Module Output

The results of processing surveillance detector output is reported by the INCES module in three formats, illustrated in Tables 29, 30 and 31. Table 29

Table 10: Description of Input Stream

Card Type	Module	Name	Data Element	Description	Frequency
99	INTRAS	Run Control	Run Code Last Run Flag Tape Status Flags Run I.D. Number	Specifies desired options Identifies whether another case follows Defines status of data stored on magnetic tape Identifies data stored on previously established files to be processed by this run	One mandatory per simulation
00	PORGIS LIS	Title Card	Case Description Run I.D. Freeway Time-Step Seed	A statement identifying this run A number (or code) identifying this run The minimum time-step for processing freeway vehicles Random number seed	One mandatory per simulation
01	PORGIS LIS	Network Name	Network Description "Fill" time	A statement identifying the network Upper bound of initialization time	One mandatory per simulation
02	PORGIS LIS	Link Geometry Card	Identifying node numbers Link length Link type Free-flow speed Number of lanes Receiving links Grade code Advanced warning sign data	Upstream and downstream node numbers Freeway, ramp or surface link Mean desired free-flow speed Through lanes excluding pockets or auxiliary lanes Links receiving traffic exiting this link Vertical gradient Location of sign and off-ramp identification	Once per link per simulation
03	PORGIS LIS	Link Name Card	Link name	Alphanumeric link name	Optional, may occur once per link per simulation

Table 10 (continued)

Card Type	Module	Name	Data Element	Description	Frequency
04	PORGIS LIS	Freeway Operation Card	Curvature	Radius, superelevation and pavement condition	Once per freeway link per simulation
			Auxiliary lane data	Right or left, type (full acceleration or deceleration) and length	
			Lane alignment	Lane alignment with downstream freeway link	
			Lane separation barriers	Identification of lanes separated	
05	PORGIS LIS	Ramp Operation Card	Queue discharge parameters	Specified for off-ramps only. Mean headway, first vehicle lost time	Once per ramp link. May be repeated each subinterval
			Lane alignment	Alignment with downstream through link, specified once only	
06	PORGIS LIS	Surface Link Operation Cards	Queue discharge parameters	Mean headway, first vehicle lost time	Once per surface link. May be repeated each subinterval
			Link opposing left-turners	Identification of link opposing left-turning traffic	
			Turning pockets	Pocket size and position (left or right)	
			Lane channelization	Dedication of lanes to right or left-turners	
08	PORGIS LIS	Link Turning Movement Cards	Amount of vehicles	Count or percent of vehicles for each possible movement	Once per link per simulation. May be repeated once per link per subinterval
10	PORGIS LIS	Sign and Signal Control Cards	Traffic responsive control flag	Identifies algorithm providing logical control at intersection (for on-ramp control and diversion strategies)	Once per node per simulation
			Traffic responsive control parameters	(If applicable)	
			Fixed time signal data	Includes interval durations, signal indications facing each approach for each interval and offset	
			Sign parameters	Unrestricted, yield or stop for each approach	

Table 10 (continued)

Card Type	Module	Name	Data Element	Description	Frequency
15	PORGIS LIS	Actuated Controller Card	Node numbers Controller definitions Coordination	Upstream and downstream node numbers of approach links and any other links referenced by controller Standard controller options in effect Time relationship with other signalized intersections	Optional. May occur once per controller per simulation
16	PORGIS LIS	Phase Card	Actuation code Interval timings	Code indicating whether phase is actuated or not Durations and appropriate time extensions for all actuated and non-actuated intervals within the subject phase	Optional. Must occur once per simulation for each controller for which a Type 15 Card was input
17	PORGIS LIS	Phase Operation Card	Signal codes Detector locations	Signal indications facing each approach for subject phase Lane and link locations for all detectors providing data to control subject phase	Optional. Must occur once per simulation for each controller for which a Type 15 Card was input
20	PORGIS LIS	Demand Volume Cards	Total entry flow Percent of flow Percent of flow	 Specified by vehicle type Specified by incoming lane (optional)	Once per entry link per simulation. May be repeated each subinterval
25	PORGIS LIS	Surveillance Cards	Detector location Detector type Size	Link, lane and longitudinal placement Single or double loop or doppler radar Length of loops and separation for double loops	Optional. May occur once per detector per simulation
30	PORGIS LIS	Incident Specification Cards	Location of incidents Time of incident Degree of incident	Link, lanes affected, longitudinal position and length of roadway Start and finish Lane condition - unobstructed, blocked or speed reduced by "rubbernecking" factor	Optional. May occur once in first subinterval of simulation

Table 10 (continued)

Card Type	Module	Name	Data Element	Description	Frequency
35 to 49	PORGIS LIS	Revision to embedded calibration	Queue discharge Turn speeds Vehicle type parameters Driver type parameters	Distributions about mean for first vehicle last time and headway Right and left turn speeds at intersections Length, acceleration, deceleration, maximum speed, grade effects, lane choice Acceptable gaps, response to amber, percent of mean speed	Optional. May occur once in first subinterval of simulation
50	PORGIS LIS	Plot Data Generation Request	Trajectory, plot data specification	Time step and link identification	Optional. May occur once in first subinterval of simulation
51	PORGIS LIS	Plot Data Generation Request	Contour plot data specification	Time step, station spacing and link identification	Optional. May occur once in first subinterval of simulations
55	PORGIS LIS	On-line Incident Detection Specification Card	Output mode Frequency	Analog or digital polling flag Digital polling and evaluation period frequency	Optional. May occur once in first subinterval of simulations
56	PORGIS LIS	On-line Incident Detection Algorithm Parameter Card	Algorithm identification Algorithm parameters	Values for parameters of specified algorithm	Optional. May occur once in first subinterval of simulation
57	PORGIS LIS	On-line Incident Detection Detector Station Identification Card	Station numbers	Freeway detector station identification to be used for incident detection	Optional. May occur in first subinterval of simulation

Table 10 (continued)

Card Type	Module	Name	Data Element	Description	Frequency
60	PORGIS LIS	Subinterval Control Cards	Subinterval duration Frequency of output Frequency of network status Last subinterval flag	 Frequency of standard output report Frequency of network status report	Once per subinterval
65	INCES	Off-line Incident Detection and MOE Estimation Specification Card	Processing type Output mode Frequency	Point processing, MOE estimation or incident detection Analog or digital polling flag Digital and evaluation period frequency	Once per INCES processing application
66	INCES	Incident Detection Algorithm Parameter Card	Algorithm identification Algorithm parameters	 Values for parameters of specified algorithms	Optional. Once per INCES processing application
67	INCES	MOE Algorithm Parameter Card	Algorithm identifications Algorithm parameters	 Values for parameters of specified algorithms	Optional. Once per INCES processing application
68	INCES	Off-line Incident Detection and/or MOE Estimation Detector Station Card	Station numbers	Freeway detector station identification to be used for incident detection or MOE estimation	Optional. Once per INCES processing application

Table 10 (continued)

Card Type	Module	Name	Data Element	Description	Frequency
70	INPLOT	Plot Request Card	INPLOT request type	Trajectory, contour, contour value table revision	Once per plot
			Run identification	Simulation run identification (for locating data file)	
			Link identifications		
			Lane numbers	Lane numbers for trajectory plots	
			MOE identification	Spot speed, volume, density, delay, headway, etc. (for contours only)	
			Time period to be plotted		
			Plot scale factors		
			Revised values	Revised standard contour values	
			Last request indication		
90	SAM	SAM Control Card	Activity flag	Statistical analysis of file management	Once per SAM run
			File management flag	Editing or file creation	
			Simulation run identification	For files to be compared	
91	SAM	File Update Card	Run identification	Files to be deleted	Optional. May occur once per SAM run
92	SAM	Network Identification Card	New file identification	File to be created from external data	Optional. May occur once per SAM run
			Size	Number of links and subintervals	

Table 10 (concluded)

Card Type	Module	Name	Data Element	Description	Frequency
93	SAM	Subinterval Duration Card	Subinterval durations	Defines each subinterval for new file	Once per new file subinterval
94	SAM	Link Identification Card	Link identifications	Upstream and downstream, nodes of new file links	Once per new file link
95	SAM	Link Data Card	Link statistics	Definition of link MOE	Once per new file link per subinterval
96	SAM	Network Data Card	Network statistics	Definition of network MOE	Once per new file per subinterval
97	SAM	Delimiter Card	End of SAM data		

Table 11: Sample Freeway Link Definition Report

FREEWAY LINKS

				AUXILIARY LANES FIRST				SECOND				MEAN FREE FLOW		PERCENT OF VOLUME/ DESTINATION NODES			CURVATURE			RT. LANE OF SEP. PAIR		REC	
L	LINK	LANE	SPAN	LGH	A	D	F	LGH	A	D	F	SPEED	GRADE	LEFT	THRU	RIGHT	RAD	P	EL	FIRST	SECOND	LANE	IDENTIFICATION
1	(701,1)	3	0	0	0	0	0	0	0	0	0	54	2	0/ 0	100/ 2	0/ 0	0	0	0	0	0	1	FREEWAY-T
2	(1,2)	2	600	0	0	0	0	0	0	0	0	54	0	0/ 0	100 3	0/ 0	1000	1	10	0	0	1	FREEWAY-A
3	(2,3)	3	198	0	0	0	0	0	0	0	0	54	0	0/ 0	100 4	0/ 0	0	0	0	1	0	1	FREEWAY-B
4	(3, 4)	3	249	249	0	0	8	0	0	0	0	54	2	0/ 0	80/ 5	20/ 9	0	0	0	1	0	1	FREEWAY-C
5	(4,5)	3	600	249	0	8	0	0	0	0	0	54	0	0/ 0	90/ 6	10/ 11	0	0	0	0	0	8	FREEWAY-D
6	(5,6)	2	198	129	8	0	0	0	0	0	0	54	4	0/ 0	100/708	0/ 0	0	0	0	0	0	1	FREEWAY-E

ADVANCED WARNING SIGNS

L	LINK	DISTANCE FROM DOWNSTREAM NODE	NODE LOCATING OFF-RAMP	DISTANCE FROM OFF-RAMP
2	(1, 2)	450	4	897

Table 12: Definition of Column Headings in "Freeway Link Definition" Report

Column Heading	Definition
L	Freeway link index
LINK	Upstream and downstream nodes of link
LANE	Number of through lanes
SPAN	Link length (feet), no value printed for entry links
AUXILIARY LANES	
LGH	Auxiliary lane length (feet)
A,D,F	The auxiliary lane numeric code (see section 2.1) will appear in the appropriate column to indicate acceleration deceleration, full auxiliary lane status
MEAN FREE FLOW SPEED	Input value of desired free-flow speed (miles per hour)
GRADE	Imbedded calibration value of grade (percent) which most closely represents the input value
PERCENT OF VOLUME/DESTINATION NODE	Percent of traffic performing the movements left-turn (LEFT), no-turn (THRU) and right-turn (RIGHT) at the downstream intersection; followed by the node number at the downstream end of the next link. Turn percent and destination node number are separated by a slash, "/".
CURVATURE	Indicates set of three parameters used to calculate limiting speed
RAD	Radius of curvature (feet). "0" indicates no value input, implying straight roadway
P	Pavement condition code
EL	Superelevation (percent)
RT. LANE OF SEP. PAIR	Right lane of pair separated by physical barrier. Two such separations are permitted per link, hence, the FIRST and SECOND subheadings
REC LANE	Lane in downstream "through" link receiving traffic from lane 1 of this link
IDENTIFICATION	Text describing link
DISTANCE FROM DOWNSTREAM NODE	Position within link locating advanced warning sign (feet)
NODE LOCATING OFF-RAMP	Node at which off-ramp referenced by advanced warning sign begins
DISTANCE FROM OFF-RAMP	Distance from advanced warning sign to off-ramp (feet)

Table 13: Sample Ramp and Surface Link Definition Report

RAMP LINK

L	LINK	LANE	SPAN	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	MEAN QUEUE DISCHGE HEADWAY	LOST TIME	CURVATURE RAD	P	EL	ON/OFF RAMP	REC LANE	IDENTIFICATION
1	(8, 3)	1	300	24	-4	0/ 0	100/ 1	0/ 0	1	0	0	1000	2	5	ON	8	RAMP-G
2	(4, 9)	1	300	24	0	0/ 0	100/ 10	0/ 0	1	24	22	0	0	0	OFF	3	RAMP-I
3	(5, 11)	1	450	24	0	0/ 0	100/]2	0/ 0	1	24	22	0	0	0	OFF	1	RAMP-L

SURFACE LINKS

L	LINK	LANE	SPAN	POCK L	POCK R	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	LOST TIME	MEAN QUEUE DISCH HEAD	OPP. LINK	LANE CHAN. 1	2	3	4	5	IDENTIFICATION
1	(802, 7)	2	0	0	0	24	2	0/ 0	100/ 8	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-U
2	(7, 8)	2	350	0	0	24	0	60/ 3	40/ 9	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-F
3	(8, 9)	2	750	0	0	30	0	0/ 0	100/ 10	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-H
4	(9, 10)	3	300	0	0	24	0	33/814	34/ 11	33/813	2	15	20	0	4	0	1	0	0	SURFACE-J
5	(10, 11)	1	300	0	0	24	0	0/ 0	100/ 12	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-K
6	(11, 12)	1	400	0	0	24	0	0/ 0	100/807	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-M
7	(13, 10)	1	300	0	0	30	0	0/ 0	50/814	50/ 11	2	15	20	0	0	0	0	0	0	SURFACE-O
8	(14, 10)	1	400	0	0	30	0	20/ 11	80/813	0/ 0	2	15	20	7	0	0	0	0	0	SURFACE-P
9	(806, 13)	1	0	0	0	30	0	0/ 0	100/ 10	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-R
10	(805, 14)	1	0	0	0	30	0	0/ 0	100/ 10	0/ 0	1	22	24	0	0	0	0	0	0	SURFACE-S

Table 14: Definition of Column Headings in "Ramp and Surface Link Identification Report"

Column Heading	Definition
L	Ramp or Surface link index
LINK	Upstream and downstream nodes of link
LANE	Number of lanes (excluding pockets for surface links)
SPAN	Link length (feet), no value printed for entry links
POCK L R	Capacity of Left and Right turn pockets (passenger car vehicle lengths), for surface links only
MEAN FREE FLOW SPEED	Input value of desired free-flow speed (miles per hour)
GRADE	Imbedded calibration value of grade (percent) which must closely represents the input value
PERCENT OF VOLUME/DESTINATION NODE	Percent of traffic performing the movements left-turn (LEFT) no turn (THRU) and right-turn (RIGHT) at the downstream intersection; followed by the node number at the downstream end of the next link. Turn percent and destination node number are separated by a slash, "/".
TYPE OF DWNSTREAM INTRSECTN	Code indicating queue discharge characteristics at downstream intersection
LOST TIME	Time required for first queued vehicle to react to green signal (tenths of a second). A "0" indicates a distribution will be used, referenced by driver type. Not required for on-ramps
MEAN QUEUE DISCHGE HEADWAY	Mean time between discharge of queued vehicles (tenths of a second)
CURVATURE	Indicates set of three parameters used to calculate limiting speed
RAD	Radius of curvature (feet). "0" indicates no value input, implying straight roadway.
P	Pavement condition code
EL	Superelevation (percent)
ON/OFF RAMP	Indicates, for ramp links, which end connects to freeway
REC LANE	Lane in downstream "through" link receiving traffic from lane 1 of this link
IDENTIFICATION	Text describing link
OPP.LINK	Link index identifying source of traffic opposing left-turners from this link
LANE CHAN	Channelization code indicating restrictive (left-turn only, right-turn only) status of each lane

Table 15: Sample Sign and Signal Control Definition Report

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (4, 9)	(8, 9)
9	1	56 (47P)	0 (0P)	2	1
9	2	4 (3P)	56 (47P)	2	0
9	3	56 (47P)	60 (50P)	1	2
9	4	4 (3P)	116 (97P)	0	2

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (9, 10)	(13, 10)	(14, 10)
10	1	20 (17P)	5 (4P)	3	3	4
10	2	4 (3P)	25 (21P)	0	0	0
10	3	44 (37P)	29 (24P)	2	9	7
10	4	4 (3P)	73 (61P)	2	0	0
10	5	44 (37P)	77 (64P)	1	2	2
10	6	4 (3P)	1 (1P)	0	2	2

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (5, 11)	(10, 11)
11	1	56 (47P)	60 (50P)	2	7
11	2	4 (3P)	116 (97P)	2	0
11	3	56 (47P)	0 (0P)	1	2
11	4	4 (3P)	56 (47P)	0	2

NODE 12 IS UNDER SIGN CONTROL

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (11, 12)
12	1	0 (100P)	0 (0P)	1

SIGNAL CODE GLOSSARY

CODE	MEANING
0	YIELD SIGN OR AMBER
1	GREEN
2	RED
3	RED WITH GREEN RIGHT ARROW
4	RED WITH GREEN LEFT ARROW
5	STOP OR RED WITH RIGHT TURN PERMITTED
7	"NO TURNS" - GREEN THRU ARROW
8	RED WITH LEFT AND RIGHT GREEN ARROWS
9	NO LEFT TURN, GREEN THRU AND RIGHT

Table 16: Definition of Column Headings in "Sign and Signal Control Definitions" Report

Column Heading	Definition
NODE	Node number identifying intersection
INTVL	Signal interval number
DURATION	Duration of signal interval (seconds); followed by (in parentheses) percent of signal cycle length represented by this interval. For sign control only one interval is presented of duration "0".
OFFSET	Offset of beginning of interval from reference time (seconds); followed by (in parentheses) percent of signal cycle length represented by this offset.
SIGNAL CODES FACING INDICATED APPROACHES	The upstream and downstream node numbers defining the approach links to the subject intersection are given as column headings. The signal codes defining the permitted movements for each approach during each signal interval are presented under the link identification headings. A glossary of the signal codes is given at the end of this report.

Table 17: Sample Entering Traffic Definition Report

SUB-INTERVAL 1

ENTRY LINK STATISTICS

LINK	TOTAL FLOW RATE (VEH/HR)	PERCENT BY VEHICLE TYPE					PERCENT VEHICLES BY LANE				
		1	2	3	4	5	1	2	3	4	5
(701, 1)	3000	60	20	6	6	8	40	30	30	0	0
(806, 13)	300	70	5	10	15	0	100	0	0	0	0
(802, 7)	600	50	20	10	10	10	50	50	0	0	0
(805, 14)	400	100	0	0	0	0	100	0	0	0	0

VEHICLE TYPE	DESCRIPTION
1	LOW PERFORMANCE PASSENGER CAR
2	HIGH PERFORMANCE PASSENGER CAR
3	INTERCITY BUS
4	HEAVY SINGLE UNIT TRUCK
5	TRAILER TRUCK

Table 18: Definition of Column Headings in "Entering Traffic Definition" Report

Column Heading	Definition
LINK	Upstream and downstream node numbers which define each entry link.
TOTAL FLOW RATE	Rate at which vehicles are generated on the entry link (vehicles/hour)
PERCENT BY VEHICLE TYPE	Percentage of TOTAL FLOW RATE allocated to each vehicle type
PERCENT VEHICLES BY LANE	Percentage of TOTAL FLOW RATE allocated to each lane of link. Applies to freeway entries only.

Table 19: Sample Surveillance System Definition Report

SPECIFICATION OF SURVEILLANCE DETECTORS

DETECTOR STATIONS

LINK(2, 3)

STATION NUMBER	NUMBER	LANE	TYPE	LOCATION	LENGTH
1	1	1	1	250	3
1	2	2	1	250	3
1	3	3	1	250	3

LINK(3, 4)

STATION NUMBER	NUMBER	LANE	TYPE	LOCATION	LENGTH
2	1	1	1	250	3
2	2	2	1	250	3
2	3	3	1	250	3

DETECTORS WITHOUT STATIONS

LINK(4, 5)

NUMBER	LANE	TYPE	LOCATION	LENGTH
1	3	0	50	0
2	3	3	100	5
3	3	4	90	5

GLOSSARY

CODE	DETECTOR TYPE
0	DOPPLER RADAR
1,	SHORT LOOP
3	DOWNSTREAM LOOP OF COUPLED PAIR
4	UPSTREAM LOOP OF COUPLED PAIR

Table 20: Definition of Column Headings in "Surveillance System Definition" Report

Column Heading	Definition
STATION NUMBER	Identification of group of detectors which comprise a detector "Station" for Incident Detection or MOE Estimation
NUMBER	Sequence number of surveillance detector within link
LANE	Lane containing detector
TYPE	Detector type as defined in "GLOSSARY" at end of report
LOCATION	Distance from upstream node of link to upstream end of detector, or acquisition point for doppler radar (feet)
LENGTH	Detector length (feet), does not apply for doppler radar

Table 21: Sample Incident Definition Report

INCIDENT DATA

LINK	INCIDENT CODE BY LANE 1 2 3 4 5 6 7 8 9	UPSTREAM LOC. (FT)	LENGTH AFFECTED (FT)	TIME OF ONSET (SEC)	DURATION (SEC)	RUBBERNECK FACTOR (PCT)
(3, 4)	0 1 2 0 0 0 0 0 0	10	20	30	40	50

INCIDENT CODES

0	NOT AFFECTED
1	SLOWED BY RUBBERNECKING
2	BLOCKED

Table 22: Definition of Column Headings in "Incident Definition" Report

Column Heading	Definition
LINK	Upstream and downstream node numbers which define link
INCIDENT CODE BY LANE	Incident code for each lane of Link (as described in glossary at end of report)
UPSTREAM LOC.	Distance from upstream node of link to upstream end of incident (feet)
LENGTH AFFECTED	Length of roadway affected by incident extending downstream from "UPSTREAM LOC." (feet)
TIME OF ONSET	Time that incident begins measured from start of simulation (seconds)
DURATION	Length of time incident exists (seconds)
RUBBERNECK FACTOR	Percentage reduction in capacity due to rubbernecking

Table 23: Sample Freeway Statistical Report Design

SUBINTERVAL SPECIFIC OUTPUT AT TIME 10 05 00
FREEWAY LINK STATISTICS

		VEHICLES		LANE	CURR	AVG	VEH-	VEH-	SECONDS/VEHICLE			VEH-MIN/ VEH-MILE			VOLUME	DENSITY	SPEED
L	LINK	IN	OUT	CHNG	CONT	CONT	MILES	MIN	TOTAL TIME	MOVE TIME	DELAY TIME	M/T	TOTAL	DELAY	VEH/LN/HR	VEH/LN-MILE	MILE/HR
2	(1, 2)	332	334	25	10	11.4	38.00	57.0	10.2	7.6	2.6	.74	1.50	.38	2000.	50.0	40.0
3	(2, 3)	498	495	16	7	5.9	18.78	29.5	3.5	2.5	1.0	.71	1.57	.70	1990.	52.1	38.2
4	(3, 4)	475	479	19	9	8.0	22.47	40.0	5.0	3.1	1.9	.63	1.78	.67	1907.	56.6	33.7
5	(4, 5)	489	492	20	17	18.7	55.78	93.5	11.4	7.6	3.8	.67	1.67	.56	1965.	54.9	35.8
6	(5, 6)	303	300	23	5	4.5	11.33	22.5	4.5	2.5	2.0	.44	1.99	.88	1809.	59.9	30.2
AVERAGES AND TOTALS				103	48	48.5	146.36	242.5				.66	1.66	.56	1918.	53.8	36.2

NETWORK STATISTICS INCLUDING RAMP AND SURFACE LINKS

VEHICLE-MILES = 200.33, VEHICLE-MINUTES = 428.5, MOVING/TOTAL TRIP TIME = .680,

AVERAGE CONTENT = 85.7, CURRENT CONTENT = 85, SPEED(MPH) = 28.05,

TOTAL DELAY (VEH-MIN) = 137.12, TRAVEL TIME (MIN)/VEH-MILE = 2.14, DELAY TIME (MIN)/VEH-MILE = .68

Table 24: Definition of Column Headings in "Sample Freeway Statistical" Report

Column Headings	Definition
L	Freeway link index
LINK	Upstream and downstream node numbers defining link
VEHICLES IN	Number of vehicles entering link during reporting period
VEHICLES OUT	Number of vehicles leaving link during reporting period
LANE CHNG	Number of lane changes in link during reporting period
CURR CONT	Current number of vehicles on link
AVG CONT	Average number of vehicles on link during reporting period
VEH-MILES	Total distance traveled on link by all vehicles during reporting period (miles)
VEH-MIN	Total time spent on link by all vehicles during reporting period (minutes)
SECONDS/VEHICLE	
TOTAL TIME	Total time spent on link per vehicle (seconds)
MOVE TIME	Ideal time spent on link per vehicle assuming all vehicles travel at their desired speeds (seconds)
DELAY TIME	Excess time spent on link per vehicle (seconds) DELAY = TOTAL - MOVE
M/T	Ratio of MOVE TIME to TOTAL TIME
VEH-MIN/VEH-MILE	
TOTAL	Time to travel one mile at prevailing speed (minutes)
DELAY	Excess time to travel one mile above that required at desired speed (minutes)
VOLUME	Flow rate of vehicles through link (vehicles/lane/hour)
DENSITY	Concentration of vehicles per unit roadway area (vehicles/lane-mile)
SPEED	Prevailing space mean speed (miles/hour)

Tabel 25: Sample Ramp and Surface Statistical Report Design

SUBINTERVAL SPECIFIC OUTPUT AT TIME 10 05 00
RAMP AND SURFACE STATISTICS

L	LINK	VEHICLES IN	VEHICLES OUT	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SPEED MPH	SECONDS/VEHICLE TOTAL TIME	SECONDS/VEHICLE MOVE TIME	SECONDS/VEHICLE DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	VEH-MIN/VEH-MILE DELAY	PERCENT QUEUE DELAY	AVG SAT PCT	CYCLE FAILURE	LINK TYPE
1	(8, 3)	43	44	2	1.5	2.48	7.5	19.8	10.3	8.6	1.7	.83	3.02	.50	73	10.2	0	Ramp
2	(4, 9)	49	48	2	2.2	2.81	11.0	15.3	13.4	8.6	4.8	.64	3.90	1.40	85	14.9	0	Ramp
3	(5, 11)	48	50	4	3.0	4.20	15.0	16.8	18.2	12.8	5.4	.70	3.57	1.06	79	13.5	0	Ramp
2	(7, 8)	100	102	3	4.6	6.71	23.0	17.5	13.6	9.9	3.7	.73	3.43	.93	91	13.2	1	Surface
3	(8, 9)	97	98	7	8.9	13.87	44.5	18.7	27.3	21.3	6.0	.78	3.21	.71	83	11.8	0	Surface
4	(9, 10)	95	93	4	3.6	5.40	18.0	18.0	11.4	8.6	2.8	.75	3.33	.82	88	12.0	0	Surface
5	(10, 11)	151	149	6	6.8	8.56	34.0	15.1	13.6	8.6	5.0	.63	3.97	1.46	72	15.0	1	Surface
6	(11, 12)	48	47	3	2.2	3.59	11.0	19.6	14.0	11.4	2.6	.81	3.06	.57	79	10.9	0	Surface
7	(13, 10)	47	48	2	2.1	2.71	10.5	15.5	13.2	6.8	6.4	.52	3.87	1.86	89	14.3	0	Surface
8	(14, 10)	46	48	4	2.3	3.64	11.5	19.0	14.4	9.1	5.3	.63	3.16	1.16	90	11.4	0	Surface
AVERAGES AND TOTALS				37	37.2	53.97	186.0	17.4				.71	3.45	1.00	83	12.7	2	

Table 26: Definition of Column Headings in "Sample Ramp and Surface Statistical" Report

Column Headings	Definition
L	Ramp or surface link index
LINK	Upstream and downstream node numbers
VEHICLES IN	Number of vehicles entering link during reporting period
VEHICLES OUT	Number of vehicles leaving link during reporting period
CURR CONT	Current number of vehicles on link
AVG CONT	Average number of vehicles on link during reporting period
VEH-MILES	Total distance traveled on link by all vehicles during reporting period (miles)
VEH-MIN	Total time spent on link by all vehicles during reporting period (minutes)
SPEED	Mean speed of all vehicles on link during reporting period (miles/hour)
SECONDS/VEHICLE	
TOTAL TIME	Total time spent on link per vehicle (seconds)
MOVE TIME	Ideal time spent on link per vehicle assuming all vehicles travel at their desired speeds (seconds)
DELAY TIME	Excess time spent on link per vehicle (seconds) DELAY = TOTAL - MOVE
M/T	Ratio of MOVE TIME to TOTAL TIME
VEH-MIN/VEH-MILE	
TOTAL	Time to travel one mile at prevailing speed (minutes)
DELAY	Excess time to travel one mile above that required at desired speed (minutes)
PERCENT QUEUE DELAY	Percentage of delay time spent in queue
AVG SAT PCT	Average percentage of link area occupied by vehicles during reporting period
CYCLE FAILURE	Number of instances during reporting period when queue present at start of green was not discharged by end of green
LINK TYPE	Identifies link as Ramp or Surface type

Table 27: Sample Freeway Station Headway and Speed Report Design

SUBINTERVAL SPECIFIC FREEWAY LINK STATION DATA
TIME 10 05 00

FREEWAY LINK 2 (1, 2) STATION PLACEMENT 300 FEET FROM NODE 1

	MEAN	MEAN	PERCENT OF TRAFFIC AT OR BELOW INDICATED SPEED,MPH													PERCENT OF TRAFFIC AT OR BELOW INDICATED HEADWAY,SEC													
LANE	SPEED MPH	HEADWAY SEC	26	28	30	32	34	36	38	40	42	44	46	48	50	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6	5.0	5.4	5.8	6.2
1	38.9	1.92	1	3	7	15	24	37	51	68	79	86	92	97	99	10	26	47	63	75	85	89	92	97	100	100	100	100	100
2	40.5	1.73	0	0	0	4	10	22	36	52	70	85	95	99	100	20	38	55	69	78	84	88	93	96	99	100	100	100	100
3	41.0	1.78	0	0	3	8	12	20	30	48	71	87	97	100	100	18	37	56	70	78	85	89	92	94	97	100	100	100	100

FREEWAY LINK 5 (4, 5) STATION PLACEMENT 250 FEET FROM NODE 4

	MEAN	MEAN	PERCENT OF TRAFFIC AT OR BELOW INDICATED SPEED,MPH													PERCENT OF TRAFFIC AT OR BELOW INDICATED HEADWAY,SEC													
LANE	SPEED MPH	HEADWAY SEC	22	24	26	28	30	32	34	36	38	40	42	44	46	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6	5.0	5.4	5.8	6.2
1	34.5	1.99	0	0	0	4	11	27	45	65	81	89	94	99	100	16	31	50	65	76	83	89	94	97	99	100	100	100	100
2	36.3	1.77	0	0	1	3	8	15	30	47	65	82	92	97	98	18	36	57	71	83	90	95	98	99	100	100	100	100	100
3	36.5	1.76	0	0	0	2	6	14	28	46	63	81	90	96	99	20	36	58	70	82	87	93	96	98	99	100	100	100	100

Table 28: Definition of Column Headings in "Sample Freeway Station Headway and Speed" Report

Column Headings	Definition
FREEWAY LINK	Freeway link index followed by upstream and downstream nodes in parentheses
STATION PLACEMENT	Distance from upstream node (feet)
LANE	Lane code number (i.e., 1→5 for through lanes, 6→9 for auxiliary lanes)
MEAN SPEED	Time mean speed for all vehicles crossing station in indicated lane during reporting period (miles/hour)
MEAN HEADWAY	Mean time between passage of individual vehicles for indicated lane during reporting period (seconds)
PERCENT OF TRAFFIC AT OR BELOW INDICATED SPEED	Subheadings beneath this general heading indicate the upper limit of each cell of a cumulative frequency distribution of speed (miles/hour). Under each speed value is displayed the number of vehicles which have passed the station, in the indicated lane, at or below the heading speed value, during the reporting period.
PERCENT OF TRAFFIC AT OR BELOW INDICATED HEADWAY	Subheadings beneath this general heading indicate the upper limit of each cell of a cumulative frequency distribution of headway (seconds). Under each headway value is displayed the number of vehicles which have passed the station, in the indicated lane, at or below the heading headway value, during the reporting period.

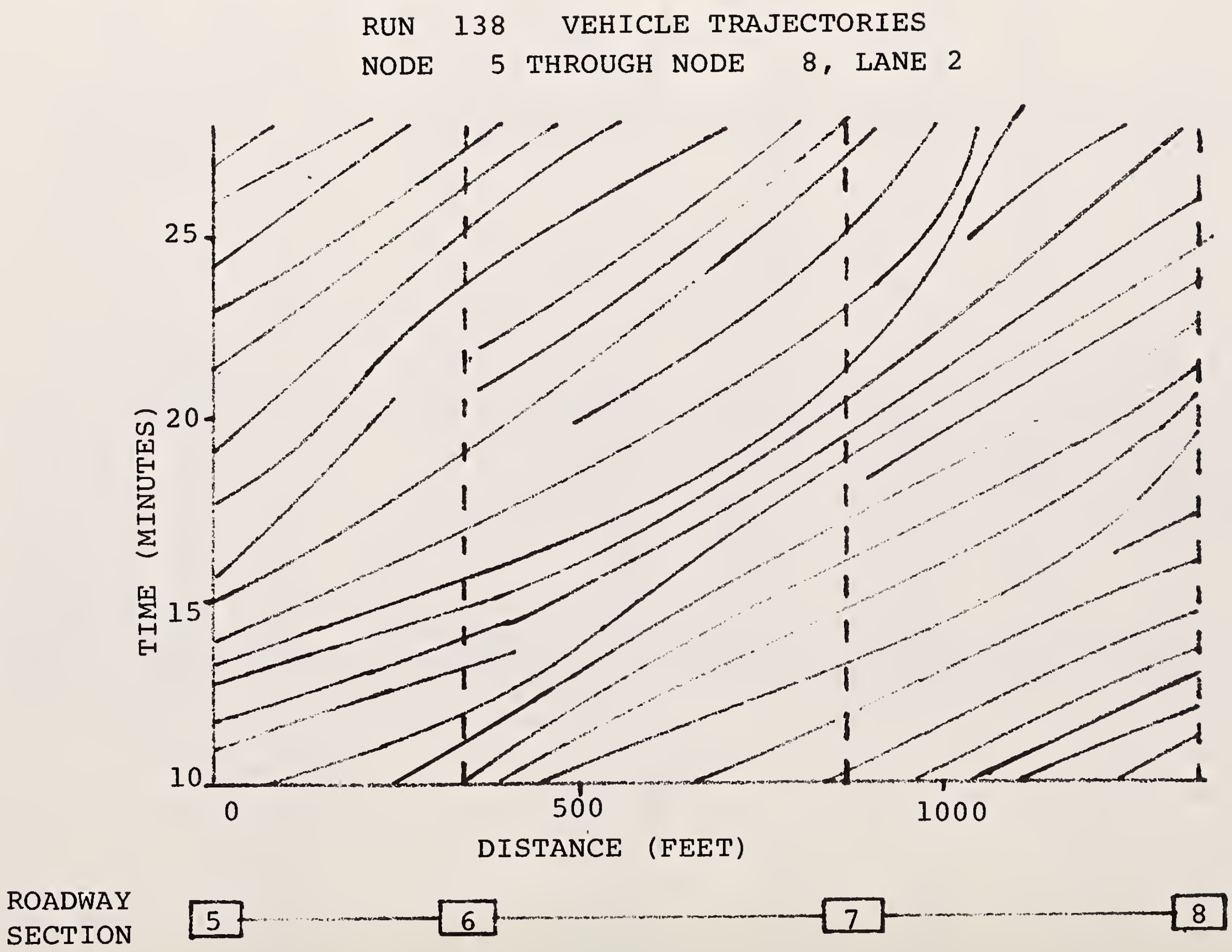


Figure 7: Samp ɴPLOT Program Vehicle Trajectory Plot Design

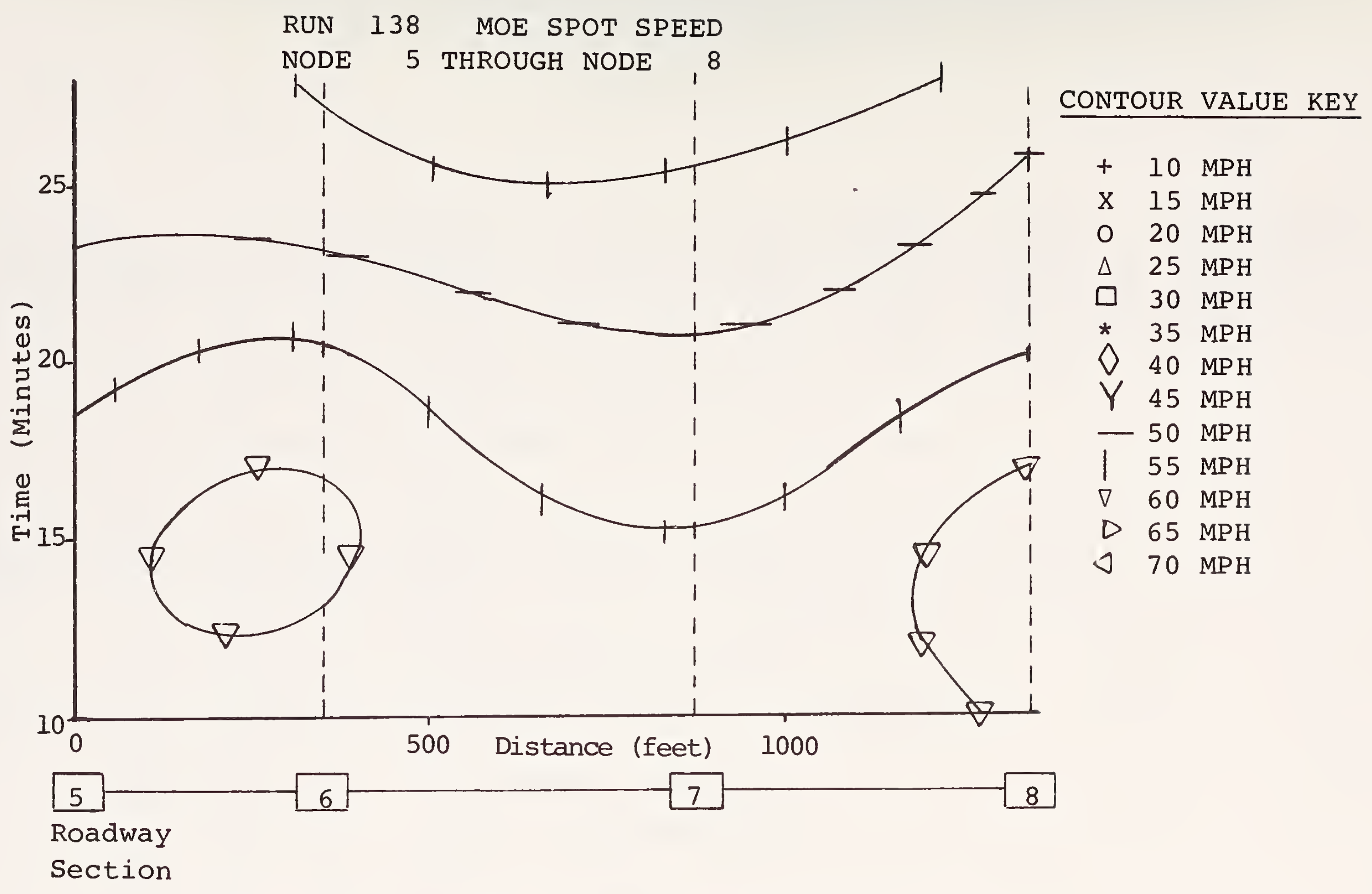


Figure 8: Sample of INPLOT Program Contour Plot Design

Table 29: Sample Point Processing Report Design

INCES POINT PROCESSING OUTPUT

SIMULATION RUN 999

FREEWAY LINK 3 (2, 3), DOPPLER RADAR DETECTOR IN LANE 3 AT 50 FEET FROM NODE 2

	EVALUATION PERIOD (SEC)											
	120	240	360	480	600	720	840	960	1080	1200	1320	1440
VOLUME,VPH	1900	1862	1857	1883	1990	1942	1910	1894	1771	1792	1824	1836
TIME MEAN SPEED,MPH	39.5	39.8	40.0	39.9	38.5	38.3	39.4	39.6	40.4	40.1	39.7	39.7
MEAN HEADWAY,SEC	1.89	1.93	1.94	1.91	1.81	1.85	1.88	1.90	2.03	2.01	1.97	1.96

FREEWAY LINK 3 (2, 3), COUPLED LOOP DETECTOR IN LANE 3 AT 90 FEET FROM NODE 2

	EVALUATION PERIOD (SEC)											
	120	240	360	480	600	720	840	960	1080	1200	1320	1440
VOLUME,VPH	1895	1865	1856	1885	1989	1946	1905	1895	1773	1791	1827	1837
TOTAL MEAN SPEED,MPH	39.5	39.9	40.2	39.8	38.5	38.6	39.2	39.3	40.5	40.1	40.0	39.6
MEAN HEADWAY,SEC	1.90	1.93	1.94	1.91	1.81	1.85	1.89	1.90	2.03	2.01	1.97	1.96
MEAN OCCUPANCY	.182	.177	.175	.179	.196	.191	.194	.183	.166	.169	.173	.176

Table 30: Sample MOE Estimation Report Design

INCES MOE ESTIMATION OUTPUT, SIMULATION RUN 999

ALGORITHM 2

FROM
STATION 1, LINK 2
TO
STATION 2, LINK 3

TIME (SEC)	VOLUME IN VPHPL	VOLUME OUT VPHPL	SPACE MEAN SPEED MPH	DENSITY VEHICLES PER LANE MILE	VOLUME IN VPHPL	VOLUME OUT VPHPL	SPACE MEAN SPEED MPH	DENSITY VEHICLES PER LANE MILE	VOLUME IN VPHPL	VOLUME OUT VPHPL	SPACE MEAN SPEED MPH	DENSITY VEHICLES PER LANE MILE
20	1880	1885	38.5	48.9								
40	1861	1858	39.0	47.7								
60	1865	1866	39.1	47.7								
80	1878	1873	38.8	48.3								
100	1892	1895	37.6	50.4								
120	1921	1850	33.5	56.2								
140	1893	1801	31.0	59.6								
160	1890	1787	28.6	64.2								
180	1898	1799	27.3	67.6								
200	1905	1800	26.4	70.1								
220	1840	1813	25.7	71.1								
240	1833	1852	26.1	70.6								
260	1851	1908	28.3	66.5								
280	1866	1890	29.3	64.2								
300	1869	1885	30.0	62.5								

Table 31: Sample Incident Detection Report Design

INCES INCIDENT DETECTION OUTPUT, SIMULATION RUN 999

ALGORITHM 3

PARAMETER 1 = 6.000000+E01, PARAMETER 2 = 2.000000+E01, PARAMETER 3 = 3.000000+E00, PARAMETER 4 = 1.000000+E01

PARAMETER 5=-4.400000-E01, PARAMETER 6 = 3.100000-E01, PARAMETER 7 = 2.900000+E01, PARAMETER 8 = 3.000000+E01

	FROM STATION 1, LINK 2 TO STATION 2, LINK 3					
TIME (SEC)	STATE	STATE	STATE	STATE	STATE	STATE
20	FREE					
40	FREE					
60	FREE					
80	FREE					
100	FREE					
120	CWAV					
140	CWAV					
160	CWAV					
180	TENT					
200	CONF					
220	INCD					
240	INCD					
260	TERM					
280	FREE					
300	FREE					

CODE	DEFINITION
FREE	NO INDICENT IN SECTION
TERM	INCIDENT TERMINATED
CWAV	COMPRESSION WAVE
TENT	TENTATIVE INCIDENT
CONF	INCIDENT CONFIRMED
INCD	INCIDENT IN PROGRESS

illustrates the output of the point processing procedures which calculate traffic parameter values on a detector specific basis.

To illustrate the MOE estimation and incident detection output formats, it is assumed that a series of fully detectorized (one detector in each lane) stations have been defined by the user along the length of the freeway. Table 30 is an example of the MOE estimation report, produced by INCES, for a consecutive pair of such stations. The "VOLUME IN" and "VOLUME OUT" values are mean values across all lanes at the upstream and downstream stations, respectively. "SPACE MEAN SPEED" and "DENSITY" are estimated generated by the particular MOE estimation procedure employed.

Table 31 is a sample of the incident detection algorithm output report. The incident history for the simulation is given as well as the various incident detection algorithm results. As for the MOE estimation report (Table 30), one such table is generated for each consecutive pair of fully detectorized freeway stations. The sample output represents a case where no incident was present in the roadway between the detector stations. This is indicated by the "CLEAR" code which appears for every evaluation period in the row denoted as "SIMULATED INCIDENT". In the sample, Algorithms 1 and 3 correctly deduce that no incident is present. Algorithm 2, however, detects a (nonexistent) incident commencing during evaluation period 5 and ending during evaluation period 7.

3.2.2.5 SAM Module Output Reports

Reports will be generated by the SAM module containing simple comparisons and statistical tests of MOE values from separate simulation runs. The MOE's to be studied are:

MOE	Application
Vehicles Discharged	All Links and Network
Delay Time (veh-min)	All Links and Network
Lane Changes	Freeway Links
Density	Freeway Links and Network
Average Saturation Percent	Non-Freeway Links
Vehicle-Miles	All Links and Network
Travel Time (veh-min)	All Links and Network
Volume	Freeway Links
Stopped Delay Time (veh-min)	Non-Freeway Links
Average Speed	All Links and Network

Tables 32 through 36 illustrate the various SAM report formats comparing two statistical data sets for a simple three link network simulated for three 5-minute time periods (subintervals). The simple data comparisons of Table 32 are repeated for all appropriate MOE's of the Freeway and Non-Freeway link categories. The same is true for the statistical test results of Tables 34 and 35. The term NETWORK may indicate all links, or optionally, all freeway links.

3.3 INTRAS Storage Array Methodology

To cope with a stringent data storage problem, most of the INTRAS arrays were designed to contain several data items per unit (word/half-word) of storage. This "packing" of data is made possible by defining all program data elements as integers. For example, the link descriptors, "number of lanes" and "link length" might be packed into one storage element of five decimal digit length, as XXXXY; where, XXXX and Y represent the digit positions assigned for "link length" and "number of lanes", respectively.

Additinally, two procedures were adopted to reduce the required storage, both for the arrays, and for the logic to access them. First, a dynamic storage allocation procedure was developed to ensure that unused space in some arrays could be reallocated for other uses. Second, efficient packing and unpacking procedures were developed and coded into modular subroutines, thereby reducing the extent of all logic requiring link and vehicle parameters.

3.3.1 Dynamic INTRAS Array Allocation

The largest allocations of computer memory in INTRAS are for link-specific and vehicle-specific data elements. Since the characteristics of surface, ramp and freeway links differ greatly, it was propitious to define three different storage structures to minimize memory allocation for each individual link and vehicle. It was recognized that this procedure could be wasteful in that the full memory allocated for the individual arrays may not be required for a particular application. To prevent such waste, the size of individual arrays are revised within the global allocation of storage, in response to the needs of each particular application.

Table 32: Sample SAM Data Element Paired Comparisons

NUMBER OF VEHICLES DISCHARGED
CASE A,CODE NO. 100
CASE B,CODE NO. 714

FREEWAY LINKS

SUBINTERVAL

LINK		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12
(1, 2)	MOE(A)	851	299	272	280									
	MOE(B)	827	291	265	271									
	(A)-(B)	24	8	7	9									
	(A)/(B)	1.03	1.03	1.03	1.03									
(2, 3)	MOE(A)	809	295	253	261									
	MOE(B)	815	288	265	262									
	(A)-(B)	-6	7	-12	-1									
	(A)/(B)	.99	1.02	.95	1.00									
(3, 4)	MOE(A)	906	310	302	294									
	MOE(B)	926	307	315	304									
	(A)-(B)	-20	3	-13	-10									
	(A)/(B)	.98	1.01	.96	.97									

Table 33: Sample SAM Network Comparisons

NETWORK WIDE MOE - FREEWAY LINKS ONLY
CASE A,CODE NO. 100
CASE B,CODE NO. 714

SUBINTERVAL

		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12
NUMBER VEHICLES DISCHARGED	MOE(A)	855	301	276	278									
	MOE(B)	856	295	282	279									
	(A)-(B)	-1	6	-6	-1									
	(A)/(B)	1.00	1.02	.98	1.00									
TOTAL DELAY TIME-MIN.	MOE(A)	13	5	4	5									
	MOE(B)	12	4	4	4									
	(A)-(B)	1	1	0	2									
	(A)/(B)	1.08	1.08	1.00	1.17									
VEHICLE MILES	MOE(A)	57	20	18	19									
	MOE(B)	56	20	18	18									
	(A)-(B)	1	0	0	1									
	(A)/(B)	1.01	1.00	1.00	1.02									
VEHICLE MINUTES	MOE(A)	75	26	24	25									
	MOE(B)	74	26	24	24									
	(A)-(B)	1	0	0	1									
	(A)/(B)	1.01	1.00	1.00	1.04									
DENSITY VEH/LN-MILE	MOE(A)	25.1	26.4	24.1	24.9									
	MOE(B)	24.9	25.7	24.6	24.4									
	(A)-(B)	.2	.7	-.5	.5									
	(A)/(B)	1.01	1.03	.98	1.02									
AVERAGE SPEED	MOE(A)	45.4	45.6	45.8	44.8									
	MOE(B)	45.9	46.0	45.8	45.8									
	(A)-(B)	-.5	-.4	.0	-1.0									
	(A)/(B)	.99	.99	1.00	.98									

Table 34: Sample SAM Link Specific Statistical Test Report

NUMBER OF VEHICLES DISCHARGED
ANALYSIS OF LINK STATISTICS

FREEWAY LINKS

	CASE A		CASE B		T-TEST	WILCOXON	U-TEST	ONE-WAY ANOVA		
	MEAN	VARIANCE	MEAN	VARIANCE	T	T/Z	U/Z	SSW	SSB	F
(1, 2)	283.7	192.34	275.7	185.34	.71	-1.60	-.65	755.3	96.0	.51
(2, 3)	269.7	497.34	271.7	202.34	.13	-.53	-.65	1399.3	6.0	.02
(3, 4)	302.0	64.00	308.7	32.34	1.18	-1.07	-1.09	192.7	66.7	1.38

Table 35: Sample SAM Subinterval Specific Statistical Test Report

NUMBER OF VEHICLES DISCHARGED
ANALYSIS OF SUBINTERVAL STATISTICS

FREEWAY LINKS

SUBINTERVAL	CASE A		CASE B		T-TEST	WILCOXON	U-TEST	ONE-WAY ANOVA		
	MEAN	VARIANCE	MEAN	VARIANCE	T	T/Z	U/Z	SSW	SSB	F
1	303.3	66.14	295.3	107.33	1.06	- .53	- .65	340.9	96.0	1.13
2	275.7	610.33	281.7	833.33	.27	.00	-1.09	2887.3	54.0	.07
3	278.3	274.33	279.0	489.00	.04	-1.07	-1.09	1526.7	.7	.00

Table 36: Sample SAM Network Statistical Test Report

ANALYSIS OF NETWORK WIDE STATISTICS
FREEWAY LINKS ONLY

MOE	CASE A		CASE B		T-TEST	WILCOXIN	U-TEST	ONE-WAY ANOVA		
	MEAN	VARIANCE	MEAN	VARIANCE	T	T/Z	U/Z	SSW	SSB	F
NUMBER VEHICLES	285.1	385.61	285.3	414.25	.02	1.36	-.04	6398.9	.2	.00
TOTAL DELAY TIME-MIN.	4.4	4.28	4.1	5.11	.29	-1.02	-.62	75.1	.4	.09
VEHICLE MILES	19.1	103.76	18.8	92.95	.06	- .91	-.04	1573.7	.4	.00
VEHICLE MINUTES	25.1	173.11	24.6	164.78	.08	-1.59	-.18	2703.1	1.1	.01
DENSITY VEH/LN-MILE	25.13	3.02	24.90	2.36	.30	- .91	-1.41	43.0	.2	.09
AVERAGE SPEED MPH	45.70	1.86	45.86	1.71	.73	- .91	-1.41	28.6	.9	.53

The vehicle array memory allocation is truly dynamic, changing during simulation whenever the previous allocation would be exceeded for either surface, ramp or freeway vehicles. The remaining available space is then divided proportionally among the three vehicle arays. Link array memory allocation is performed, during the reading of input geometry data, to provide ample memory for the particular application. After the needed link storage has been established (at the end of input processing) the link memory allocation is reduced to the minimum required.

In the final INTRAS design a large one dimensional array, NLV, is defined to contain all link and vehicle data. Six two-dimensional arrays - LNKF, LNKR, LNKS, VF, VR and VS, are equivalenced to NLV. Potentially then, all elements of NLV may be referenced by any of the six specific arrays. Consecutive portions of NLV are allocated to the specific arrays in the order given above. The size of each of these portions is regulated by internal logic to agree with current storage requirements. Thus, if only ten freeway links are required for a particular application, only 10 x N elements of storage are allocated for freeway links, where N is the number of elements of storage per link. The numeric equivalent of N is required as a system parameter for each of the six arrays. In addition, two other array-specific parameters are required. They are "number of the particular link or vehicle type currently allocated," M, and "number of link or vehicle vectors not usable because of allocation to other arrays," P. The term "vector" is used here to indicate a group of storage elements containing all parameters for a particular link or vehicle.

If the current allocation of storage to one of the arrays is to be changed (either enlarged or reduced) the corresponding M parameter is internally revised. The offset, P, (beginning of usable space), for all following arrays is also revised to indicate the required shift of these arrays within the global allocation (NLV). The allocation, M, of some other link or vehicle array must, of course, be increased or reduced to compensate for the consequent alteration in available storage. Lastly, the elements of each of the affected arrays are relocated to correspond to the new total allocation. The following example should clarify the storage method:

The six arrays and their parameters are defined as follows:

Array	Content	Sequence, i	Ni	Mi
LNKF	Freeway Link Parameters	1	42	20
LNKR	Ramp Link Parameters	2	18	20
LNKS	Surface Link Parameters	3	22	30
VF	Freeway Vehicle Parameters	4	22	300
VR	Ramp Vehicle Parameters	5	8	100
VS	Surface Vehicles Parameters	6	8	--

In this example, the parameters N and M are as defined in the preceding text. M_6 is not specified, as the allocation for surface vehicle will consist of the remainder of the NLV array. The problem posed is how to assign values to P_i, such that the storage elements $N_i \times M_i$ required for each array are not mutually conflicting.

The first array, LNKF, is defined to start at the beginning of the NLV array. Therefore, its "offset", P_i is zero. That is, there are no storage elements located between the beginnings of NLV and LNKF dedicated to other arrays.

The first $N_1 \times M_1$, or 840, elements of NLV are, therefore, dedicated to the LNKF array. The lowest numbered element of NLV available to LNKR is 841.

Dividing total dedicated storage by N_2 and rounding all fractions upward yields

$$P_2 = \frac{840}{18} = 46 + \frac{12}{18} = 47$$

The first 47 link vectors of LNKR are unusable as they are either partially, or totally, devoted to prior arrays (in this case only LNKF) in the array sequence. Storage and retrieval of parameters pertaining to the first ramp link must be accomplished by adding the scalar ("offset") 47 to the ramp link number before referencing the LNKR array. This process is automatically applied by the packing and unpacking routines described in the next section.

The calculation of this and subsequent P_i elements may be performed via the equation

$$P_i = \frac{(M_{i-1}+P_{i-1}) \times N_{i-1}}{N_i}$$

remembering to round fractions up.

Applying this rule, the following results are obtained for P_i:

$$P_3 = \frac{(20+47) \times 18}{22} = 55$$

$$P_4 = \frac{(30+55) \times 22}{22} = 85$$

$$P_5 = \frac{(300+85) \times 22}{8} = 1059$$

$$P_6 = \frac{(100+1059) \times 8}{8} = 1159$$

Resolution of the final M_i parameter, M_6, is accomplished by allocation of the remainder of NLV, where the number of elements in NLV is given by R

$$M_6 = \frac{R}{N_6} - P_6$$

For this calculation, the fraction must be truncated. If R = 15000, then

$$M_6 = \frac{15000}{8} - 1159 = 716$$

Calculation of the M and P parameters is performed internally by the INTRAS program on the basis of need. During the geometric data input process, a reallocation of link space occurs whenever an excess of one link category is recognized. A reduction of allocated link space to the minimum necessary, is performed after the data input process, to provide maximum storage for vehicles. During simulation, vehicle array space is reallocated whenever the number of one category of vehicles equals the allocated maximum.

Suppose that at some point in the simulation process storage were required for an additional 50 freeway vehicles. Then;

$$M_4' = M_4 + 50 = 350$$

and, by use of the preceding equations,

$$P_5' = \frac{(350 + 85) \times 22}{8} = 1197$$

$$P_6' = \frac{(100 + 1197) \times 8}{8} = 1297$$

$$M_6' = \frac{15000}{8} - 1297 = 578$$

The contents of the VR and VS arrays would then be shifted to new areas in NLV corresponding to the changes in the corresponding offsets P_5' and P_6'. Although this example sacrifices storage originally allocated to surface vehicles (i.e., $M_6 > M_6'$), the actual program procedure would apply this reduction proportionally to both ramp and surface vehicle storage allocations.

3.3.2 INTRAS Data Array Packing and Unpacking Procedures

To simplify the process of accessing link and vehicle data to reduce the program debugging activity and to reduce the storage devoted to in-line data access, modular subroutines are included in the INTRAS design to perform parameter packing and unpacking. Two basic pack/unpack activities may be performed. The first, via subroutines UNPAK and PAK, either retrieves or stores the entire parameter vector for a specified vehicle, or link, of any type. The second activity retrieves or stores one selected parameter of the specified vector.

Whereas PAK and UNPAK may act on any of the six arrays, the individual element access routines are array specific. This avoids burdening single parameter access with the overhead associated with array selection. The eight subroutines which perform single parameter data access for ramp and surface link and vehicle arrays are identified in Table 2. Freeway link and vehicle arrays contain one parameter per element and are accessed directly to conserve time.

The packing and unpacking process is achieved by locating the specified link or vehicle vector in NLV and then applying a parameter storage pattern to each element. The storage pattern for every parameter of the six arrays is a three-digit number, XXY, where

X = Element of vector containing this parameter, and

Y = Digit position of element containing low order digit of parameter.

The Y field also implies the high order digit of the previous parameter. Parameter storage patterns are stored in a separate array which is indexed by unique parameter numbers. For example, the following parameter identifications prevail for the LNKS array.

Parameter	Parameter Number	Storage Pattern Code
Free-flow speed, fps	27	121
Percent of traffic proceeding thru	28	123
Total moving time, halves-of-an-hour	29	131

If the contents of the 12th element of a particular surface link vector were 3044 then

Free-flow speed = 44 fps, and
Percent of traffic proceeding thru = 30%.

The Y field for the "Percentage" parameter is 3. This implies that digit 2 (i.e., 2 = 3-1) is the high order digit of "Free-flow Speed." Also, since the XX field for the "Moving Time" parameter indicates that it is in a different element than the "Percentage", then the entire high order portion of element 12 (starting with digit 3) is devoted to the "Percentage."

The generalized calling sequence for the data access routines is CALL Subroutine Name (L, I, JPARAM) where,

L = The particular link or vehicle number

I = Either, parameter number (array specific) or, an index which defines which array is to be unpacked (packed) in the generalized vector routines (PAK and UNPAK) as follows:

I	Array
1	LNKF
2	LNKR
3	LNKS
4	VF
5	VR
6	VS

JPARAM = location of unpacked information. This is a single cell for the individual parameter pack (unpack) operations, or an array, for the generalized operation.

The following four examples illustrate the use of the INTRAS packing and unpacking procedures.

1) To unpack the current lane (parameter number 4) for surface vehicle M, and store in variable LN.

```
Call UVS (M,4,LN)
```

2) To pack current lane for surface vehicle M, from variable LN

```
Call PVS (M,4,LN)
```

3) To unpack all parameters for surface vehicle (second argument I=6) M, and store in the first 17 elements of array IV.

Call UNPAK (M,6,IV)

4) To pack all parameters for vehicle M, from the first 17 elements of array IV.

Call PAK (M,6,IV)

3.4 INTRAS Error Procedures

Experience with computer programs containing complex data verification procedures has shown that the reporting of error conditions often proves costly in terms of computer storage due to the storage consumed by FORMAT statements. A generalized error message procedure was designed for INTRAS to alleviate the storage demands of diagnostic processing.

Each recognizable error condition in INTRAS generates a standard message which identifies the message code number and reports the current value of up to 10 pertinent parameters.

The following is an example of the INTRAS generalized error message format:

```
****    ERROR 107, PARAMETERS =     27,      93,       6
```

Because the INTRAS program contains nine major overlay modules, each with its own family of reportable error conditions, the message code numbers are stratified by originating module as follows:

Module	Message Codes
INTRAS	1→ 99
PORGIS	100→399
LIS	400→499
POSPRO	500→549
FUEL	550→599
SIFT	600→699
INCES	700→799
INPLOT	800→899
SAM	900→999

For the above example, Error 107 is generated during the execution of the PORGIS Module.

Full documentation of a computer program normally includes detailed descriptions of the conditions which may cause each error message. Generally, this is necessary to clarify these abbreviated error messages. The INTRAS documentation includes detailed descriptions of each module's error messages. The following is a group of PORGIS Module error messages which might be generated by a typical run. The notation P_i indicates the appropriate placement in the error message for the value of the i^{th} parameter.

107 - Link (P_1, P_2) on card type P_3 could not be found in link array. Link ignored. Simulation inhibited.

128 - Upstream node, P_1, of link whose through traffic opposes left-turning traffic from link (P_2, P_3) specified after first interval; subinterval = P_4. Card Type 6. Simulation inhibited.

150 - Link (P_1, P_2) has designated P_3 on Card Type 4 as the lane receiving its lane 1 traffic in link (P_2, P_4) but (P_2, P_4) does not have a lane P_3. Simulation inhibited.

169 - Entry in SIGI array for node P_1, but no Type 10 card was input for this node. Simulation inhibited.

255 - Incident code specified for non-existent lane P_3 on link (P_1, P_2). Card Type 30.

$P_3 \leq 5$ - lane number
$P_3 = 6$ - 1st left auxiliary lane
$P_3 = 7$ - 2nd left auxiliary lane
$P_3 = 8$ - 1st right auxiliary lane
$P_3 = 9$ - 2nd right auxiliary lane
$P_4 =$ - actual number of lanes on link
P_5,P_6 - actual 1st and 2nd auxiliary lanes on link

Simulation inhibited.

For the example cited above, a link (denoted by upstream node 27 and downstream node 93) is referenced on a surface Link Operation Card (Type 6). This link was not previously defined on a Type 2 Link Geometry card.

4. INTRAS FREEWAY PARAMETER CALIBRATION

UTCS-1 model applications perform as would "real" urban traffic networks by virtue of the UTCS-1 logic and a family of independent calibration parameters. Extensive evaluations were performed during UTCS-1 model development to measure these parameters and the results of those calibration activities are "built-in" to the model. These same parameters are imbedded in the INTRAS model to govern traffic performance on the surface and ramp links.

Surface street traffic performance is dominated by the intersection and intersection dependent phenomena. Accurate representation of freeway traffic depends upon the quality of representation of vehicular dynamics and interaction in an uninterrupted flow scenario. Vehicle interactions are represented in INTRAS by the car-following and lane-changing logic discussed in the previous sections. The importance of vehicle dynamics dictates a more detailed calibration of vehicle capabilities and driver characteristics than that required for the surface links.

This section describes the parameters imbedded in the INTRAS model to represent the dynamics of freeway traffic flow.

4.1 Vehicle Type Specific Calibration Parameters

INTRAS is capable of representing up to five independent vehicle types. By virtue of the capability of updating imbedded calibration parameters via card input (see Section 2) virtually any desired vehicle type may be simulated. A choice was made as to those types of vehicles most representative of (without further user input) a typical freeway traffic stream.

This initial selection includes: low performance passenger car, high performance passenger car, intercity bus, single unit truck (of more than four tires), and trailer truck combinations. The single unit truck category specifically excludes pickup trucks and light vans which are similar in performance to low performance passenger cars.

A survey was performed of prior research on evaluation of vehicle performance parameters. Survey results indicated that many characteristics influenced the desired vehicle-type specific parameters, including frontal area, weight, power and gearing. It would be possible to define vehicle types stratified by each of these parameters. Since it is not reasonable to assume that the potential user would be able to categorize incoming traffic by these parameters, a practical alternative was chosen. The five vehicle types described above were identified, and then parameter evaluation was attempted.

Several sources (Refs. 5-10) proved useful in identifying vehicle performance characteristics. From these sources, one descriptive characteristic, weight to horsepower ratio, was identified as having the best correlation with performance. The values of this ratio, selected as representative of the chosen vehicle types, and corresponding vehicle lengths, are as follows:

Vehicle Type	Lbs/brake Horsepower	Vehicle Length* (ft.)
Low Performance Passenger Car	< 20	20
High Performance Passenger Car	>20	20
Intercity Bus	100	43
Heavy Single Unit Truck	100	26
Truck Trailer Combination	300	53

*The vehicle lengths include a three foot buffer for stopped separation.

Vehicle length characteristics were taken from Ref. 5 for the 50-percentile vehicle of each class. Truck-trailer combinations assumed the mean length of 40- and 50-foot wheelbase vehicles. An exception to this procedure was made for the bus category. Here, it was felt that the General Motors specifications (Ref. 10) were more appropriate.

The vehicle type-specific parameters of acceleration, deceleration and maximum speed are all influenced by gradient as well as the vehicle characteristics. The most significant work on grade effects, uncovered during the vehicle performance research survey, is a "Modified SAE Procedure" described in the NCHRP 3-19 Draft Final Report (Ref. 8). This procedure is a modification of the predictive algorithm, published by the Society of Automotive Engineers (Ref. 11), to include the effects of coasting during gear shifting. The results of the revised procedure were compared, during the course of Project 3-19, to data drawn from References 12 and 13. These comparisons served to further refine the algorithm. The majority of the INTRAS bus and truck vehicle parameter calibration is based on this procedure, as applied to the weight to horsepower ratio for the particular vehicle type.

The following subsections describe the individual parameter evaluations.

4.1.1 Limiting Vehicle Speeds

Vehicles traversing highway sections are restricted by a maximum attainable speed related to gradient and vehicle characteristics. For the gradient levels prevalent on most freeway systems, it is assumed that passenger car type vehicles are capable of eventually attaining their "desired speed". As such, no attempt is made to evaluate maximum attainable speed for passenger cars. Acceleration and deceleration characteristics of these vehicles (vs. grade) are treated in subsequent sections.

From Reference 8, the following limiting speeds (expressed in feet per second) are adopted for INTRAS vehicle-type calibration. For downgrades it is assumed that all desired free-flow speeds may be attained (i.e. are not subject to limit).

	Grade			
Vehicle Type	0°	2°	4°	6°
Bus and Heavy Single Unit Trucks	98	84	70	57
Truck Trailer Combination	84	50	32	23

The source document also describes the deceleration profiles followed by vehicles which enter a gradient section at a speed higher than their limiting speed. INTRAS applies integer values of both speed and acceleration (deceleration). The deceleration to maximum speed is best represented in all cases by a value of one foot per second.

4.1.2 Vehicle Acceleration Profiles

Typical vehicle acceleration is influenced by speed as well as by grade and vehicle characteristics. Therefore, any acceleration calibration must be stratified by speed level. In addition, passenger car vehicles are not normally operated at full available horsepower during acceleration. In this respect, acceleration is a behaviorial phenomenon. Studies have shown (Ref. 6) that target speed affects the acceleration profile. The following assumptions and decisions were made in the calibration of INTRAS to cope with these aspects of vehicle acceleration.

- Speed categories, within which acceleration is constant, are defined with a range of 20 feet per second each. A definition of normal acceleration was required for each vehicle type-grade-speed category combination.

- Normal mean acceleration for passenger car vehicles, at zero grade, are taken from tests performed by the Highway Traffic Safety Center, Michigan State University as presented in Figure 2.9 of the Traffic Engineering Handbook (Ref. 6). This source provides acceleration profiles for both rural (60 MPH target speed) and urban (35 MPH target speeds) environments. In INTRAS these two profiles (illustrated in Figures 9 and 10) are used to represent freeway and non-freeway zero grade accelerations, respectively.

- Variation from the passenger car zero grade mean acceleration profiles for high and low performance passenger cars is assumed to be proportional to the variation in maximum attainable accelerations for these vehicle types. Adoption of a combination of the "low" and "medium" performance categories from Table B-1 of Reference 8 as the INTRAS low performance vehicle results in an approximate maximum acceleration for this category of 9 feet/second^2. High performance passenger car vehicles are characterized in this source by a maximum acceleration of 16.5 feet/second^2. Integer acceleration rates are chosen, for the INTRAS calibration, which ensure that the low and high performance passenger car vehicles will exhibit respectively lower and higher than mean speed versus time characteristics during acceleration. To the extent allowed by the integer acceleration rate constraint of INTRAS, the ratio of high performance to low performance passenger car acceleration approximates the maximum acceleration ratio (16.5 to 9), for each speed category. The resulting speed versus time profiles are shown in Figures 9 and 10. INTRAS calibration passenger car acceleration rates are presented in Tables 37 and 38.

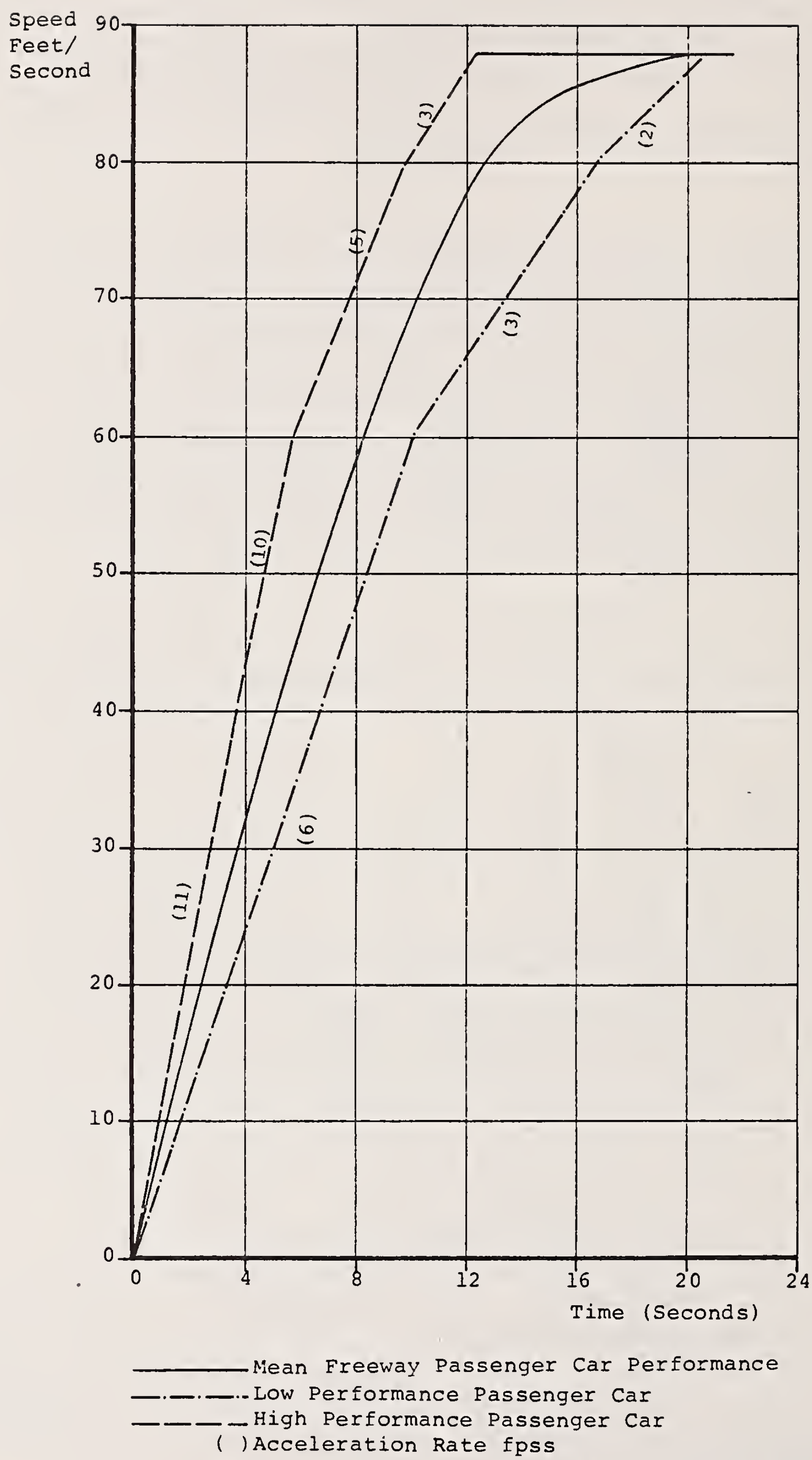
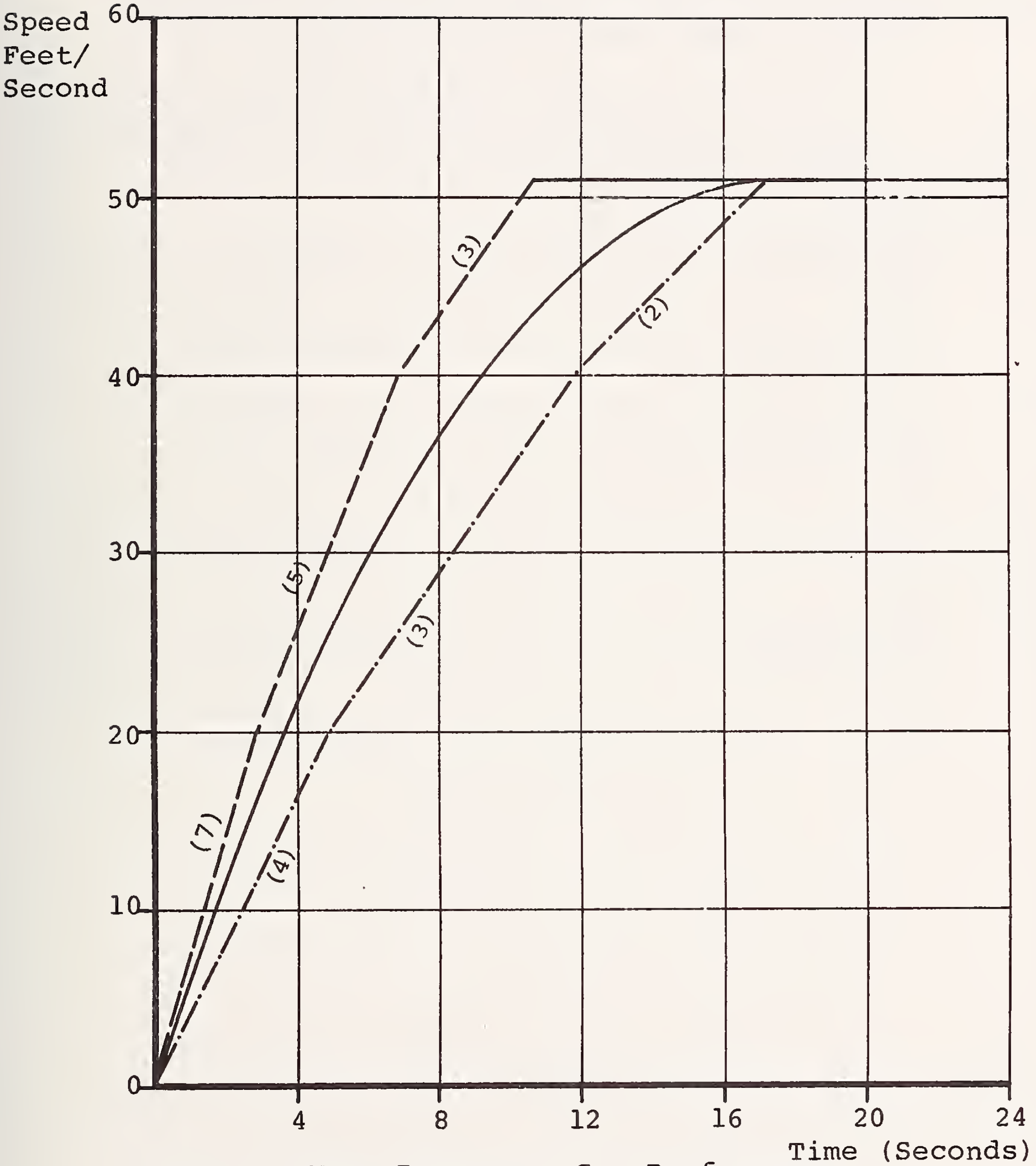


Figure 9: Freeway Passenger Car Zero Grade Acceleration



Mean Passenger Car Performance
Low Performance Passenger Car
High Performance Passenger Car
( ) Acceleration Rate fpss

Figure 10 : Non-Freeway Passenger Car Zero Grade Acceleration

Table 37: INTRAS Calibration Normal Acceleration Rates for Low Performance Passenger Cars

Integer Acceleration Rates in Ft/Sec^2

Grade	Roadway	Speed (ft/sec) 0→20	20→40	40→60	60→80	Above 80
-4%	Freeway	8	8	8	5	3
	Non-Freeway	5	4	3	3	3
0%	Freeway	6	6	6	3	2
	Non-Freeway	4	3	2	2	2
2%	Freeway	6	6	5	2	1
	Non-Freeway	4	3	2	1	1
4%	Freeway	5	5	3	1	1
	Non-Freeway	3	3	1	1	1
6%	Freeway	5	5	3	1	1
	Non-Freeway	3	3	1	1	1

Table 38: INTRAS Calibration Normal Acceleration Rates for High Performance Passenger Cars

Integer Acceleration Rates in Ft/Sec^2

Grade	Roadway	Speed (ft/sec) 0→20	20→40	40→60	60→80	Above 80
-4%	Freeway	15	14	14	8	5
	Non-Freeway	9	6	5	5	5
0%	Freeway	11	11	10	5	3
	Non-Freeway	7	5	3	3	3
2%	Freeway	10	10	8	4	2
	Non-Freeway	7	5	3	2	2
4%	Freeway	9	9	5	2	1
	Non-Freeway	6	5	2	1	1
6%	Freeway	9	9	4	2	1
	Non-Freeway	6	4	1	1	1

- The effect of grade on passenger car acceleration as described in the Traffic Engineering Handbook (Ref. 6) is based on earlier research by Saal (Ref. 14). From graphs presented in this earlier source, multiplicative factors were developed to relate zero acceleration at each INTRAS grade level to that at zero grade. These factors are given in Table 39. The resulting accelerations are those shown in Tables 37 and 38.

- Truck and bus accelerations are those predicted by the modified SAE truck ability procedures of Reference 8. These procedures agree substantially with field test data reported by Western Highway Institute (Ref. 12), and the Road Research Laboratory (Ref. 13). Integer acceleration values were chosen for the INTRAS calibration so as to provide the closest possible agreement with speed-distance curves presented in Appendix E of Reference 8. Figures 11 and 12 illustrate the resulting speed distance profiles for the selected bus and truck types. The values of acceleration for each vehicle type, by grade and speed category, are presented in Tables 40 and 41.

4.1.3 Vehicle Deceleration Profiles

Deceleration rates as applied in the freeway logic of INTRAS are determined by the car following logic. For the case where deceleration is mandated by the position of a leader vehicle, the only necessary calibration is the specification of a maximum deceleration, by vehicle type.

Table 2.8 of the 1976 Edition of the Transportation and Traffic Engineering Handbook (Ref. 15) contains skidding friction coefficients for both new and badly worn tires. Application of these coefficients in the stopping distance equations:

$$S = \frac{V^2}{30f} \quad \text{from Reference 15}$$

and,

$$S = \frac{\left(\frac{22}{15} V\right)^2}{2d} \quad \text{from the laws of dynamics}$$

where

Table 39: Multiplicative Factors Relating Passenger Car Acceleration on INTRAS Grades to Acceleration at 0% Grade

Grade	Speed (ft/sec) 0→20	20→40	40→60	60→80	Above 80
-4%	1.329	1.299	1.539	1.600	1.714
0%	1.0	1.0	1.0	1.0	1.0
2%	.930	.959	.833	.739	.522
4%	.846	.908	.556	.430	--
6%	.791	.889	.441	.343	--

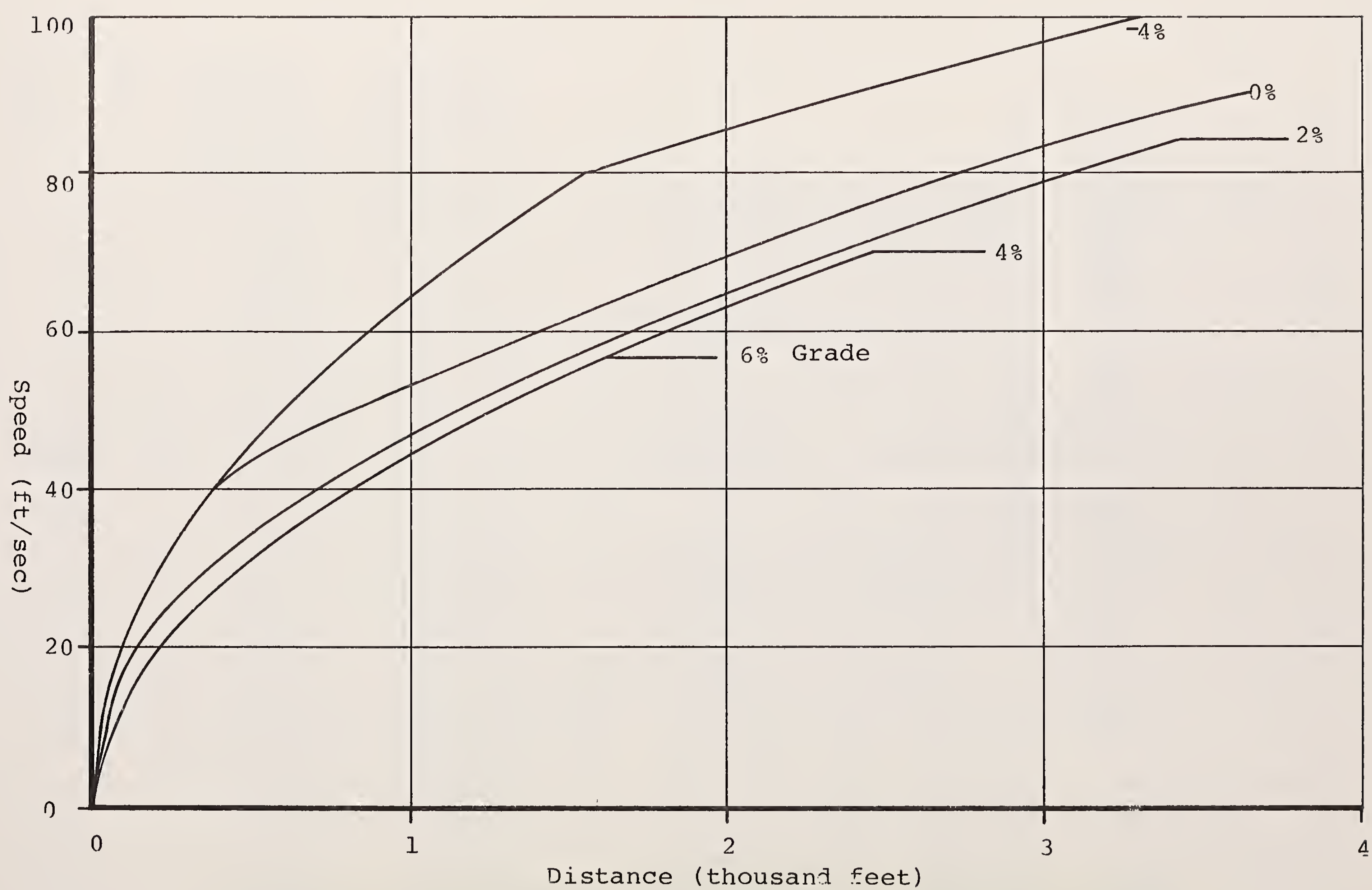


Figure 11: Speed-Distance Profiles for Intercity Buses and Heavy Single Unit Trucks

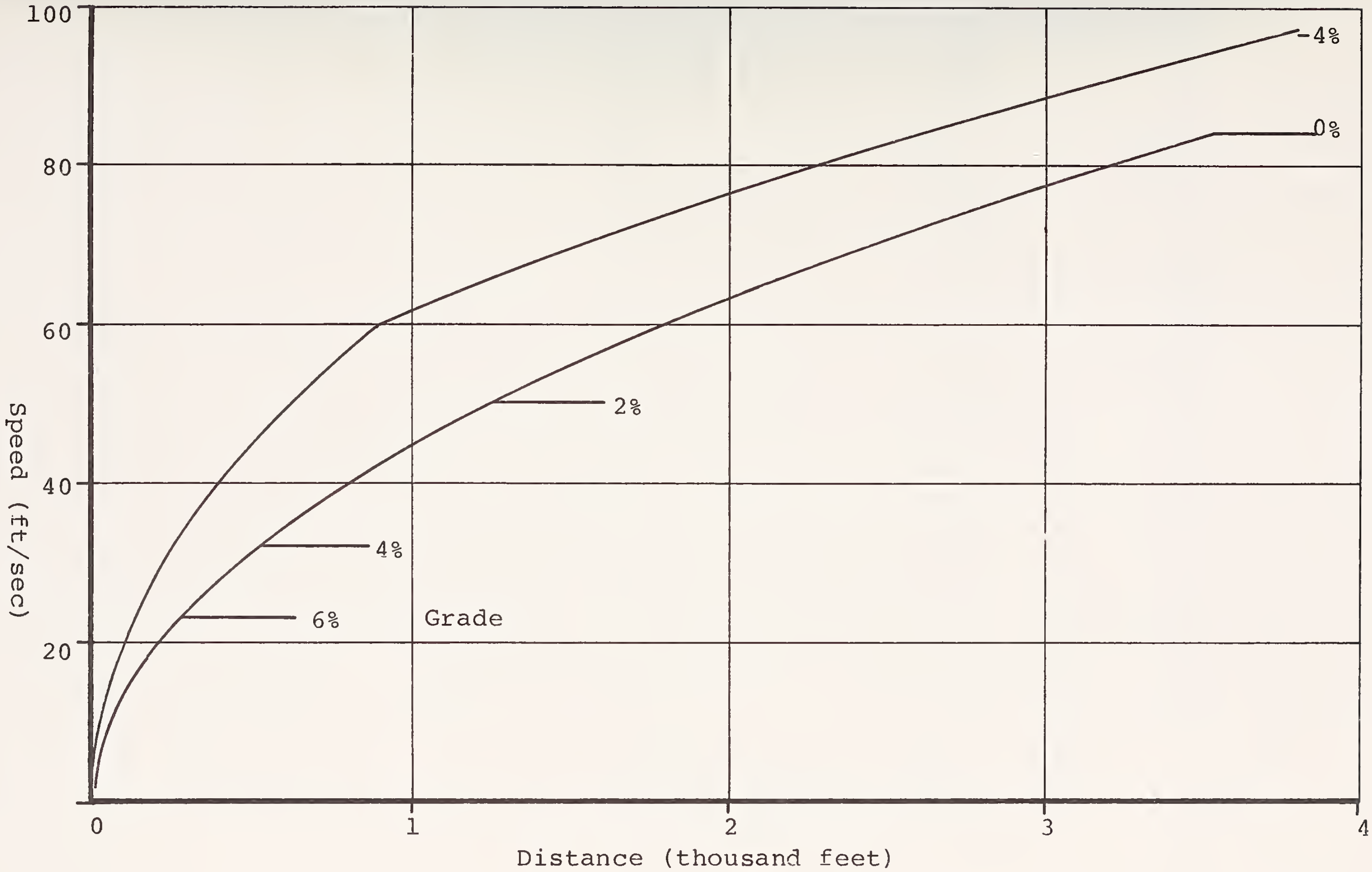


Figure 12: Speed-Distance Profiles for Trailer Truck Vehicle Type

Table 40: INTRAS Calibration Normal Acceleration Rates for Buses and Heavy Single Unit Trucks

Integer Acceleration Rates in Ft/Sec^2

	Speed (ft/sec)				
Grade	$0 \rightarrow 20$	$20 \rightarrow 40$	$40 \rightarrow 60$	$60 \rightarrow 80$	Above 80
-4%	3	2	2	2	1
0%	3	2	1	1	1
2%	2	1	1	1	1
4%	1	1	1	1	0
6%	1	1	1	0	0

Table 41: INTRAS Calibration Normal Acceleration Rates for Trailer Trucks

Integer Acceleration Rates in Ft/Sec^2

Grade	Speed (ft/sec) 0→20	20→40	40→60	60→80	Above 80
-4%	2	2	2	1	1
0%	1	1	1	1	1
2%	1	1	1	0	0
4%	1	1	0	0	0
6%	1	0	0	0	0

S = stopping distance in feet,

V = speed of vehicle before braking, mph

f = friction coefficient,

and, d = deceleration rate in fpss,

makes possible the calculation of a maximum deceleration rate. For the INTRAS calibration a mean friction coefficient of .65 is assumed based upon the values presented in Reference 15. The resulting deceleration rate is 21 fpss. This value is imbedded in INTRAS for all vehicle types except trailer trucks. Figure 2.13 of Reference 6 describes the frequency distribution of maximum deceleration for a number of vehicle types. The 50th percentile maximum deceleration for trailer trucks is 16 fpss in this source. This more conservative value is used in the INTRAS calibration of the trailer truck vehicle type.

Deceleration required to respond to signal indications and intersection turning movements occurs only on the surface and ramp links. The modeling of this phenomena in INTRAS is similar to that of the UTCS-1 model.

Freeway decelerations to achieve a new, lower, desired speed are assumed to be "coasting" decelerations (i.e., engine engaged, brake not applied). Table 2.5 of the Traffic Engineering Handbook expresses passenger car coasting deceleration as a function of speed. The following rules apply:

Speed Range (fps)	Deceleration (fpss)
0-40	1
40-60	2
Above 60	3

A coasting deceleration of 1 foot/second^2 is used in INTRAS for truck and bus vehicles.

4.2 Other INTRAS Calibration Parameters

A statistical basis is required, by INTRAS, for the assignment of lane specific volumes and desired free-flow speeds. Data, provided by FHWA, representing free-flow conditions on the Long Island Expressway, and a wide range of volumes on the Los Angeles Freeway system, was analyzed to provide the required parameters. The following sections describe these activities.

4.2.1 Lane and Vehicle Specific Desired Speed

The freeway vehicle generation procedures of INTRAS maintain two vehicles in each lane of the freeway entry link. As each vehicle is discharged from the entry, another is generated. Lane, then, is a prescribed input to the vehicle generation procedure. The assignment of vehicle-specific desired speed must reflect this a priori knowledge. To facilitate assignment of desired speed to each new vehicle, it is necessary to develop a relationship which defines lane-specific mean desired speed as a function of overall mean desired speed.

The definition of desired speed (also referred to as free-flow speed) is that speed which would be maintained on a roadway given no impedance from other vehicles (i.e., free-flow conditions). The Long Island Expressway data base (reduced from aerial motion pictures) describes approximately 125 miles of freeway traffic under free-flow (600 to 1000 vehicles/lane/hour) conditions. The subject roadway section is three lanes in width and free of ramps. The total data base is divided into eight individual sequences. If it is assumed that the available data is sufficient to describe lane-specific mean free-flow speed for a three-lane section, then additional data is still required to characterize traffic on roadways of other widths.

The Los Angeles data base consists of magnetic tapes containing raw detector data from all detector stations on the San Diego and Santa Monica Freeways. Data for a number of fully instrumented (all lanes detectorized) four- and five-lane stations have been isolated to provide a basis for lane-specific speed evaluation. The chosen stations are not in close proximity to either ramps or lane additions or drops. A total of 1675 minutes of four-lane data, and 585 minutes of five-lane data, representative of volumes from 1000 to 2000 vehicles/lane/hour have been reduced to provide the ratio of lane mean speed to overall mean speed. Data considered to be drawn from the forced-flow regime (i.e., density > 60 vehicles/lane mile, or speed < 40 miles/hour) was specifically eliminated from consideration. Table 42 presents the resulting speed ratios stratified by volume level.

Since no consistent trend was revealed to indicate a predictable variation in the ratio of lane mean speed to overall mean speed with volume, it was decided that both the 1000 to 1200 vplph and 1200 to 1400 vplph data aggregates would be employed. Data aggregates for the three-, four- and five- lane roadway widths are shown plotted versus lateral position in Figure 13. For the three-lane data, each point represents one of the eight time sequences of the Long Island Expressway data base. One longitudinal location (station) was chosen within the extent of the Long Island Expressway data base roadway section. Vehicle speeds and volumes were reduced from the data base for vehicles passing this station. In this way, the statistical data reduced from this data base was made comparable to that from the detector stations of the Los Angeles data base. Also illustrated is a third degree polynomial "fit" to the data via a least squares regression procedure. For this purpose, the data points were weighted by contributing time duration. In addition to the 125 minutes of three-lane data, 390 and 170 minutes of data for the four- and five-lane sections were applied, respectively.

The resulting INTRAS lane speed calibration consists of factors, drawn from the polynomial curve, to be applied to overall mean desired speed to generate lane-specific values. The final factors are as follows:

Section	Lane				
Width	1	2	3	4	5
2 Lanes	.94	1.06	-	-	-
3 Lanes	.93	1.01	1.06	-	-
4 Lanes	.93	.97	1.05	1.05	-
5 Lanes	.94	.95	1.01	1.06	1.04

Table 42: Ratio of Lane Speed to Mean Speed for Los Angeles Detector Data

Four-Lane Aggregates

Lane	Volume Category (veh/lane/hour) 1000→1200	1200→1400	1400→1600	1600→1800	1800→2000
1*	.92	.92	.93	.92	.93
2	.99	1.00	.97	.97	.96
2	.99	1.00	.97	.97	.96
3	1.05	1.06	1.08	1.07	1.07
4	1.04	1.02	1.02	1.03	1.04

Five-Lane Aggregates

Lane	1000→1200	1200→1400	1400→1600	1600→1800	1800→2000
1*	.99	.97	.96	.92	.86
2	.93	.92	.92	.92	.95
3	.98	.97	.98	1.01	1.00
4	1.05	1.07	1.07	1.04	1.07
5	1.04	1.07	1.08	1.11	1.12

* Note: Lane 1 is extreme right lane.

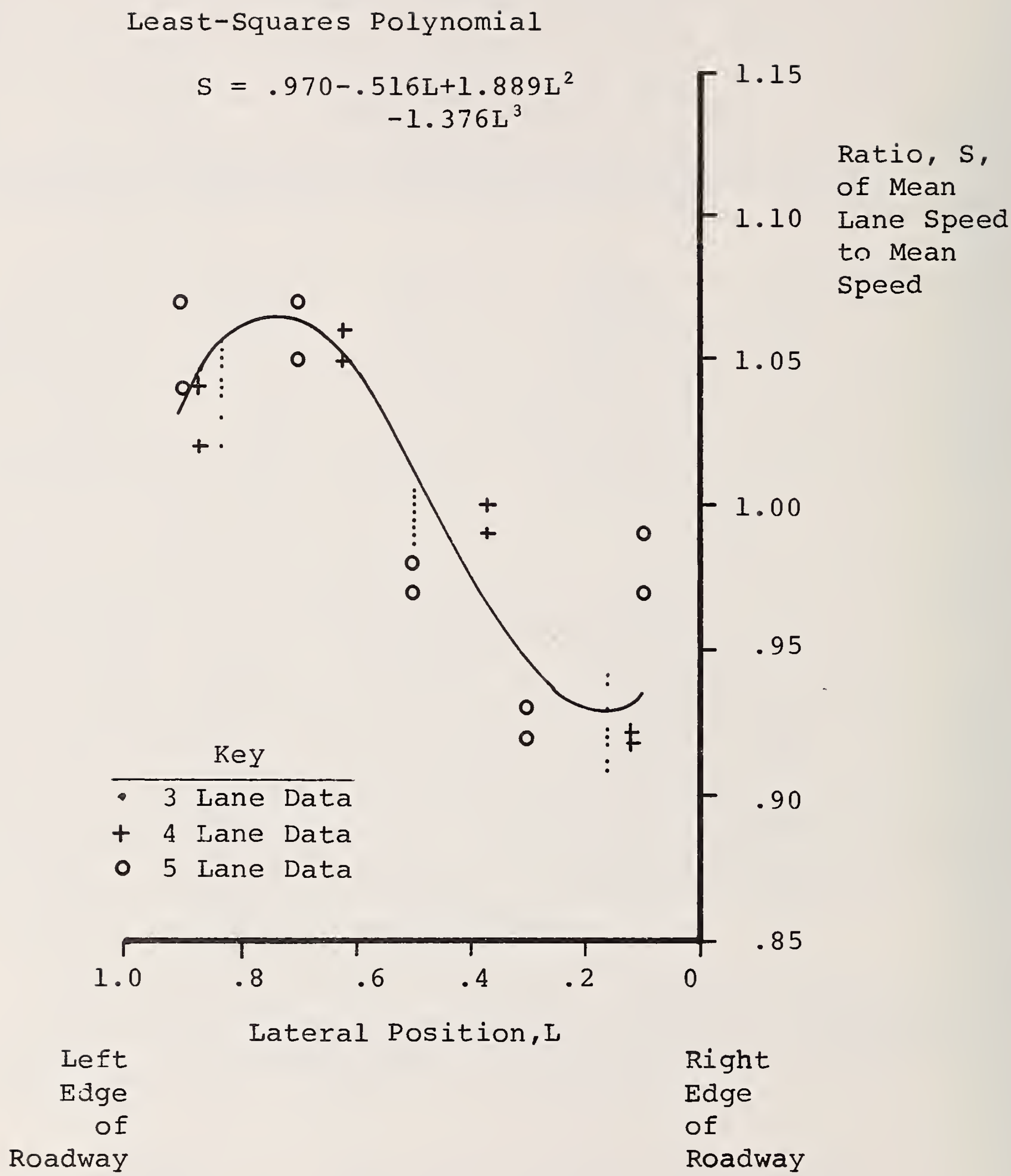


Figure 13: Lane-Specific Mean Speed Ratio

To generate desired speeds for individual vehicles from lane-specific mean desired speed, a cumulative frequency distribution is required describing variation about the mean lane value.

Individual vehicle speeds for the Long Island Expressway data base were grouped into lane-specific distributions. One decile distribution was generated for each lane of each time sequence. The ratio of cell speed to lane speed was calculated for each decile distribution element. A cumulative frequency diagram of these data points is presented in Figure 14. Also shown is a mean curve, based on the data, which is used to evaluate the required INTRAS decile distribution. The resulting distribution, referenced by driver type, is as follows:

Driver Type	1	2	3	4	5	6	7	8	9	10
% of Mean Lane Speed	82	91	94	97	99	101	103	106	109	118

4.2.2 Lane-Specific Volume Distribution

In parallel with the determination of lane mean speed ratios, the relationship of lane volume and overall volume was calculated. The resulting ratios (lane volume/overall volume per lane) are presented in Table 32 stratified by road width and overall volume level. This data indicates that volume level alone is not an adequate predictor of lateral volume distribution. Apparently each individual roadway displays its own distributive characterstics.

The following summarizes the data sources for Table 32:

Number of Lanes	Roadway Identification	Number of Stations
3	Long Island Expressway	1
4	San Diego Freeway	6
5	Santa Monica Freeway	3

As previously mentioned, the stations enumerated above were selected for the absence of local geometric effects (ramps, lane drops). Other roadway, traffic and environmental (sight lines, truck percentage, urban vs. suburban,etc.)

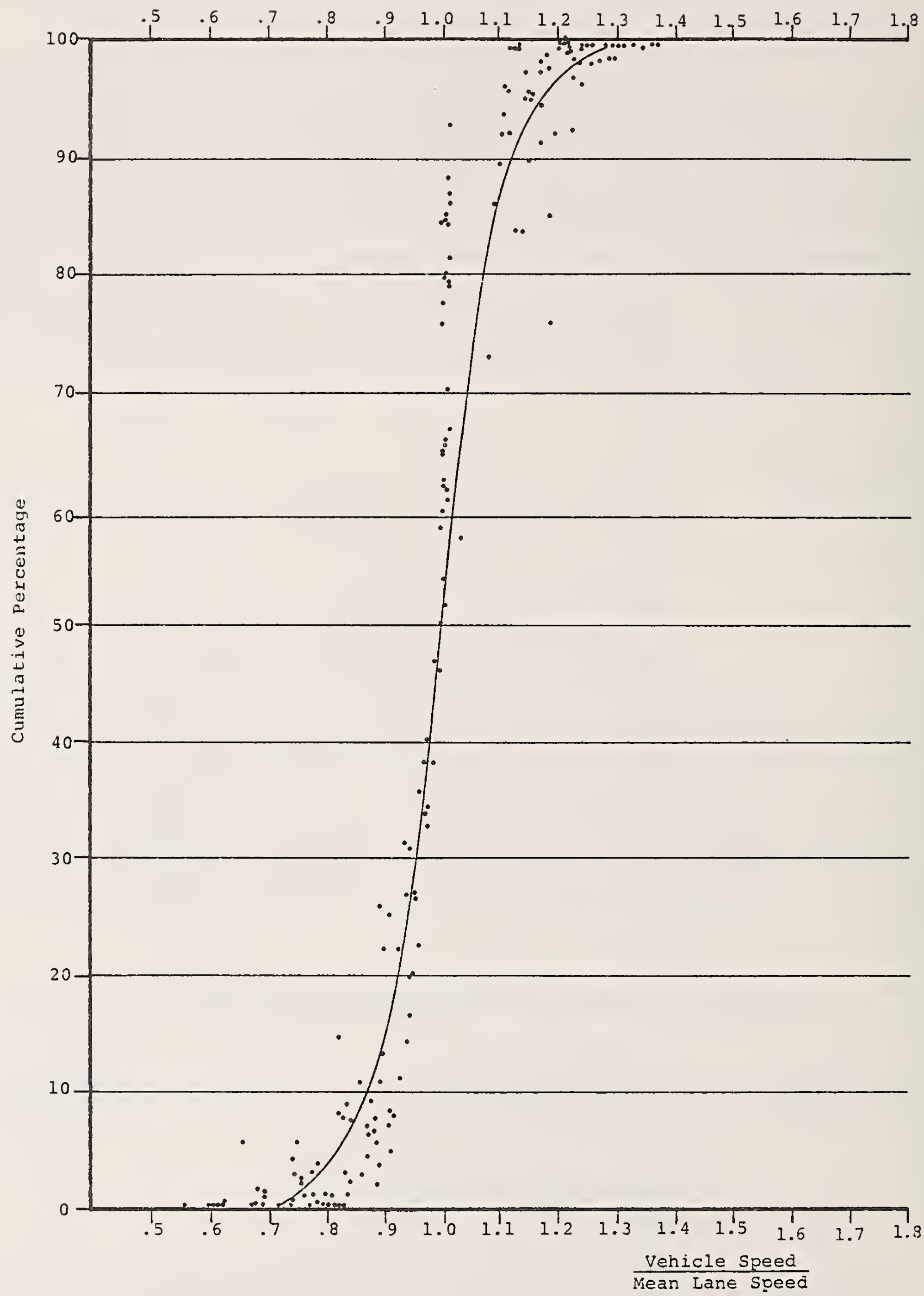


Figure 14: Cumulative Frequency of Speed to Mean Lane Speed Ratio

Table 43: Ratio of Lane Volume to Overall Per Lane Volume

Overall Volume Veh/Hr/Lane	Lane: Right 1	2	3	4	Left 5	Minutes of Data	
908	1.30	1.12	.58	-	-	27	Long Island Expressway
926	1.26	1.14	.60	-	-	29	
817	1.36	1.14	.50	-	-	12	
1368	1.38	1.11	.52	-	-	16	
818	1.33	1.10	.57	-	-	12	
657	1.21	1.11	.69	-	-	18	
741	1.09	1.19	.73	-	-	9	
813	1.19	1.23	.58	-	-	7	
1118	.93	1.05	1.05	.97	-	105	San Diego Freeway
1313	.92	1.02	1.01	1.05	-	285	
1515	.94	1.01	1.01	1.04	-	385	
1702	.95	1.00	1.00	1.05	-	645	
1864	.94	1.00	1.01	1.06	-	255	
1117	.48	1.00	1.23	1.16	1.13	25	Santa Monica Freeway
1322	.58	1.05	1.13	1.16	1.08	145	
1511	.69	.97	1.11	1.12	1.11	215	
1702	.91	.91	.99	1.06	1.12	95	
1909	1.02	.91	.95	1.01	1.12	105	

factors not present in the data base must be assumed to dictate lane choice.

Because no suitable predictor may be developed from the available data, the default lane-specific distribution of volume in INTRAS is rectangular. This procedure is particularly appropriate at or near capacity volume. Since the user may well have more specific information, the distribution of total volume by lane may be input (see Section 3).

Data on the lateral distribution of commercial vehicles was taken from two sources. The weaving section trajectory data base, acquired from the Polytechnic Institute of New York (PINY) for component model validation (see Volume 2), identifies each trajectory by vehicle type. Commercial vehicle counts were reduced, from this source, for two-and three-lane sections.

Freeway traffic films, taken of the North Central Expressway in Dallas (Ref. 15), were reduced to provide further data on commercial vehicle lane placement on two-lane sections. The commercial vehicle counts obtained from these sources are as follows:

	Commercial Vehicle Counts		
Source	Right Lane	2nd Lane	3rd Lane
PINY Experiment 6	96	89	6
PINY Experiment 7	142	25	-
Dallas Films	180	71	-

Figure 15 displays the cumulative frequency of vehicles by lateral position based on the above data. The alignment of data points permits a straight line approximation (also shown in the figure). This approximation is used to generate the following lane assignments for commercial vehicles:

	% of Commercial Vehicles Assigned to Lane				
Number of Lanes	Right Lane	2nd Lane	3rd Lane	4th Lane	5th Lane
2	75	25	-	-	-
3	50	50	0	-	-
4	38	37	25	0	-
5	30	30	30	10	0

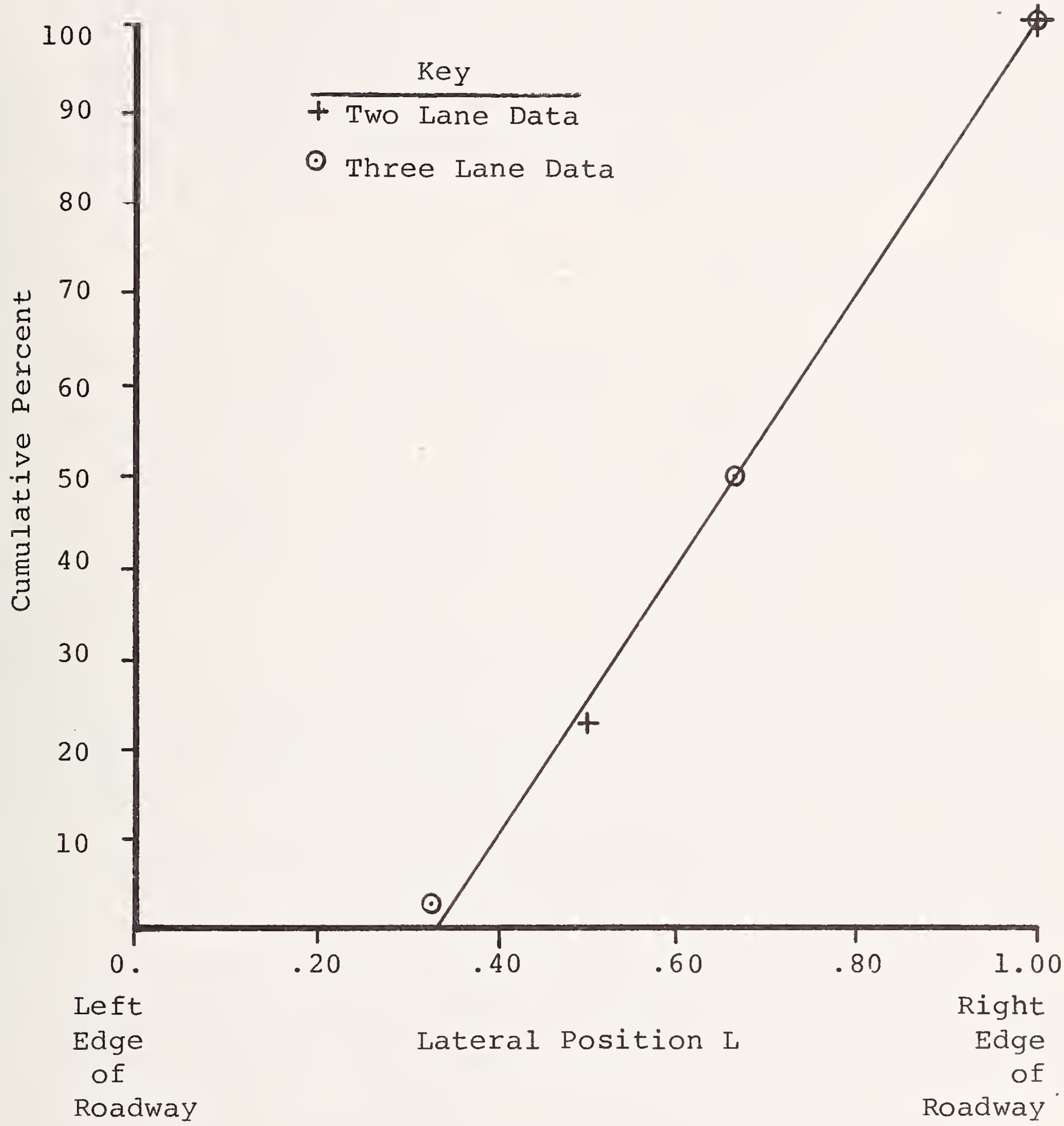


Figure 15: Percent of Commercial Vehicle Population to the Left of Lateral Position L

The basis for the above commercial vehicle lane assignment approximation is admittedly weak. A data collection effort might be undertaken to examine lane assignment by volume level, number of lanes and specific vehicle type, at locations isolated from on and off-ramp effects. This information is not present in the available data bases. Such a data collection is beyond the scope of the subject project.

5. LITERATURE REVIEW

This review is divided into three segments. The narrative discussion which follows describes car-following traffic models and their application to freeway simulation. Both car-following models and traffic simulation models are reviewed in the form of an annotated bibliography of selected publications provided as Appendix C to the report. A more extensive Bibliography is also provided.

5.1 Analytical Car-Following Models

Initially, a distinction must be made between that set of "microscopic" models describing the behavioral response mechanisms of individual vehicles, and those macroscopic" models describing the overall behavior of the traffic stream. The work presented here deals with the first group of models and is referred to as "car-following theory."

For the class of microscopic models, a single car is assumed to follow a leading car and both are constrained to remain in the same lane. The model can be postulated as follows:

Consider a car, n, at a position, $x_n(t)$. At time, t, its speed is $\dot{x}_n(t)$ and its acceleration is $\ddot{x}_n(t)$. A trailing car, n+1, is at position, $x_{n+1}(t)$, with speed, $\dot{x}_{n+1}(t)$, and acceleration $\ddot{x}_{n+1}(t)$. The acceleration of the (n+1)th vehicle at time, t, can be expected to depend on the relative speeds and separation distance of the two vehicles.

Two primary concerns must be kept in mind.

- Stability
- Acceptable realism.

The question of stability addresses the form of the model. Consider the following forms:

(a) $\ddot{x}_{n+1}(t) = \mu[x_n(t) - x_{n+1}(t)]$

(b) $\ddot{x}_{n+1}(t) = K[\dot{x}_n(t) - \dot{x}_{n+1}(t)]$

where the parameters, μ and K, must be determined from field observation

(c) A linear combination of the previous two laws:

$$\ddot{x}_{n+1}(t) = \mu[x_n(t)-x_{n+1}(t)]+K[\dot{x}_n(t)-\dot{x}_{n+1}(t)].$$

All these laws are linear laws, which might be appropriate only for small deviations from the desired state of traffic. The response of the (n+1)th driver is proportional to a deviation for which he wishes to compensate. The parameters, μ and K, are called sensitivities of the response to the deviations. Large values of μ and K correspond to strong compensation, and small values correspond to weak compensations.

A standard approach to investigate the effect of disturbances and of the stability of linear systems is to perform a harmonic (frequency) analysis of the disturbance to determine how individual frequency components are propagated through the system. Assuming that the deviation of the motion of the lead car in a platoon is the source of the disturbance, its motion can then be harmonically analyzed. When this is done in law (a), it turns out that a resonance exists at frequency, $w=\mu/2$. That is, any frequency components at frequencies near $\mu/2$ are amplified strongly by the traffic, the law of amplification of the amplitude of the frequency component being $[1+w^2/\mu]^{-m}$. On the other hand, law (b) damps out a disturbance as $[1+w^2/K^2]^{-m}$ for the m^{th} car behind the source of the disturbance. Hence, law (b) is a reasonable one to investigate further while law (a) is not. If one investigates mixed laws such as (c) or any other law in which the acceleration is proportional to the difference in i^{th}

derivatives of the separation distance between two successive vehicles, he finds resonances (instabilities) in those laws which contain terms with even values of i. Inasmuch as it is doubtful that a driver could be sensitive to third derivatives, one is left with only law (b) as a possible one for investigation.

Since responses can never be instantaneous, law (b) should be amended to take into account the time lag between the time of the actual development of a disturbance and the moment of effective response; therefore, law (b) should be modified to read:

$$\ddot{x}_{n+1}(t+\Delta) = K[\dot{x}_n(t)-\dot{x}_{n+1}(t)].$$

When time lags are incorporated into linear systems, instabilities may result. When time lags are long, there should be weak response, K, to insure stability. This model is stable only when the condition $2K\Delta<1$ is satisfied, since a disturbance of unit amplitude is propagated back to the m^{th} car so that its amplitude at arrival is equal to or less than

$$[1+(w^2/K^2)/(1-2K\Delta)]^{-m}.$$

Finally, the basic formula can be extended so that it is applicable to cases in which large gaps have formed between cars. One possible law is that the acceleration of the follower should be inversely proportional to the vehicle spacing so that

$$\ddot{x}_{n+1}(t+\Delta) = K[\dot{x}_n(t)-\dot{x}_{n+1}(t)]/[x_n(t)-x_{n+1}(t)].$$

If we take this model in its steady state condition; i.e., $\Delta=0$, then it can be integrated to give the macroscopic functional relationships between speed, flow, and density. May and Keller (Ref.17) in their paper summarized in Appendix C, have given a broad summary of car following models with various values for the parameters. They demonstrate the macroscopic relationships that these parameter values imply and compare them with known empirical results. This gives a reasonable indication of possible microscopic models for various flow, speed, density regions. Unfortunately, no single model fits the complete range although this is understandable.

5.2 Fail-Safe Simulated Car Following

For use in digital micro simulations, the analytical car-following models described above have two drawbacks, they have been developed for a continuous rather than discrete time parameter, and no single model is appropriate to all traffic conditions. As a consequence, so called fail-safe models have been developed.

A fail-safe car-following model is the process of determining a vehicle's speed and position given that its leader has a speed and position that has already been calculated for the current time scan. Generally, the output of the model is the acceleration of the following vehicle. A fail-safe model has two elements. Firstly, there is the car-following model which calculates the follower's behavior based on some prescribed desired following distance, usually a function of the vehicle's speed. Secondly, there is an overriding collision prevention model which is based on the following vehicle being able to avoid a collision when the leader undergoes its most extreme deceleration pattern.

The PITT model described in Appendix B to this report illustrates the rationale and development of a fail-safe simulation car-following model.

6. SIMULATION DEVELOPMENT

6.1 The Car-Following Algorithm

6.1.1 Initial Selection

Five algorithms were considered for possible use. A preliminary study of one of these, the Midwest Research Institute algorithm (Ref.18), indicated that it was inappropriate for use in the context of the current developments, so it was not considered further. The main drawbacks of the MRI model were: the algorithm was complicated, it had many parameters requiring calibration, and it required a long run time on the computer.

Four candidate algorithms were analyzed in detail.

(a) The Northwestern Algorithm,

(b) The UTCS-1 Algorithm,
(c) The Aerospace Algorithm,
(d) The PITT Algorithm.

Algorithms a, b, and d are fail-safe types as described in the literature review, while algorithm c uses the May-Keller calibration of the analytic type car-following model. The notation used is:

a = acceleration of follower,
x = position of leader,
y = position of follower,
u = speed of leader
v = speed of follower,
L = length of leader,
T = simulation scanning interval,
e = maximum emergency deceleration for all vehicles,
b,k = calibration constants.

All units are in feet and seconds.

The Northwestern Algorithm

This algorithm was developed at Northwestern University by a member of the Pittsburgh research team which has, therefore, a detailed knowledge of the model and its limitations. The model has two key components, a car-following rule that sets a minimum following distance directly proportional to the following vehicle's speed, and an overriding equation that prevents the minimum following distance from being violated during times of maximum deceleration by the leading vehicle.

Given the speed, and location of the leading vehicle at the end of the scanning period, the algorithm outputs the new speed and position of the following vehicle. The mathematics of the algorithm are lengthy and are reported fully by Worrall and Bullen (Ref. 19).

The UTCS-1 Algorithm

This model consists of a spacing algorithm which provides for collision avoidance when the leading vehicle decelerates suddenly to a stop. There is no specific car-following algorithm apart from the critical headway calculation. The output of the algorithm is given by

$$a = [7(x-y-vT-L) + (2u^2 - 3v^2)/6]/(v+3).$$

The Aerospace Algorithm

This model uses the May-Keller calibration of the conventional analytical car-following model

$$a = \lambda v(u-v)/(x-y)^3$$

where λ is the driver sensitivity factor.

When (u-v) is positive or close to zero, the above formula is inoperative and normal acceleration patterns are followed subject to safe spacing limitations. These latter relationships are not clearly stated in the paper by Harju (Ref. 20).

The PITT Algorithm

This model is founded on a combination of the Northwestern car-following and the UTCS-1 collision avoidance procedures. The primary car-following relationship is that a following vehicle will attempt to maintain a space headway of L+kv+10 feet. The factor, k, which is a function of driver type, regulates maximum lane capacity since it determines the average headway at high volumes. This factor, k, therefore, is also used to establish bottleneck conditions since a reduction in lane capacity can be achieved through an increase in k.

The car-following formula is

$$a = 2[x-y-L-10-(k+T)v-bk(u-v)^2]/(T^2+2kT)$$

A lag, c, is introduced into the car-following calculations after a has been calculated. The lag is applied to the calculations of the following vehicles speed and position as shown in Appendix B. Note that c (which must always be less than T) is contained explicitly in the collision avoidance equations outlined below.

Overriding this car-following relationship is a collision avoidance set of equations which prevent collisions when vehicles are undertaking maximum emergency decelerations. The formula for the emergency constraints are

$$a \leq - B/2 + [(B^2+4C)]^{1/2}/2$$

$$\text{where } B = e + 2(ec+v)/(T-c)$$

$$\text{and } C = [2e/(T-c)^2] \cdot [x-y-vT-L-cv-(v^2-u^2)/2e]$$

$$\text{provided } a \geq [(u^2+e^2c^2)^{1/2}-ec-v]/(T-c) > 0$$

or

$$a < 2(x-y-vT-L)/(T-c)^2$$

$$\text{provided } -v/(T-c) < a < [(u^2+e^2c^2)^{1/2}-ec-v]/(T-c)$$

or

$$a \leq -v^2/2(x-y-L)$$

$$\text{provided } a < -v/(T-c).$$

The detailed derivation of this model is given as Appendix B.

6.1.2 Initial Testing

As the first step in the evaluation of the above models, qualitative assessments of their general character were made.

Northwestern Algorithm

This model is complicated and lacks flexibility. It is extremely difficult to set in modular form, since its outputs are position and speed rather than acceleration as is the case with the other alternatives. Extensive mathematical reworking would be needed to include a variable time scan and driver and vehicle characteristics. At high volumes the vehicles tend asymtopically to a state of uniform speeds and headways. Capacity flow is difficult to obtain, therefore, while congested turbulent flow is unobtainable. Bottlenecks would be difficult to implement.

UTCS-1 Algorithm

The model is simple and easily modularized. It is, however, a collision avoidance algorithm only, and there is no internal car-following algorithm to generate congested flow. As several simplifying approximations have been made, mathematical reworking would be needed to allow for different vehicle and driver types and for variable scanning periods. The model cannot reproduce bottlenecks and variable traffic conditions. These must be imposed exogenously.

Aerospace Algorithm

The major problem with this model is that it is a part of a completely different simulation design, with the basic freeway a set of cells rather than a continuous coordinate system. The car-following formula is valid only for a positive closing speed between vehicles. For other conditions, the algorithm is less clearly defined. As a consequence, the performance of the model is uncertain, especially with regard to the collision avoidance characteristics. The reproduction of bottlenecks is not easy and the analytical car-following model will be unstable at longer scanning intervals.

PITT Algorithm

This is a development which combines many advantages and eliminates many disadvantages of the Northwestern and UTCS-1 models. The PITT model is simple, flexible and easily adapted to modular form. The model is mathematically rigorous. It easily accommodates variable scanning periods, and different driver and vehicle types. Capacity conditions can be replicated and congestion is internally generated. Bottleneck conditions can be easily imposed over the full range of potential capacity reductions.

Operational Tests

The four algorithms were each given some initial operational tests through simulating the car-following behavior in a single lane. Platoons of two vehicles and five vehicles were run down the lane at a constant speed. An artificial velocity disturbance was applied to the leading vehicle, and the behavior of the followers was examined. Scanning times were varied over a range of 0.5 to 5.0 seconds. Typical outputs of this phase are shown in Figures 16 to 20.

The figures show the behavior of a five-vehicle platoon

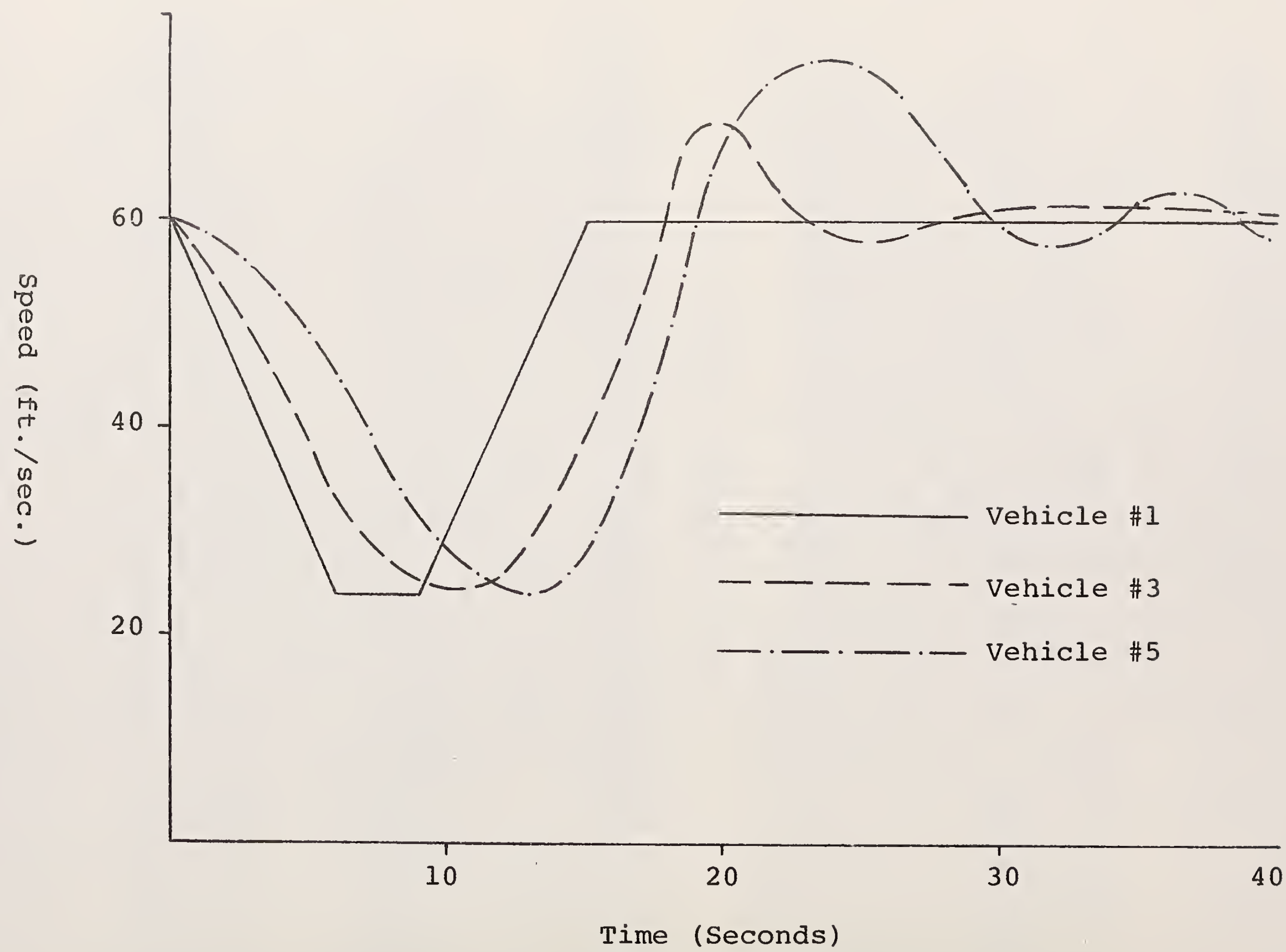


Figure 16: Platoon Behavior: PITT Algorithm-One Second Interval

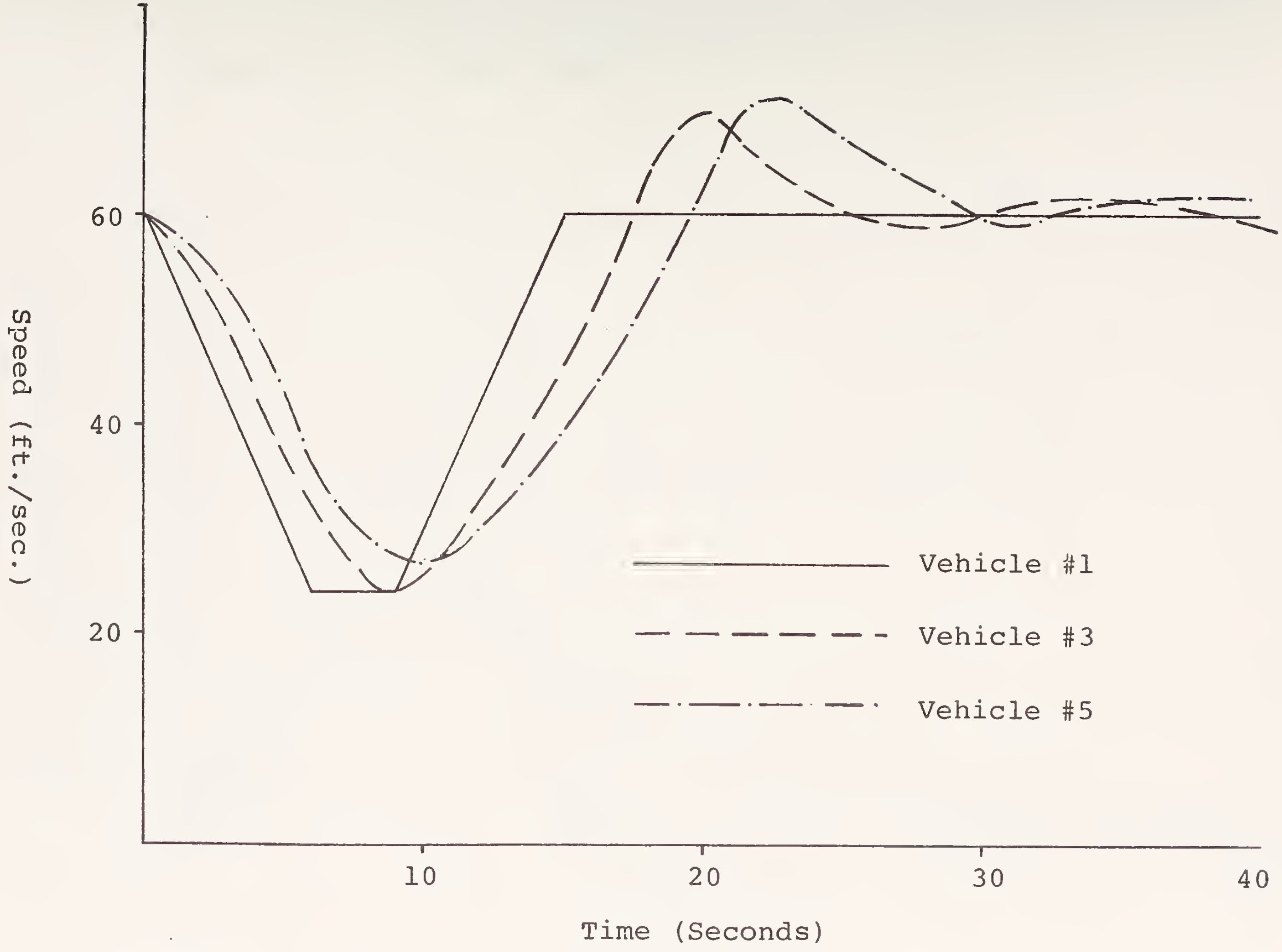


Figure 17: Platoon Behavior: PITT Algorithm-Three Second Interval

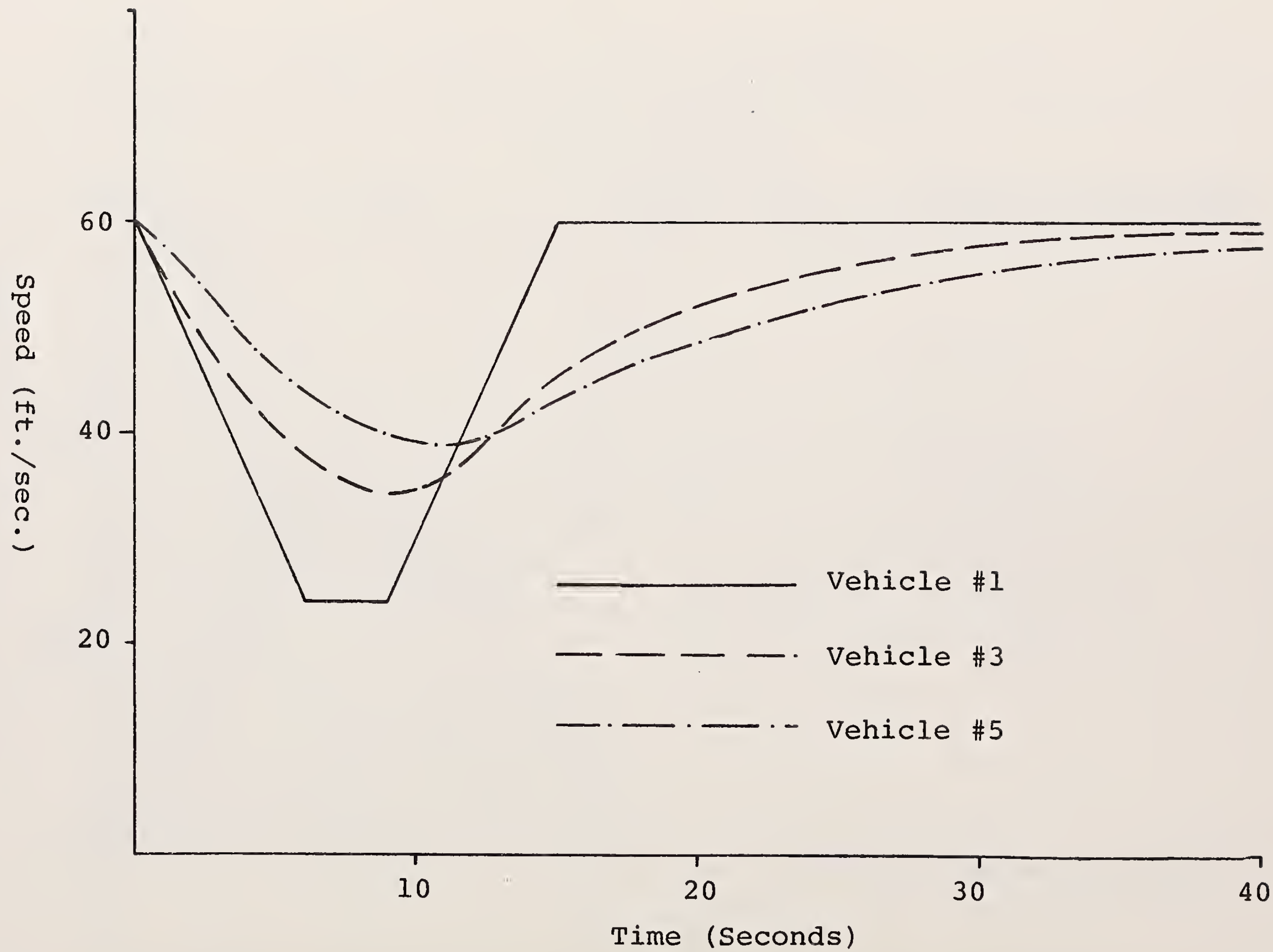


Figure 18: Platoon Behavior: UTCS Algorithm-One Second Interval

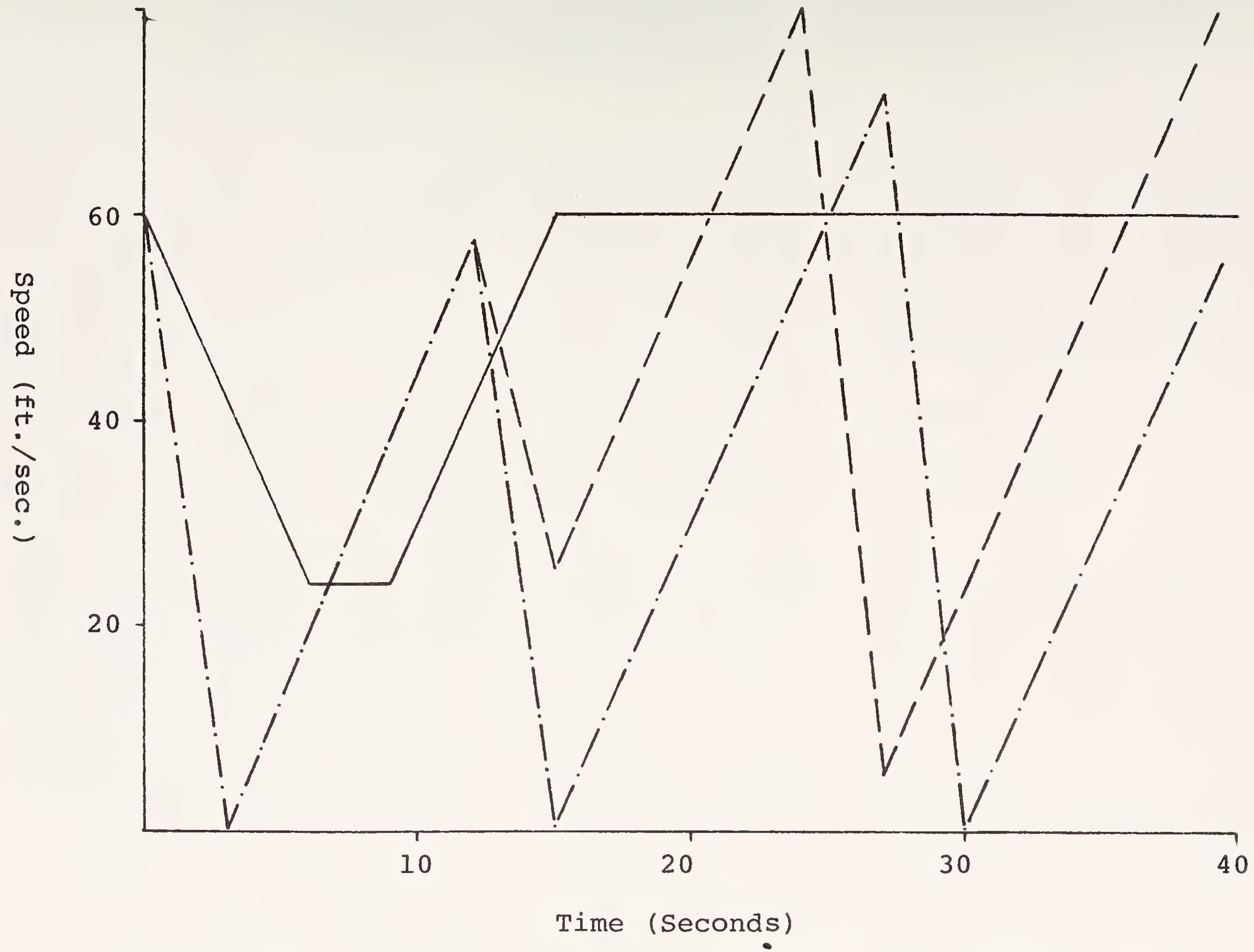


Figure 19: Platoon Behavior: UTCS Algorithm-Three Second Interval

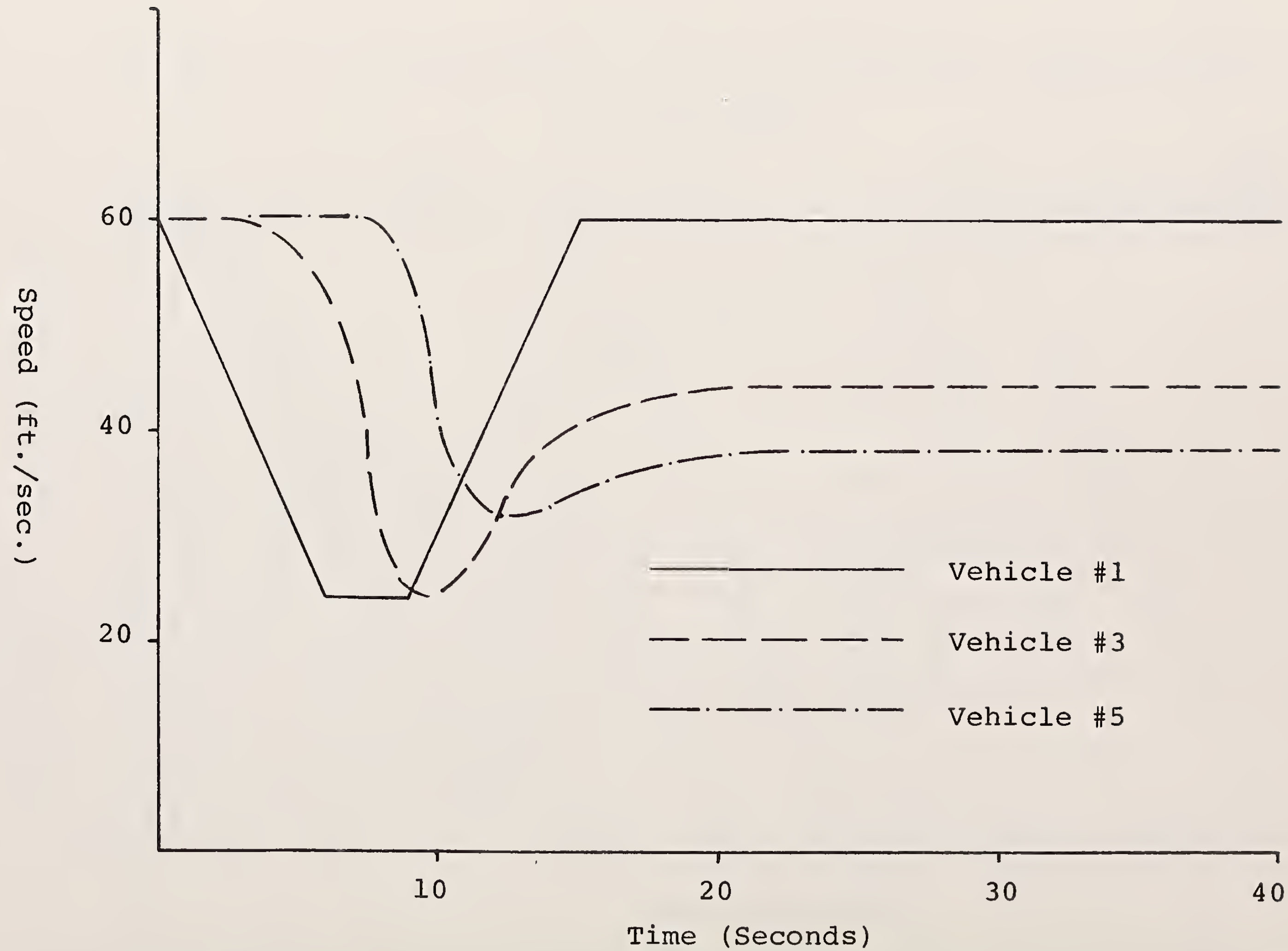


Figure 20: Platoon Behavior: Aerospace Algorithm-One Second Interval

traveling at 60 feet/second/second, with either a one-second or three-second scanning interval. The velocity of the leader was varied by applying an acceleration of -6 feet/second/second for 6 seconds, a zero acceleration for 3 seconds and an acceleration of 6 feet/second/second for 6 seconds. The figures illustrate the velocity response of the third and fifth vehicles in the platoon.

Figures 16 and 17 show the PITT model at one-second and three-second scanning intervals, respectively. The results are excellent with the following vehicles demonstrating good oscillatory behavior, while remaining fundamentally stable. The behavior at the longer scanning interval was reasonably consistent. Overall, under the simple operational tests, the PITT model consistently showed satisfactory behavior.

Figures 18 and 19 show the UTCS-1 model at one-second and three-second scanning intervals, respectively. The results at the one-second interval show reasonable and consistent behavior, but the speed patterns of the followers appear excessively damped without the oscillations demonstrated by the PITT model. This damped pattern would result in an unsatisfactory representation of congested flow. At the three-second interval, the model became most erratic with very atypical vehicle behavior.

Figure 20 shows the Aerospace model for a one-second scanning interval. The behavior was very damped and unsatisfactory. A major problem here is that apparently the model uses unpublished algorithms for positive accelerations and/or zero speeds. Hence, we could not get the vehicles out of the low steady state speeds that the system set itself into. For the same reasons, the three-second interval was a failure as the following vehicles merely stopped and stayed stopped. This has not been diagrammed as it is of little interest.

The Northwestern model has not been diagrammed, as it also was of little interest. The car-following behavior was even more damped than UTCS-1 at one-second intervals, and the model has not been developed for any other interval range.

In summary, these simple tests indicated that the PITT model alone shows all the desired characteristics; namely, good but not excessive oscillatory following behavior and reasonable consistency over a range of scanning intervals.

6.1.3 Final Selection

The evaluation of the four models covered the following factors.

Simplicity: All except the Northwestern model meet this criteria.

Internal Consistency: The Aerospace algorithm as given, applies only to a restricted range of relative speeds. The information as to how it handles the more extensive conditions is not published. In the UTCS model, basic vehicle behavior is not internally generated, since the algorithm is basically an anti-collision rule rather than a true car-following rule. The other models are good.

Applicability: The Aerospace model is least satisfactory as it was designed for a totally different simulation approach. All the others are good.

Variable Time Scans: Only the PITT model is specifically designed for this, while the others need reworking. The analytical car-following of the Aerospace model will be the first to break down as the scanning periods are increased. The UTCS-1 model also becomes erratic at longer intervals.

Driver and Vehicle Characteristics: Only the PITT and Aerospace models handle this in a generalized manner.

Capacity Reductions at Bottlenecks: Only the PITT model is specifically designed to achieve this which it does simply and efficiently. This functional requirement is a most important feature of SIFT.

Operations at the Limits: The Aerospace model requires overrides at low speeds and large headways. The Northwestern model is unsatisfactory at high volumes.

Operational Testing: The PITT model was most satisfactory while the Aerospace or Northwestern models were the least satisfactory.

Table 44 summarizes the selection process.

Under each criteria, the models have been ranked according to the test results and the qualitative analyses.

Summary

The PITT model was selected as it appears to be equal or superior to the others in all categories. The main alternative is the UTCS model but most of the key characteristics of this model have been included in the PITT model with an expanded region of application and greater mathematical rigor.

6.2 Lane Changing Development

Careful attention was given to the lane changing component, since it is an essential requirement that the model satisfactorily perform lane changing and merging at high volumes. It is also essential that the lane changing component be fully integrated with the car-following component. To meet these requirements, an algorithm has been developed beyond the fundamental approaches used by other simulations although the method has many similarities to that used by the Midwest Research Institute Simulation (Ref.18). In the usual approach, as shown in Figure 21, a vehicle wishing to change to another lane, Vehicle 3, looks at the gap available in that lane and carries out the following checks:

1) Does the lead headway to the gap leader, Vehicle 1, satisfy the car-following rules?

2) Does the lag headway to the gap follower, Vehicle 4, satisfy the car-following rules?

If the answer to both is yes, then the vehicle can move to the new lane.

Table 44: Ranking of Car-Following Algorithms

Criteria	Algorithm			
	Aerospace	Northwestern	PITT	UTCS-1
Simplicity	2	4	2	1
Consistency	3	2	1	4
Applicability	4	1	1	1
Variable Scans	4	3	1	2
Driver and Vehicles	2	4	1	3
Bottlenecks	3	3	1	2
Limiting Operations	3	3	1	1
Operational Testing	3	4	1	2
Summary	3	4	1	2

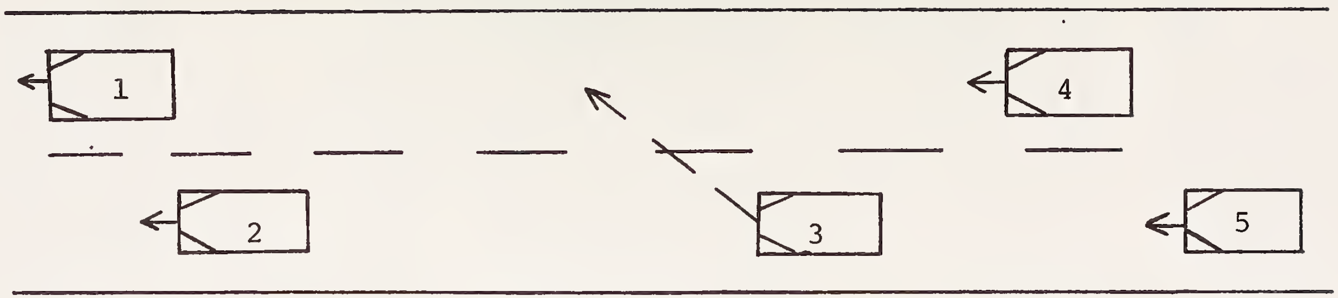


Figure 21: The Lane Changing Vehicles

With the INTRAS prototype lane changing process, these basic checks remain, but the lane change takes place over a finite period of time; i.e., the time usually taken for a vehicle to physically change lanes. This time is an input variable to the simulation. Worrall and Bullen (Ref. 19) have shown that the time to change lanes is somewhat a function of vehicle speed. This relationship, however, is not a strong one, and a constant changing time is a reasonable assumption as the variation is very small compared to the normal scanning interval.

While the lane change is actually in progress, the changing vehicle is represented in the simulation as occupying the target lane. The original follower (vehicle 5 in Figure 21) is flagged to identify it for the duration of the lane-change maneuver. The model logic can then retard acceleration of the flagged follower to fill the "vacuum" caused by the lane-change.

The generation of the decision to lane change has some important modifications. Firstly, in determining a safe headway, the changing vehicle must satisfy only the non-collision constraint equations for the gap in the new lane, rather than the car-following equations. This allows finer tolerances and expedites lane changing in heavy flow conditions. It is considered that these finer tolerances are, in fact, present in the actual lane changing process. Secondly, the changing vehicle need only occupy this "safe" position at the end of the lane change; i.e. a temporary unsafe position is allowed during the finite period of the lane change. This enables the representation of forced lane changing, with a vehicle crowding into what might normally be considered an unavailable gap.

The lane changing logic for the prototype model, therefore, consists of the following:

1) Check if the vehicle must change lanes and flag with a lane change desire. This will occur if the vehicle is exiting the freeway or if it is entering the freeway from an acceleration lane.

2) Check if the vehicle might want to change lanes even though it is not essential. This might occur

if the vehicle is below its desired speed and wishes to change lanes so that it can pass a slower vehicle. The desire to do this is generated randomly according to a binomal probability. This is known as the probability of lane change (PLC) and its calibration is described later in this report. The PLC generation is applied at user specified frequency (default is every second time-step) to all vehicles traveling below their desired speed. The desire to change lanes might also occur if the vehicle is at its desired speed but is seeking to regain its desired lane. Again, the PLC generation is applied.

3) To prevent oscillatory lane changing, a few additional constraints limit the non-essential lane change desire. A vehicle will not change if it is accelerating at a rate greater than one foot per second. Also, it will not change if the potential new leading vehicle in the new lane has a speed lower than that of the current leader, and at the same time the potential lead headway is less than the current lead headway. Also, vehicles will tolerate lower speeds before changing to the right, and they will avoid the extreme through lane adjacent to an acceleration auxiliary.

4) Vehicles flagged for a lane change are now checked to establish whether the change is possible. The first step is to check the lead headway in the desired lane. The acceleration that the changing vehicle must undergo so that it will be safely behind the new leader at the end of the lane change time is predicted. Two classes of change are dealt with, free changes and forced changes. For a free change, this acceleration must be positive or zero, i.e., the changing vehicle can change lanes without lowering its speed. For a forced change, which will occur if the changing vehicle is making an essential lane change, then some decelerations are accpetable and a forced change may be instituted. If the lower limit of acceptable deceleration, however, is less than

the minimum normal acceleration (maximum deceleration) for the vehicle, then no change can be implemented.

5) If the lead check is successful then a check of the lag headway is made. The acceleration that the following vehicle must undergo so that the changing vehicle can safely pull over ahead, is predicted. If this acceleration is greater than zero, then a free lane change can be started.

In the case of a forced change, the following vehicle may decelerate to allow the changer into the gap. A random proportion of followers, "the courtesy factor," are assumed to have this characteristic. For a non-courteous driver, a forced change cannot be implemented. For the courteous driver, the forced change can take place only if the calculated decleration is less than the vehicle's normal maximum deceleration (minimum acceleration).

The lane changing process described above is flexible and efficient. It is particularly suitable for simulating merging and weaving under very congested traffic conditions.

6.3 Vehicle Generation

Vehicle generation takes place on an entry link which feeds the first link of the freeway. The vehicle characteristics are randomly generated, i.e., driver type, vehicle type, desired lane, and desired speed. Once these have been established, the key variables that must be determined are the actual speed and position of the vehicle.

Initially, the vehicle is given an actual speed which is the lowest of its desired speed or the actual speed of the next vehicle ahead. This simple rule substitutes for the more accurate value which is very difficult to obtain since speed is an independent variable in the car-following equations. Next, the time of arrival at the upstream end of the first freeway link is predicted for the leader vehicle. The prediction method is structured so as to be biased towards early arrivals. The new vehicle is placed so as to arrive at this boundary at the proper interval (dictated by the specified demand volume) after the leader's predicted arrival.

If the early predicted arrival bias results in an excess of vehicles being generated, then further vehicle generation is inhibited until a balance is achieved.

The headway is checked through the car-following equations and, if too short, is adjusted upward to the minimum safe following position. The speed and position of the new vehicle are thus determined.

Vehicles are generated such that each lane of the dummy link always has at least two vehicles in it unless an excess of vehicles has already been generated. In this way, each generated vehicle has time to respond to the car-following rules and be operating normally by the time it enters the simulated freeway. The simulation is initialized with an empty system and fill-up must be allowed.

7. COMPONENT MODEL TESTING

7.1 Calibration

7.1.1 Data Base

The data bases used for calibration consisted of general freeway capacity characteristics available in the literature including lane capacity, lane changing intensities, and ramp merging capacities; the Long Island Expressway data set; and the Ohio State vehicle trajectories. The Long Island sets have been of limited value since there is a scarcity of congested data which is the main traffic flow regime in which the calibrations are needed. Other data sets used for validation are described in Section 7.2.

7.1.2 Procedure

The primary calibration procedure has been to establish the sensitivity of the simulation outputs to the parameters that can be varied. This allowed initial parameter specification to provide an operating simulation while also allowing users the option of alternative ranges of operations if they are prepared to adjust the parameter values.

Car-Following Calibration

The Ohio State trajectories were used mainly as a validation tool, but they were also used as indicators of some general car-following characteristics. In particular, they indicated the need for the $b(u-v)^2$ term in the car-following equations to correct for anomalies when the speed of the follower is very high relative to the speed of the leader. A value of b=0.1 was calibrated from the data set. Further, at very low speeds, the data indicated an inter-vehicle spacing of 10 feet which was added to the desired headway specification. Also, from this data set, the value of the lag, c, was set at 0.3 seconds, and 0.2 seconds for negative and positive accelerations, respectively.

The sensitivity of the simulation to the k factor is shown in Figure 22. From known capacity characteristics, a mean value for the k factor to give a lane capacity of

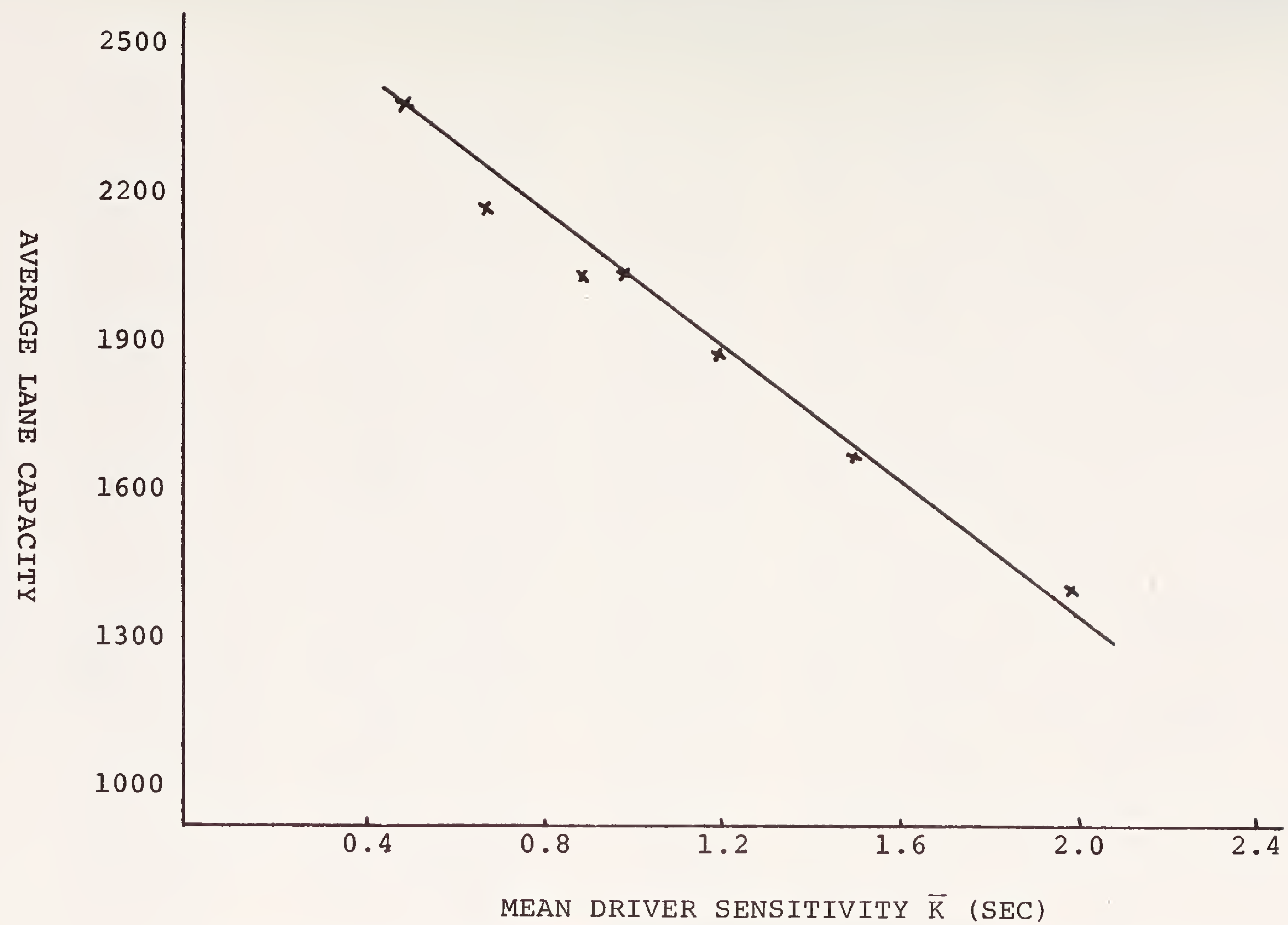


Figure 22: Driver Sensitivity ($\bar{k}$) vs. Average Lane Capacity

just over 2000 vehicles per hour was selected. This value is $\bar{k}$=0.93.

Lane Changing Calibration

The key parameters are the courtesy factor and the probability of a lane change. The freeway simulation was operated for a range of values for the "probability of lane change" (PLC). The resulting lane change intensities are shown in Figures 23, 24 and 25 and in Table 45 for two-, three- and four-lane roadways. These were then compared to the empirical results from the Northwestern University lane changing report and an appropriate probability of lane change of 0.05 assigned. The choice of a PLC of 0.05 agrees closely with the data for two- and four-lane roadways. For the three-lane case, however, the indicated value is 0.10. It should be noted that this calibration is dealing with through traffic only, and in the Northwestern three-lane case, the Stevenson Expressway in Chicago, ramp influenced lane changes probably account for the higher frequencies observed. Both the two-lane case (the Tri-State Toll Road) and the four-lane case (the Dan Ryan express lanes) are relatively free of ramp effects.

The courtesy factor was calibrated by checking the capacity performance of a single-lane entrance ramp merging with a two-lane freeway. The ramp capacity was compared with freeway capacity and Figure 26 shows the result.

As the courtesy factor increases from zero, the freeway lane capacity drops rapidly at first but soon levels out. Similarly, ramp capacity increases initially, but it too then levels out. A courtesy factor of 5 per cent was chosen as the approximate point where ramp capacity slightly exceeded the capacity of the shoulder lane of the freeway.

Vehicle Generation Calibration

Vehicles are generated using a negative exponential gap distribution. Lane volume is determined by the mean gap length which is a variable input. The program was run for varying values of mean gap length and the output

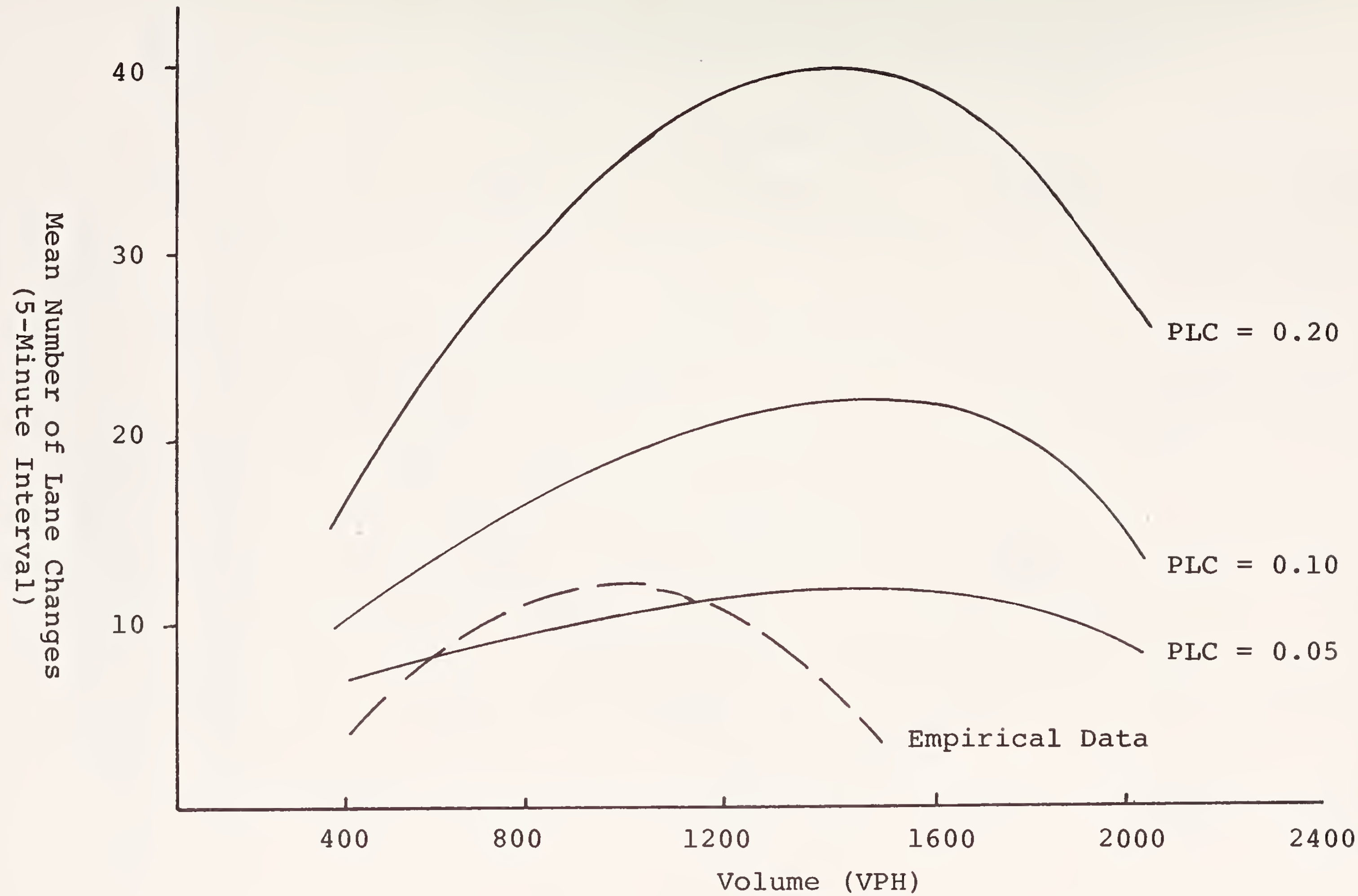


Figure 23: Intensity of Lane Changing as a Function of Volume for Two Lanes

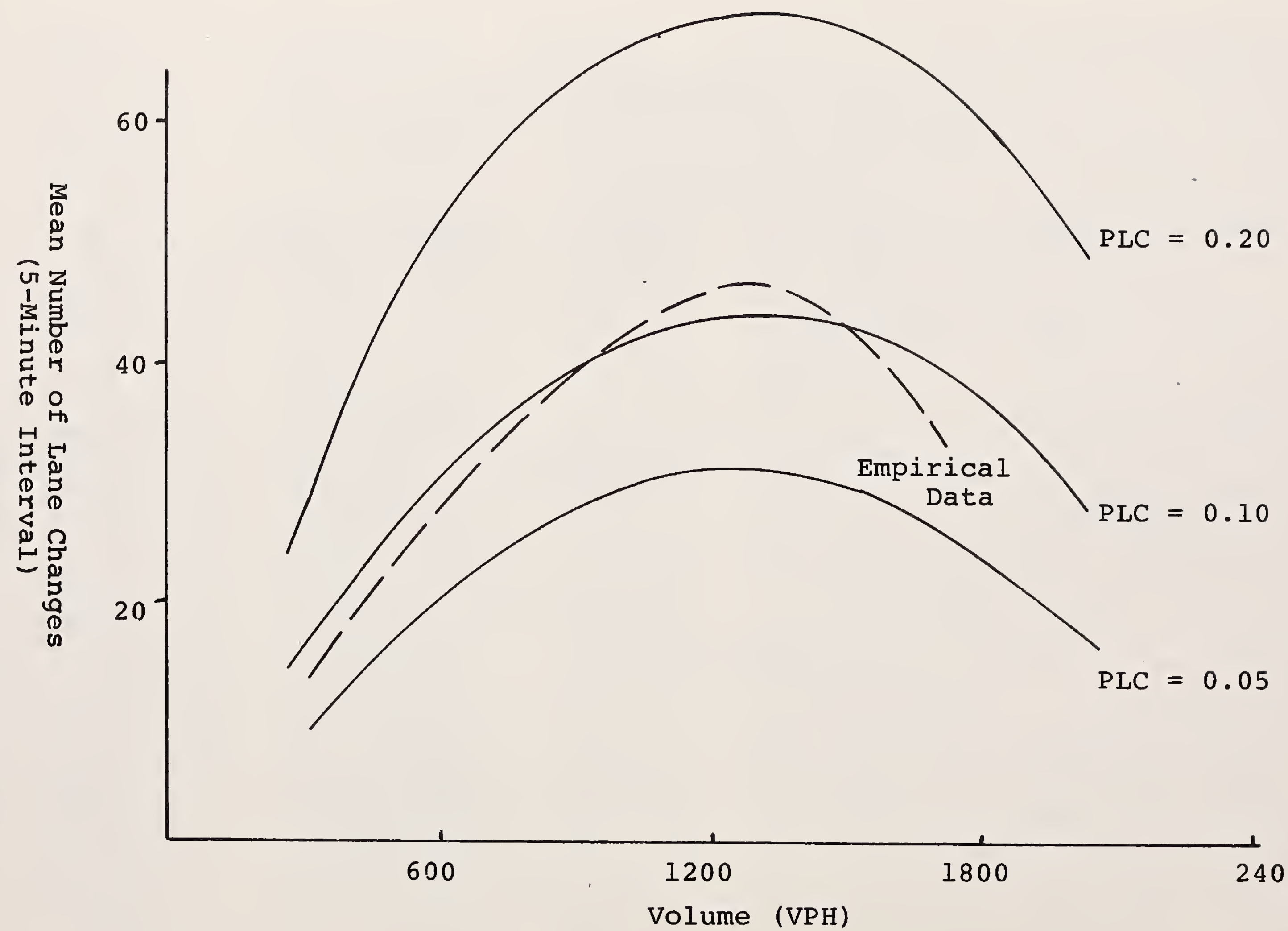


Figure 24: Intensity of Lane Changing
as a Function of Volume for Three Lanes

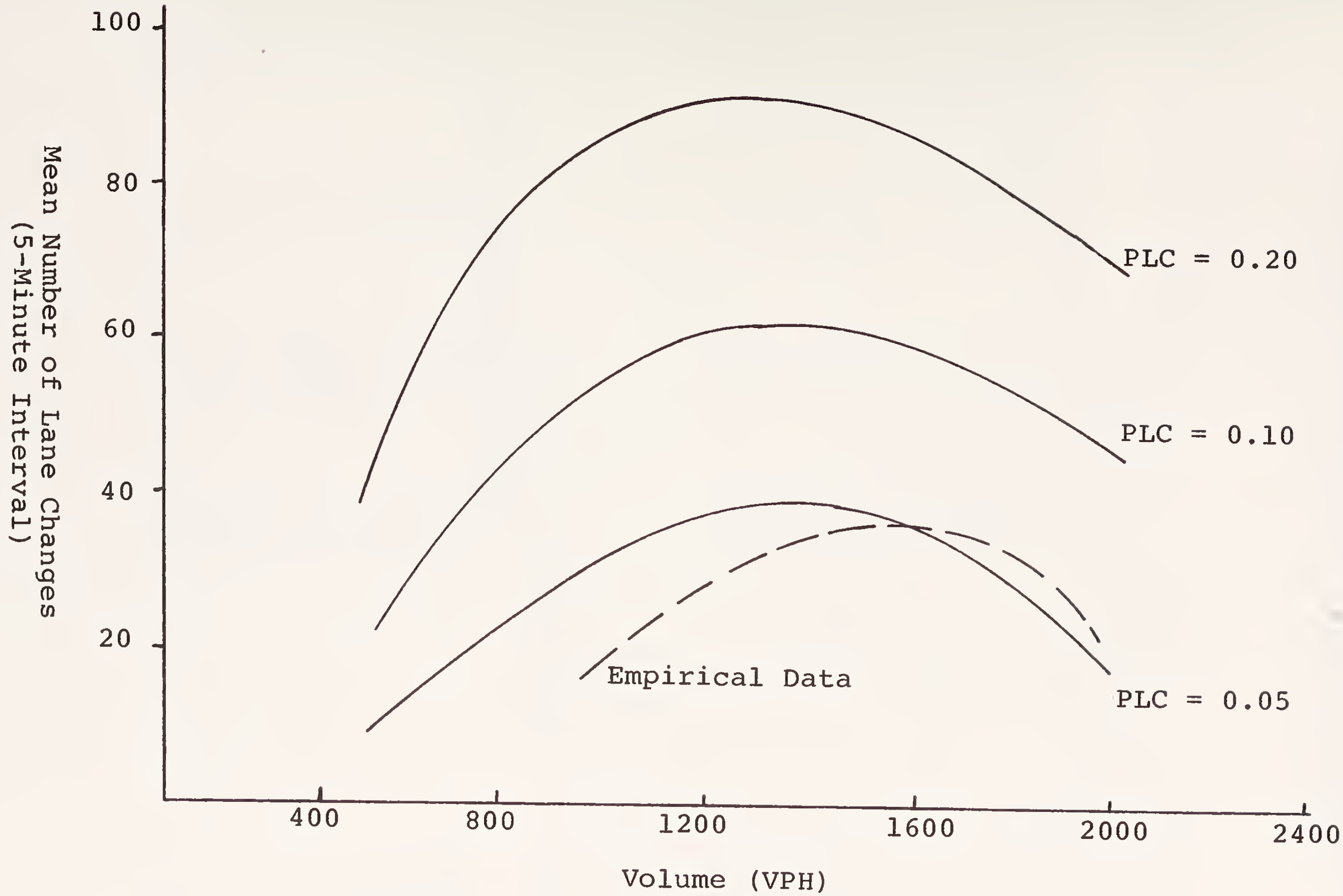


Figure 25: Intensity of Lane Changing as a Function of Volume for Four Lanes

Table 45: Mean Frequency of Lane Changing vs Probability of Lane Change and Volume

4 Lanes Section

Mean Number of Lane Changes in 5 Minutes

	Probability of Lane Change			
Volume	0.02	0.05	0.10	0.20
500	9.8	16.4	28.0	45.6
1000	17.6	32.6	51.0	83.0
1250	21.6	41.0	67.4	94.6
1500	19.8	43.6	66.4	93.6
1750	22.2	34.4	59.2	92.4
2000	12.0	32.8	50.6	73.4

3 Lanes Section

Mean Number of Lane Changes in 5 Minutes

	Probability of Lane Change			
Volume	0.02	0.05	0.10	0.20
500	6.2	13.0	19.6	26.8
1000	12.2	28.0	39.0	53.8
1250	9.8	29.2	37.4	66.0
1500	15.2	30.0	43.2	60.0
1750	13.6	26.0	39.8	58.8
2000	9.8	22.2	20.6	48.6

Table 45: Mean Frequency of Lane Changing vs Probability of Lane Change and Volume (continued)

2 Lanes Section

Mean Number of Lane Changes in 5 Minutes

	Probability of Lane Change			
Volume	0.02	0.05	0.10	0.20
500	4.0	9.6	13.6	17.2
1000	8.0	10.4	19.8	27.2
1250	7.4	13.6	22.6	36.6
1500	10.4	15.0	22.2	40.4
1750	9.4	14.2	23.4	34.2
2000	5.0	12.8	15.4	29.0

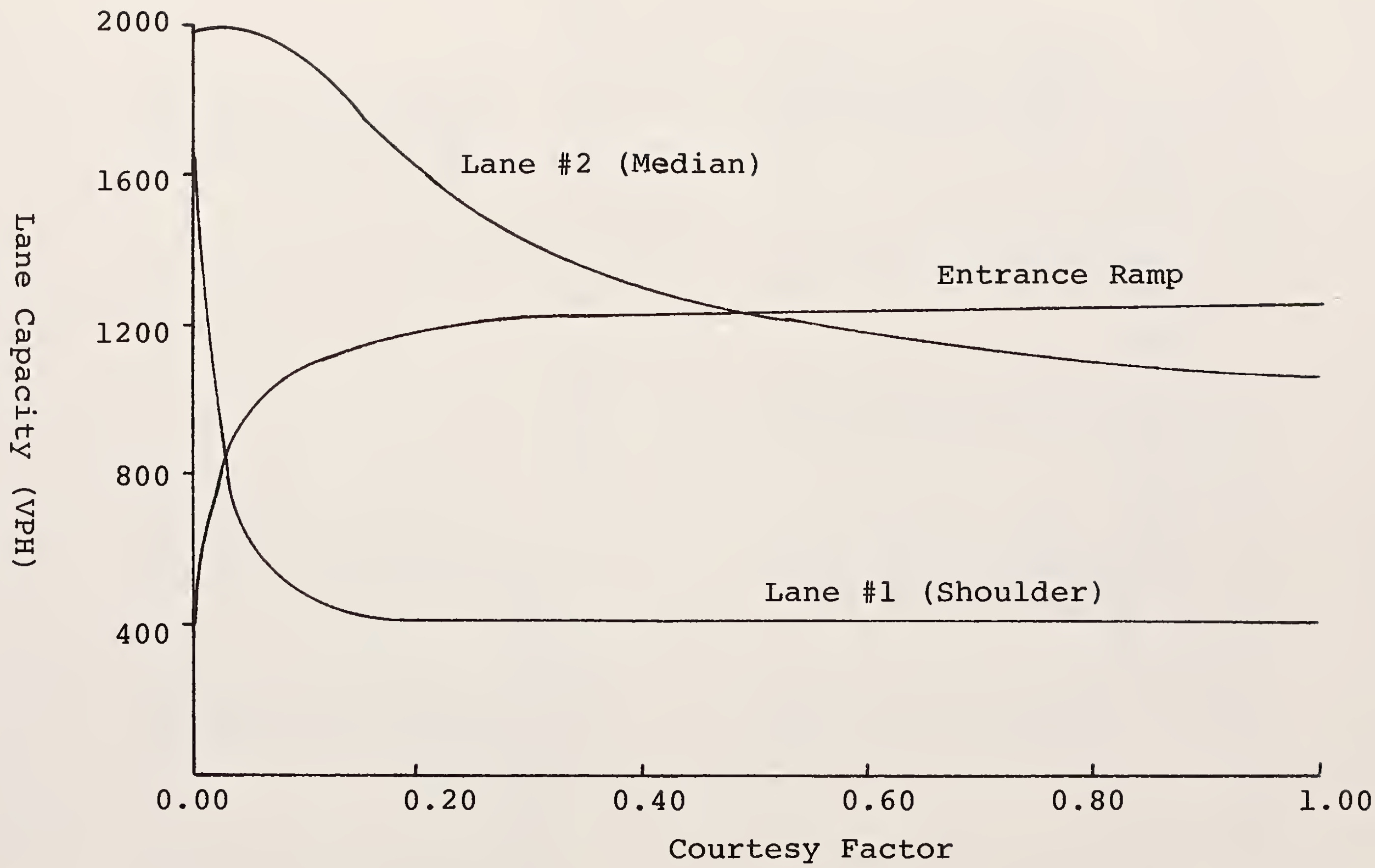


Figure 26: Courtesy Factor Calibration
Capacity Measured at Ramp Nose

volumes recorded. Figure 27 shows the relationship between mean gap length and actual generated traffic flow, and this is the relationship currently used in calculating volume inputs.

7.2 Validation

7.2.1 Data Base

Data bases that were used for validation of the simulation include the Ohio State trajectory data, the Long Island Expressway data, the PINY weaving data from the Long Island Expressway, and some of the Los Angeles closely spaced data set (30 minutes of data for three sets of detectors at about 600 feet spacings). Also, as part of the validation process, the general model outputs have been studied for consistency, and reproduction of known traffic characteristics. The major validation was with the PINY weaving data set. Good data was available for the two locations for which the geometry is shown in Figure 28. For each experiment, there were 25 minutes of suitable traffic data.

7.2.2 Procedure

General Characteristics

The simulation has been run under varying conditions to test overall relationships. Figures 29, 30 and 31 show macroscopic relationships between speed, flow and density in Lane 2 of a three-lane roadway. The generally known empirical relationships are satisfactorily reproduced. Figure 32 shows the capacity of the three-lane roadway as the percentage of trucks is varied, while Figure 33 shows the capacity of Lane 1 varying with the percentage of trucks in that lane. In both cases, the decline in capacity with increasing truck percentages is replicated. Figure 34 shows the capacity of an entrance ramp as a function of the length of the acceleration lane. The increase in capacity with increasing acceleration lane length is well replicated and indicates that the simulation is operating in a satisfactory manner for its high volume merges.

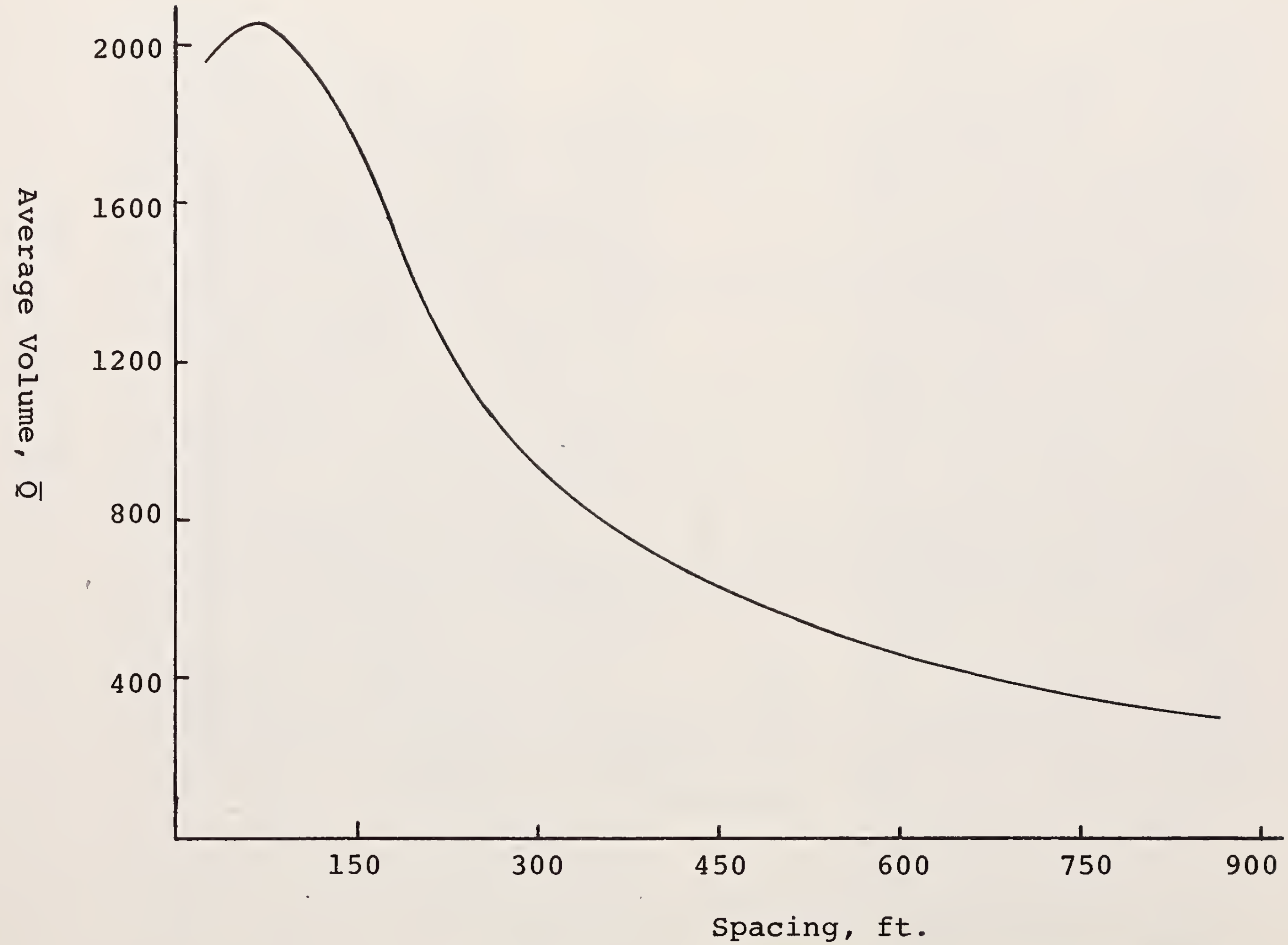
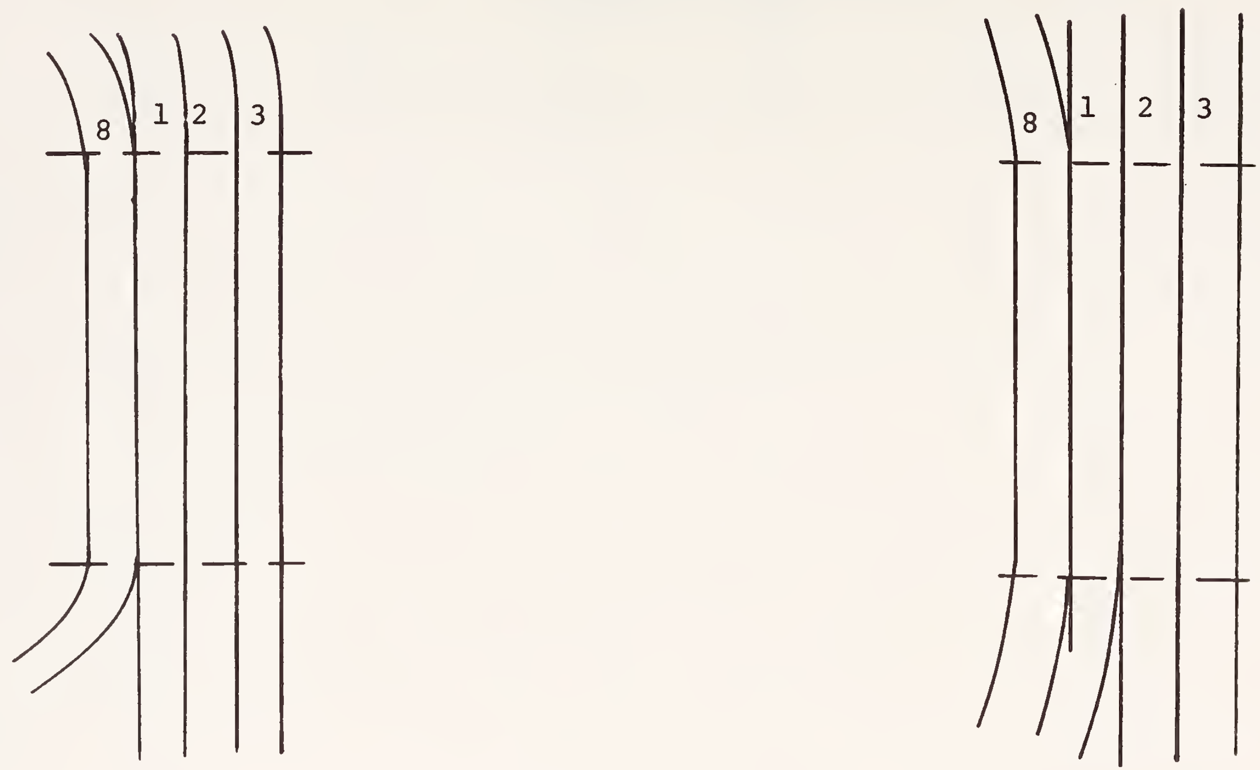


Figure 27: Input Mean Spacing vs Output Flow

Experiment 2: Southern State
Pkwy at Meadowbrook Pkwy (LINY)

Experiment 6: Cross Brony
over Alexander Hamilton Bridge
(NYC)



Fiaure 28: Lane Configuration for PINY
Experiments 2 & 6

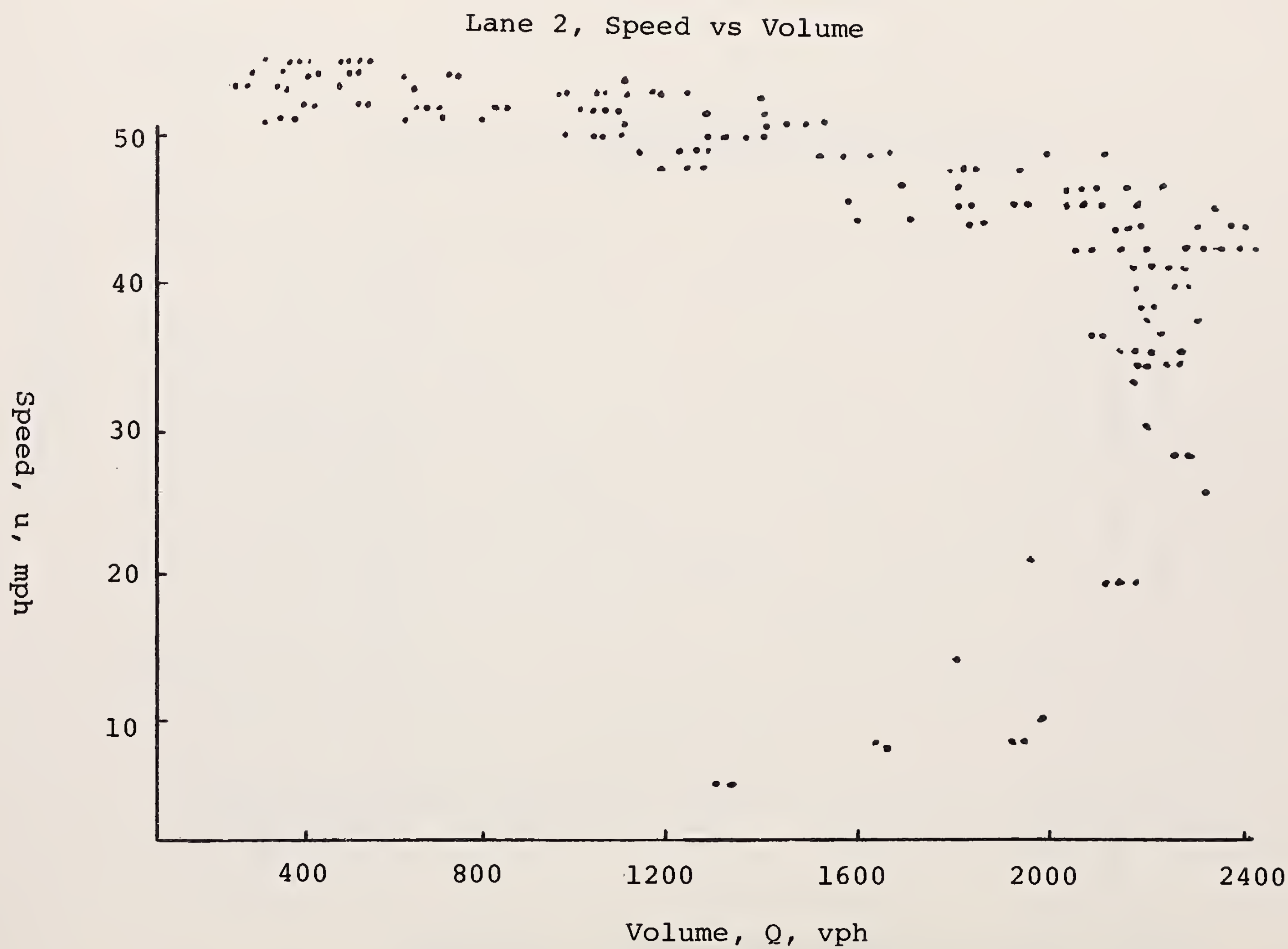


Figure 29: Speed-Volume Relationships

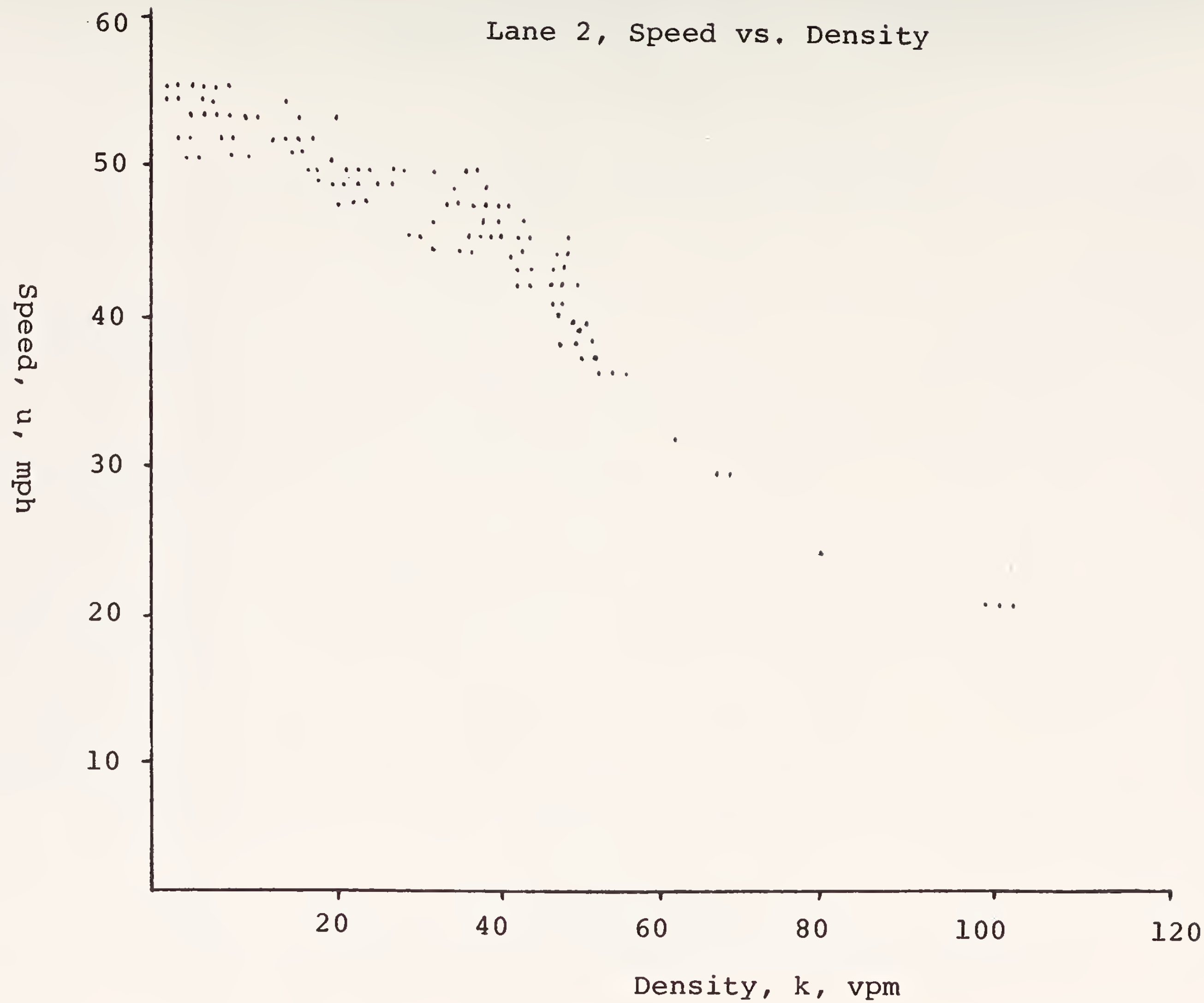


Figure 30: Speed-Density Relationships

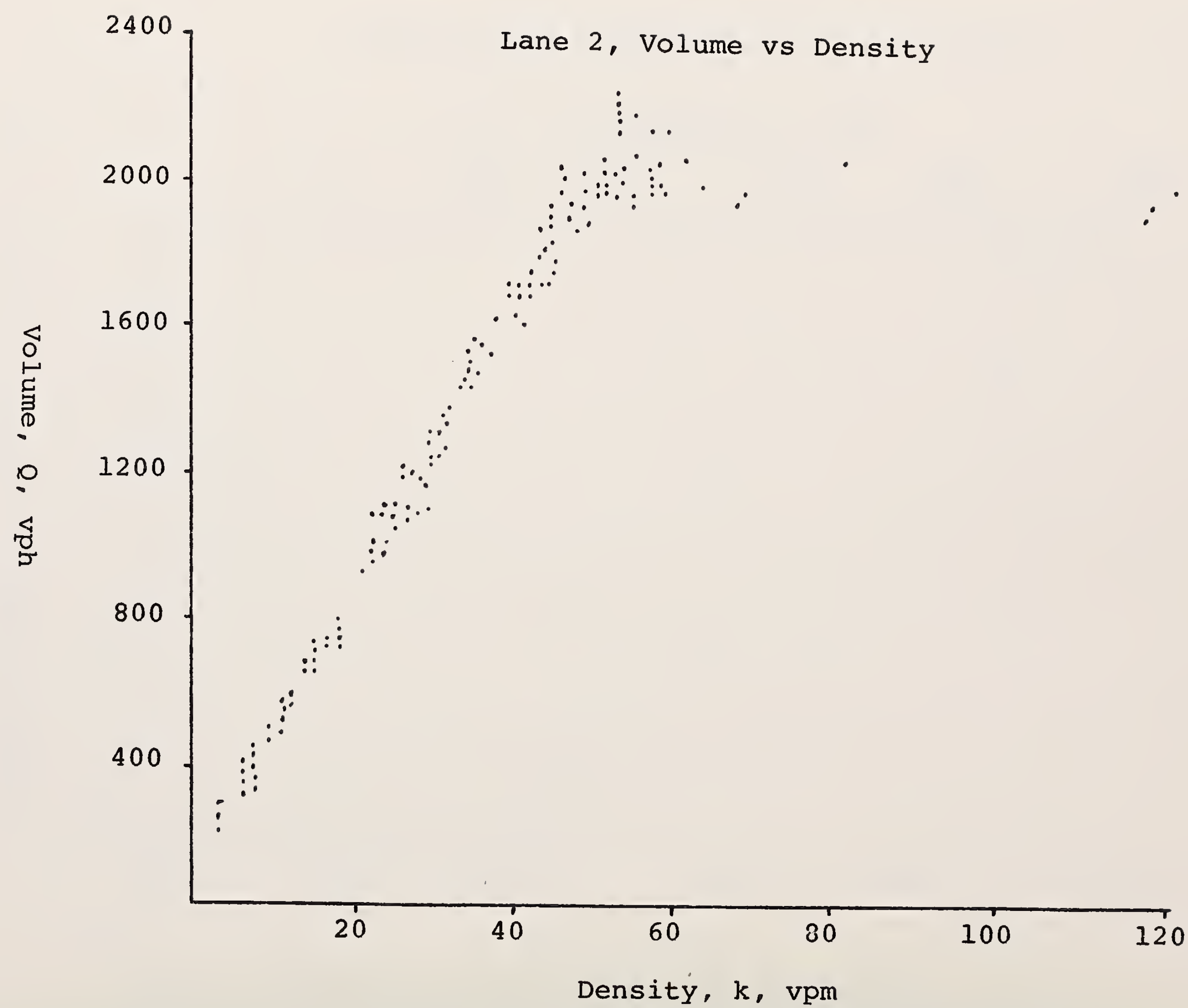


Figure 31: Volume-Density Relationships

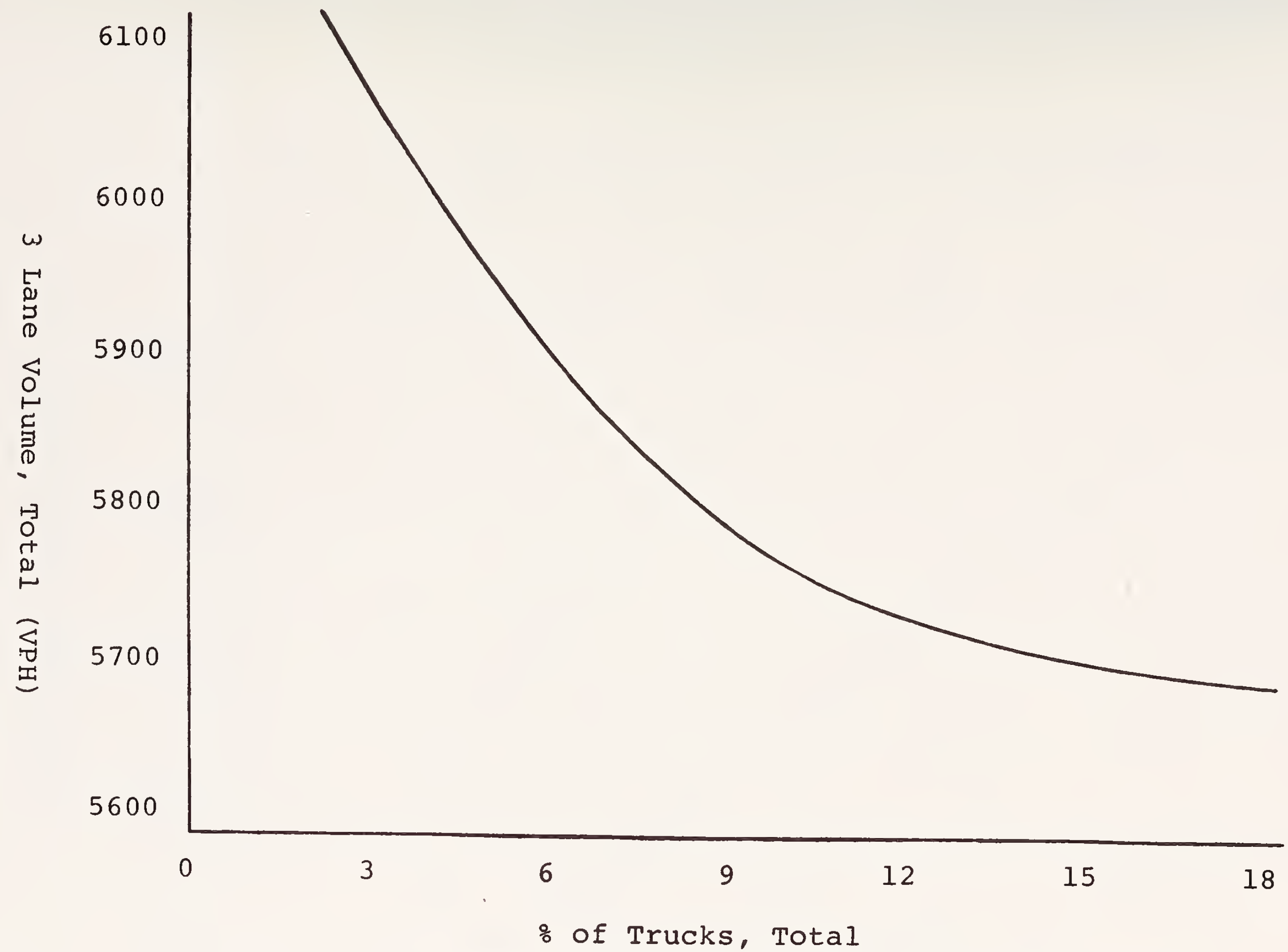


Figure 32: Freeway Volume vs Percent Trucks on Freeway

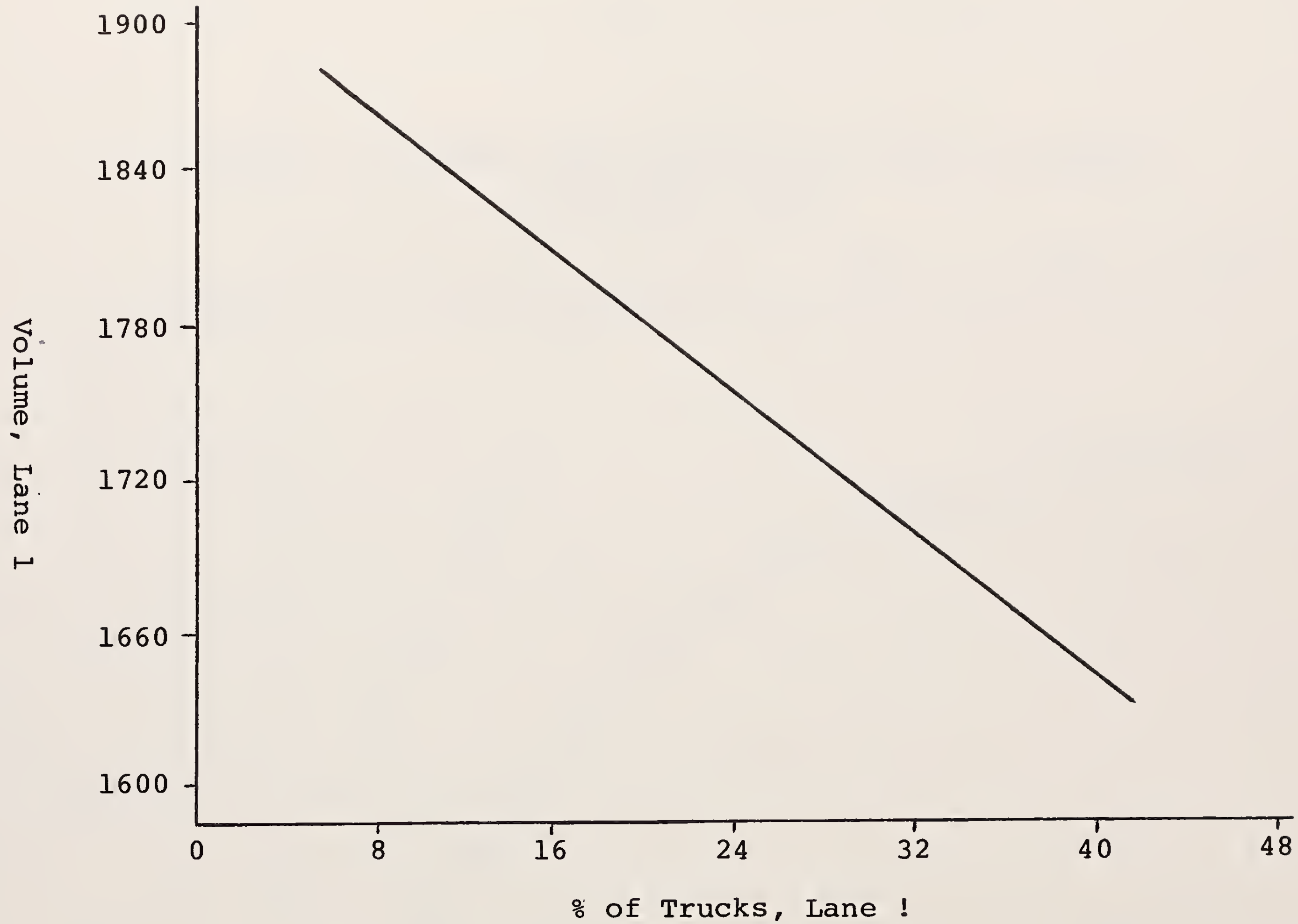


Figure 33: Lane Volume vs Percent Trucks on Freeway Lane 1

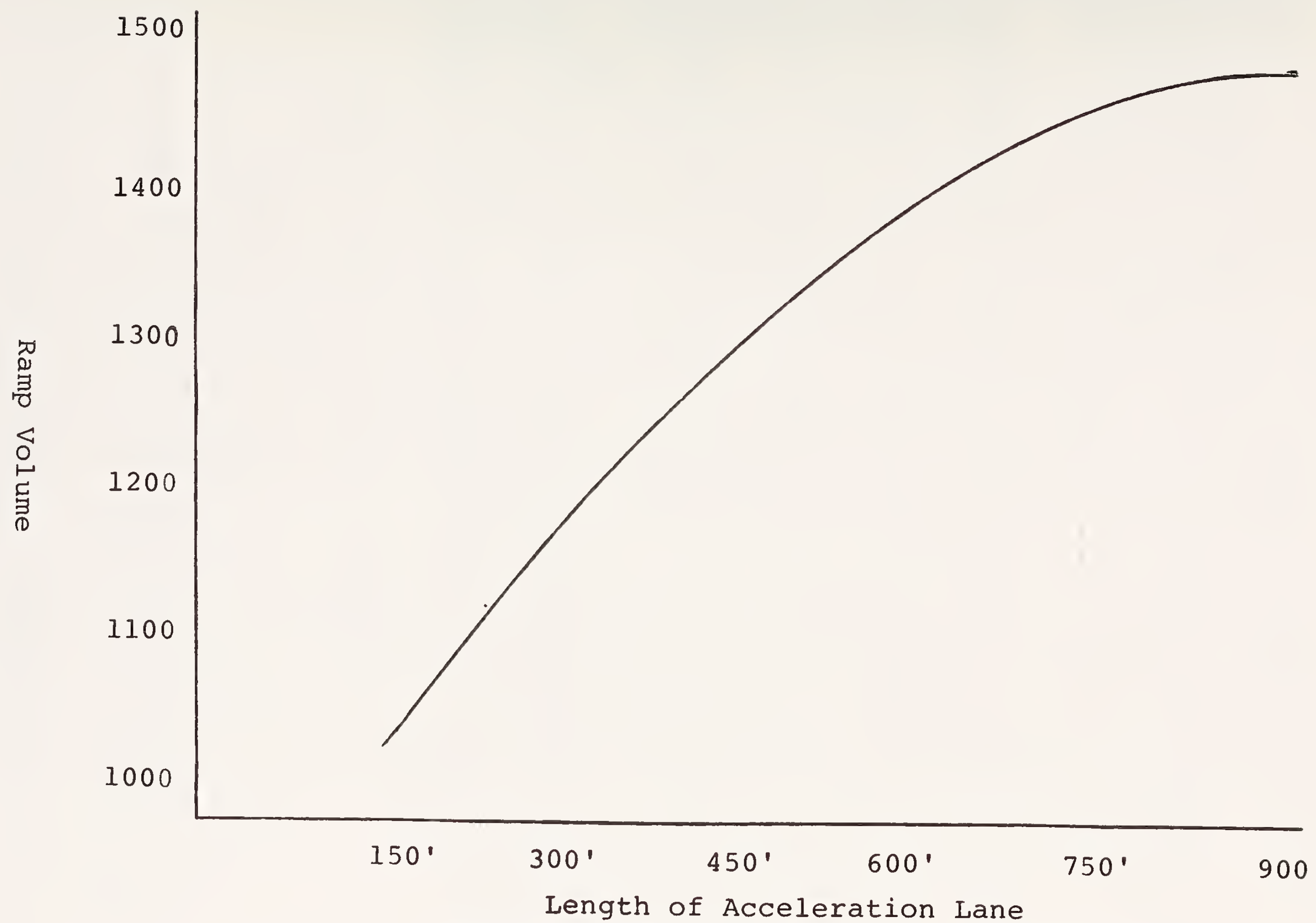


Figure 34: Ramp Capacity as a Function of Acceleration Lane Length

These results are not intended to quantify the specific empirical relationships, but rather to validate the overall structure of the simulation by showing the known trends and relationships are present.

Weaving Sections

The simulation was run for the 25-minute period using the input lane flows and speeds from each of the two PINY empirical experiments. The outputs of the simulation were then checked against the field data. Generally, the performance of the simulation model was excellent. Volumes and total lane changes were reproduced with great accuracy while speeds and lane change positioning, although not exactly reproduced, were structurally as good as could be expected. Two particular characteristics were checked as significant indicators that the simulation is able to replicate given freeway weaving behavior. The first was the intensity and structure of the lane changing between individual lanes. It was essential, of course, that the numbers of lane changes be in good agreement with the empirical base, and this was obtained. In addition, the lane changes were distributed longitudinally through the weaving section in a reasonable approximation to the field results. Perfect statistical agreement was not an objective since this would depend on local geometric and behavioral characteristics not specified in the data base. The second and most important weaving feature looked for was that the speed of the traffic stream be maintained through the weaving section at the given lane volumes and lane changing intensities. Any significant failing of the simulation would probably be first noticed in the forced lane changing process with consequent speed breakdown in high volume weaves. The fact that the simulation did compare reasonably well with the data for the <u>output</u> lane speeds (the input speeds being more closely controlled), was the major validation factor in this phase of the study. Exact statistical agreement was again not expected since the precise speed patterns depend on factors such as vehicle type and desired speed which were not available in the base data set.

The ability of the simulation to replicate these complicated, high volume weaving sections is significant, for it is this area of freeway performance that a simulation has most difficulty accommodating. The results exceeded our expectations, and indicate the power and flexibility of the new simulation program.

Each data set (Experiments 2 and 6 for the locations shown in Figure 28) was run for the 25-minute period. Input lane volumes and speeds were constrained to the data by the choice of generation parameter inputs, and then output lane volumes and speeds were compared between the simulation and the empirical results. The results are summarized in Tables 46 and 47 and they indicate that very good agreement was reached.

To test the overall agreement of the empirical and simulated lane specific values of the various traffic characteristics, a correlation analysis was performed. If the agreements were exact, then a correlation coefficient of +1.00 would be obtained. Table 48 shows the summary. Excellent agreement was obtained for all comparisons. As explained earlier, exact statistical fits were not appropriate since many key driver and vehicle parameters were not known. The correlation coefficients of .74 and .68 for speed outputs, for example, are considered to be excellent in the light of the potential for variation of this particular characteristic.

For Experiment 2, a series of runs statistically checked the operation of the simulation against the empirical base data using the standard t-test. These characteristics were tested statistically since the parameters were closely associated with the simulation's vehicle generation process.

Three separate tests were conducted:

(1) Lane inputs,
(2) Speed inputs,
(3) Lane change totals.

The data used for the tests were obtained from a steady input model of Experiment 2, where the inputs for the first 5-minute interval were used to generate ten 5-minute intervals. Thus, the sample consisted of ten generated values and the t-test determined whether the mean of these values was significantly different from the empirical data.

Table 46: Comparison of Simulation Outputs and Field Data for Experiment 6

	Volume Inputs (5 minute counts)		Volume Outputs (5 minute counts)		Speed Inputs (Miles per hour)		Speed Outputs (Miles per hour)	
	Sim.	Data	Sim.	Data	Sim.	Data	Sim.	Data
1st 5-min. interval								
Lane 1	75	74	74	77	37	38	28	32
Lane 2	55	68	59	70	42	45	37	44
Lane 3	107	125	55	87	30	30	36	34
Ramp 8	44	52	69	79	31	37	29	36
2nd 5-min. interval								
Lane 1	75	79	95	84	35	33	27	29
Lane 2	106	99	95	95	43	37	38	36
Lane 3	119	121	58	85	30	26	33	29
Ramp 8	42	61	80	85	31	28	27	29
3rd 5-min. interval								
Lane 1	82	82	83	88	40	40	30	32
Lane 2	51	53	62	61	44	46	38	37
Lane 3	106	115	67	83	30	28	36	31
Ramp 8	39	51	80	88	33	35	25	34
4th 5-min. interval								
Lane 1	73	85	61	50	35	40	33	36
Lane 2	11	0*	20	10	43	0*	38	40
Lane 3	93	102	73	69	29	31	38	33
Ramp 8	33	45	65	76	31	39	29	37
5th 5-min. interval								
Lane 1	93	90	87	86	37	23	27	31
Lane 2	1	0*	14	12	19	0*	34	35
Lane 3	110	106	63	64	30	27	36	30
Ramp 8	44	60	45	86	31	33	28	31

*Empirical Data Shows a Zero Value

Table 47: Comparison of Simulation Outputs and Field Data for Experiment 6

	Volume Inputs (5 minute counts)		Volume Outputs (5 minute counts)		Speed Inputs (Miles per hour)		Speed Outputs (Miles per hour)	
	Sim.	Data	Sim.	Data	Sim.	Data	Sim.	Data
1st 5-min. interval								
Lane 1	114	144	64	78	44	45	41	44
Lane 2	151	161	123	142	47	48	47	47
Lane 3	165	179	153	178	41	51	44	51
Ramp 8	18	18	77	98	40	35	35	45
2nd 5-min. interval								
Lane 1	183	174	105	115	38	42	37	41
Lane 2	179	163	155	152	43	44	42	43
Lane 3	171	170	171	169	47	43	48	43
Ramp 8	20	30	97	104	41	36	33	42
3rd 5-min. interval								
Lane 1	185	171	89	87	41	41	27	39
Lane 2	162	157	135	142	47	43	44	43
Lane 3	12	10	50	27	52	46	50	46
Ramp 8	26	20	136	108	41	30	20	42
4th 5-min. interval								
Lane 1	157	171	64	79	42	40	32	37
Lane 2	144	157	112	134	47	40	45	40
Lane 3	1	0	23	4	61	0*	50	39
Ramp 8	14	16	134	125	40	33	30	42
5th 5-min. interval								
Lane 1	165	175	57	99	41	40	23	0*
Lane 2	177	152	130	131	46	40	40	3*
Lane 3	0	0	38	10	0	0	43	0*
Ramp 8	26	27	84	110	38	33	13	35

*Empirical Data Shows a Zero Value

Table 48: Correlation Analysis of PINY Data and Simulation Outputs

PINY Experiment 2

Lane Inputs	r	=	.99
Lane Outputs	r	=	.96
Lane Changes	r	=	.98
Speed Inputs	r	=	.71
Speed Outputs	r	=	.74

PINY Experiment 6

Lane Inputs	r	=	.99
Lane Outputs	r	=	.94
Lane Changes	r	=	.98
Speed Inputs	r	=	.81
Speed Outputs	r	=	.68

Table 49 summarizes the results and shows that good agreement was obtained.

Finally, Figures 35 to 38 illustrate the weaving intensities longitudinally through the sections. Each base data set gave lane changes by quadrant and accordingly these were checked against simulation outputs. The cumulative numbers of lane changes by quadrant are compared and good results are obtained. The exact position of the lane changes will depend on local geometrics, signing, and traffic characteristics which cannot be introduced into the simulation. As a consequence, exact replication was not expected. The general performance of the simulation exceeded expectations.

Headway Distributions

Figure 39 shows headway distributions recorded in the simulation for free flow and congested flow. The simulation was run initially at free flow at about 1650 vehicles per hour per lane. The free flow headway distributions were recorded. Then, a bottleneck was introduced, and congestion set in with traffic flow now about 1500 vehicles per hour per lane. The congested headway distribution was recorded. The two distributions show clearly the characteristic differences with the congested distribution more normal in shape and shifted to the right.

Figure 40 shows headway distributions for medium traffic flow reproduced by the simulation and compared to field data derived from the Long Island Expressway data set.

The simulation gave a good representation of a well behaved headway distribution. The empirical data was less well behaved but reasonable agreement was obtained with a chi-squared test not significant at the 5 percent level.

As indicated earlier, the Los Angeles closely spaced data set consisted of six 5-minute counts for each of 16 detectors arranged in groups of four at 600 feet spacings. Thus, the total data set consisted of 72 5-minute counts with headways grouped by half-second interval.

Table 49: Comparison of Simulation with Given Data

Location: Experiment 2

Inputs for the first 5-minute interval were used to generate 10 5-minute intervals

Parameter	Given Value	Generated Values Mean	Generated Values Std.Dev.	Significantly Diff.
Lane 1 Input Speed	45.3	44.7	1.64	No
Lane 2 Input Speed	48.3	48.2	2.57	No
Lane 3 Input Speed	50.8	45.0	2.31	Yes
Ramp 8 Input Speed	35.4	34.8	1.48	No
Lane 1 Volume	144	146.1	11.1	No
Lane 2 Volume	161	161.0	8.19	No
Lane 3 Volume	179	183.1	8.33	No
Ramp 8 Volume	18	14.2	2.44	Yes
Lane Changes 8-1	8	9.1	3.21	No
Lane Changes 1-8	85	96.0	12.45	No
Lane Changes 2-1	19	19.2	2.70	No
Lane Changes 1-2	4	4.60	3.98	No
Lane Changes 3-2	5	5.30	2.26	No
Lane Changes 2-3	10	3.90	1.85	Yes

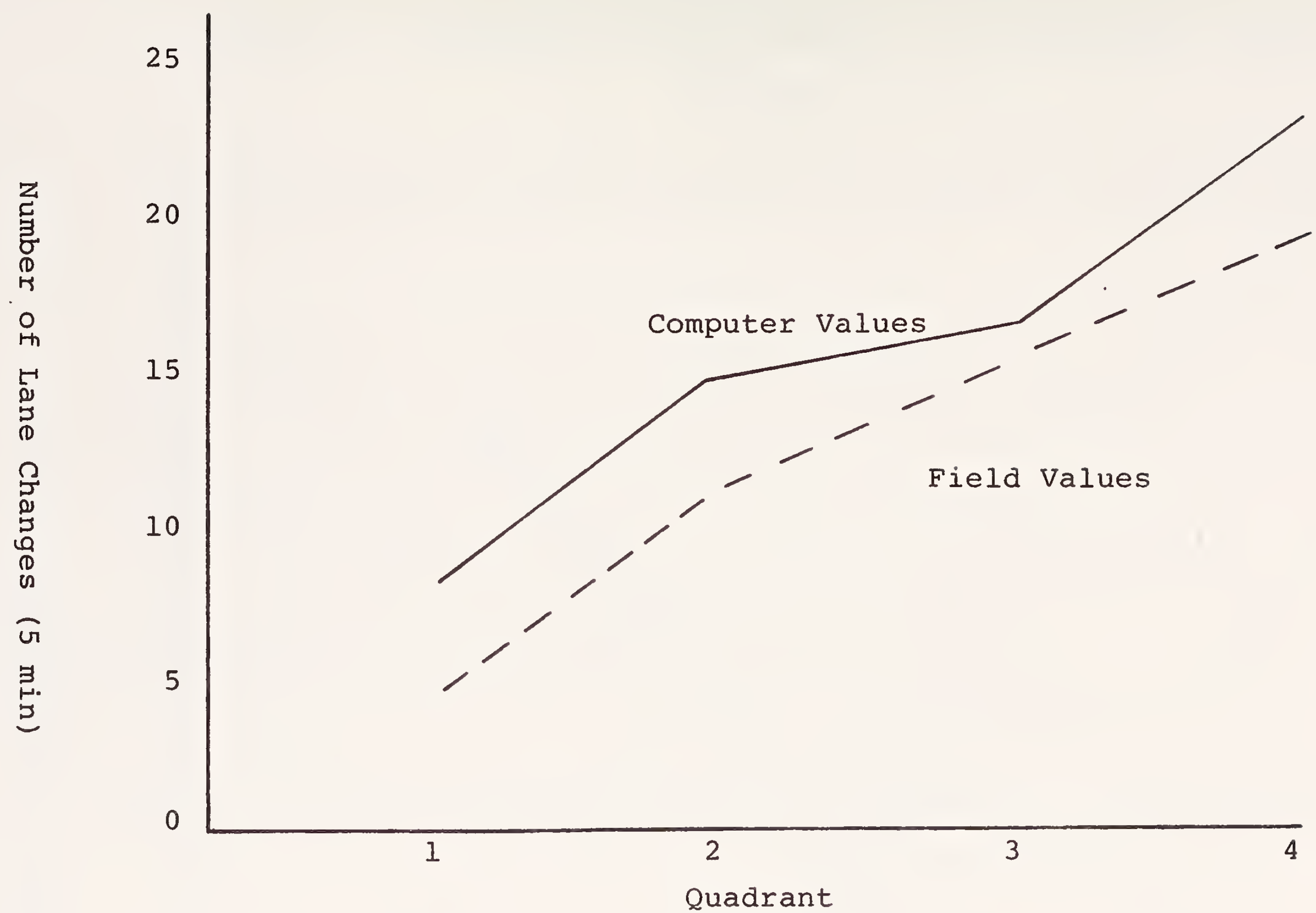


Figure 35: Comparison of Lane Changes - Lanes 2-1, Experiment 2

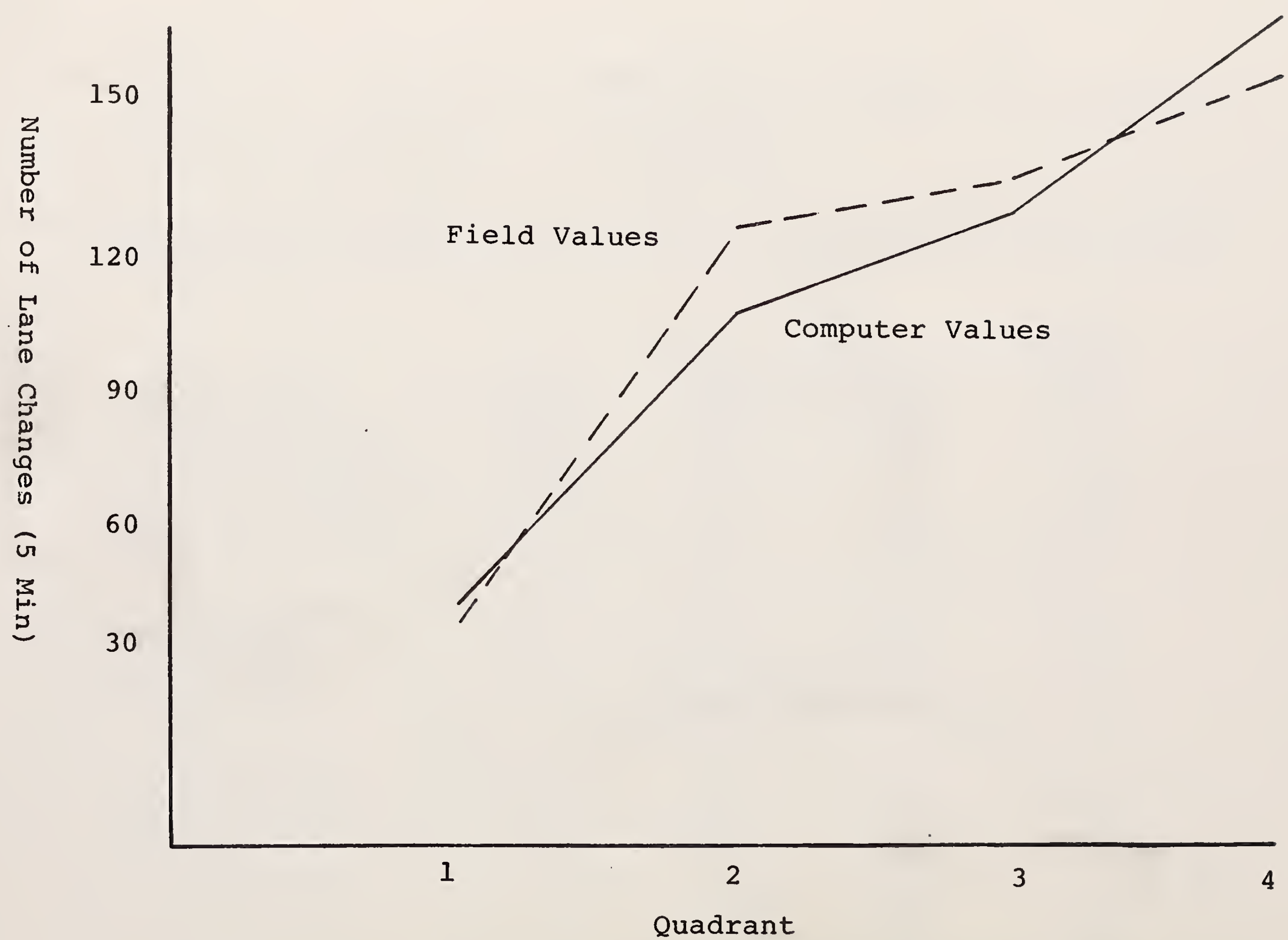


Figure 36: Comparison of Lane Changes - All Movements - Experiment 2

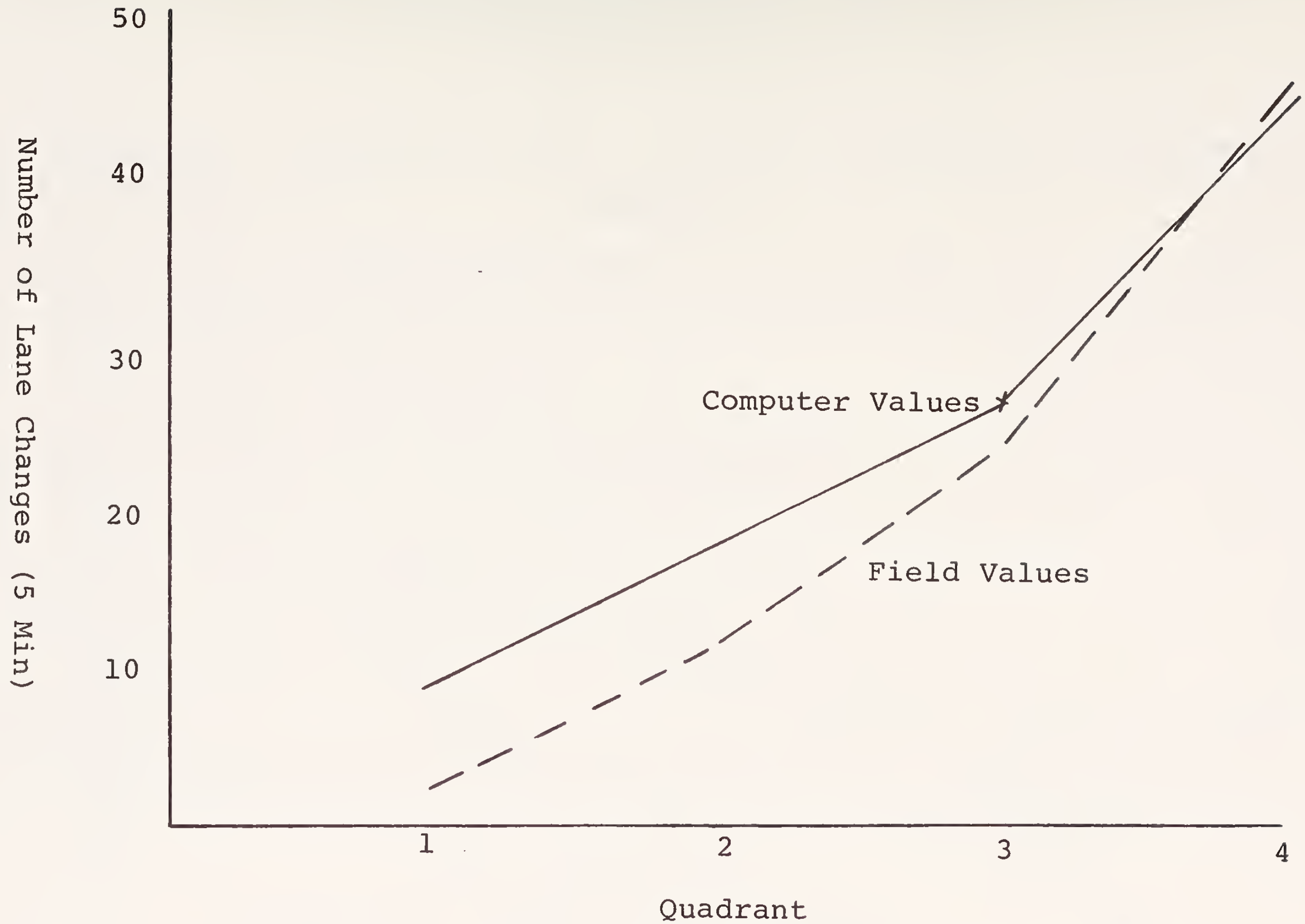


Figure 37: Comparison of Lane Changes - Lanes 1-8, Experiment 6

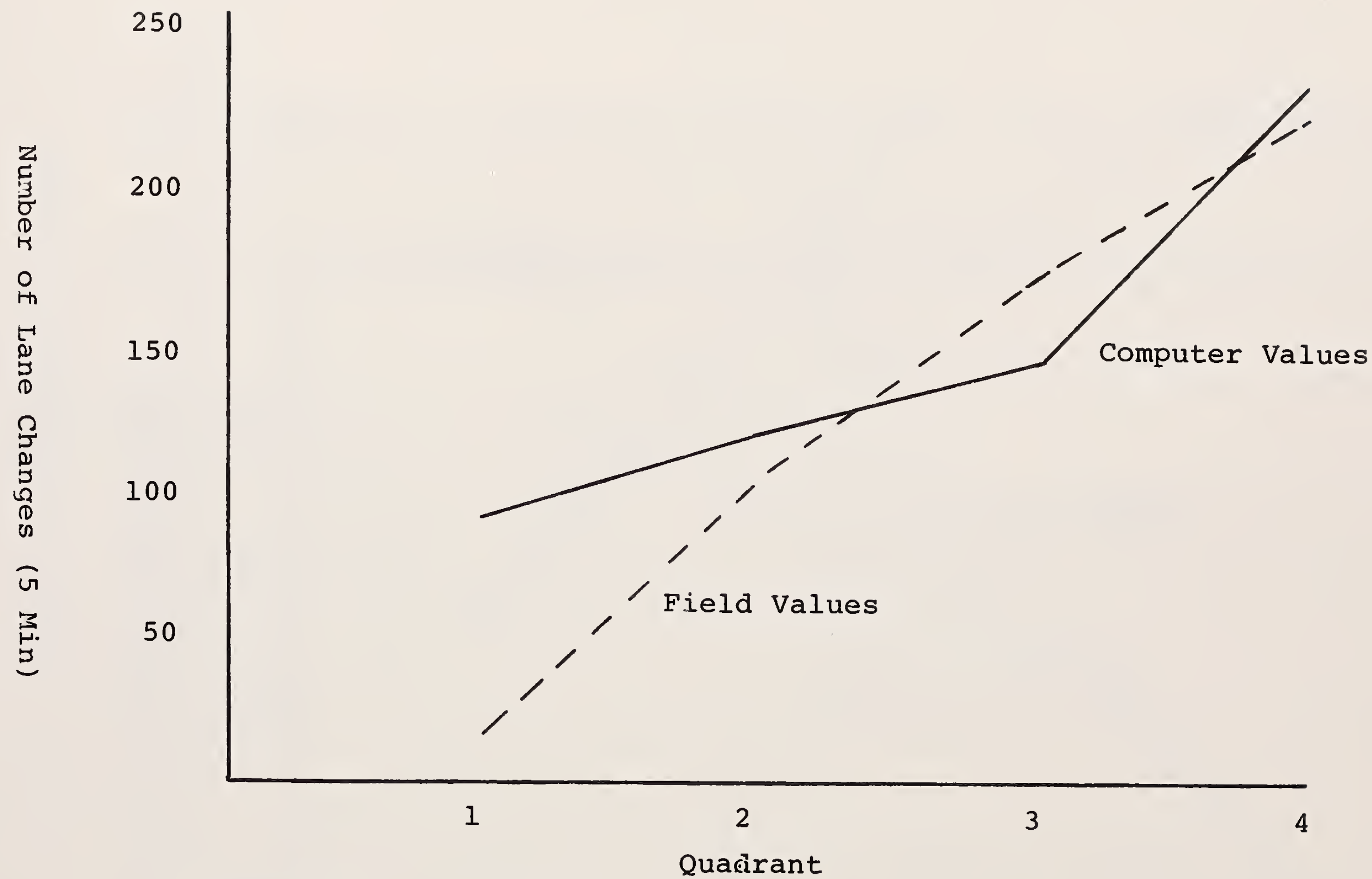


Figure 38: Comparison of Lane Changes - All Movements, Experiment 6

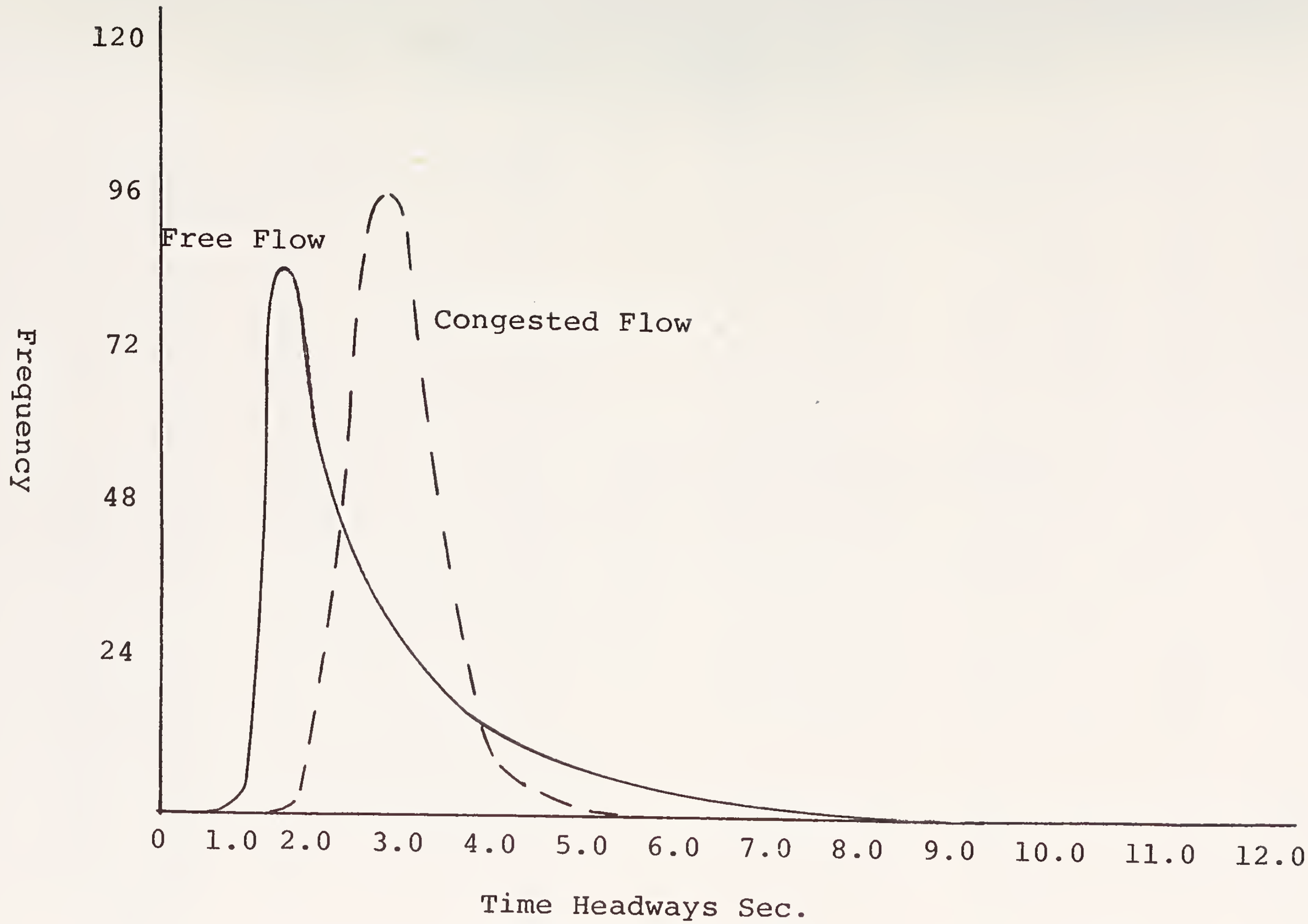


Figure 39: Headway Distributions
Free and Congested Flow

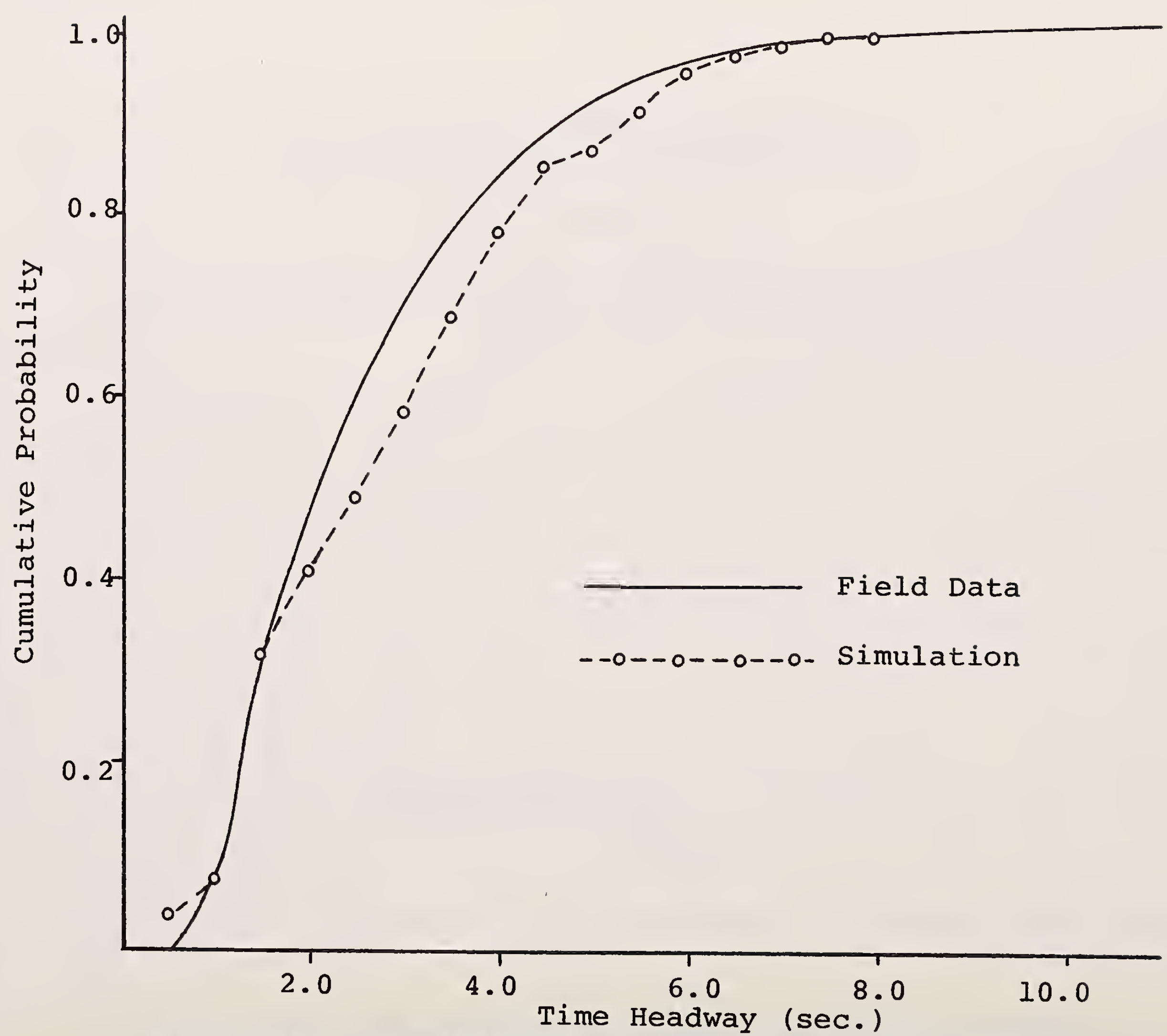


Figure 40: Comparison of Headway for Long Island Data - Total Volume 2800 VPH

The simulation was run for a 30-minute period with the same detector spacings. The generated input flows used were the overall lane averages determined from the empirical data. No attempt was made to generate the detailed 5-minute variations since exact validation at this fine level would also require knowledge of driver types, vehicle types, and geometries, including ramp locations.

A chi-squared test on the 72 5-minute counts indicated that 14 of them were significant at the one percent level.

This is considered to be a most satisfactory check in view of the fact that relevant information is lacking from the empirical data and the simulation was run at a general level without fine tuning to the detailed empirical variations.

Figures 41 to 44 show the comparison of the simulated and empirical headway distributions over the full 30-minute period for each lane at one detector set. The agreement in the structure of the distributions is very good. The agreement in the crucial area of short headways is also close.

Trajectories

The major validation here was the simulation of a 23-vehicle platoon through the shock wave indicated by the Ohio State data. The leader of the platoon was given the exact speed and position throughout the time period of 50 seconds as given by the empirical data. The 22 followers were started with the speeds and positions as given by the data set. The behavior of the platoon was then simulated for 50 seconds. The driver types were adjusted to develop the correct individual following characteristics, while an average vehicle type was assumed.

Figure 45 shows the result. The lead vehicle and last vehicle in the platoon are diagrammed along with every fifth vehicle. Agreement between the simulation and the data is very good. The main variation is for the later vehicles as they enter the shock wave where the simulated vehicles tend to decelerate a bit earlier. It should be remembered that any variations by an individual vehicle will be propagated through all followers. In

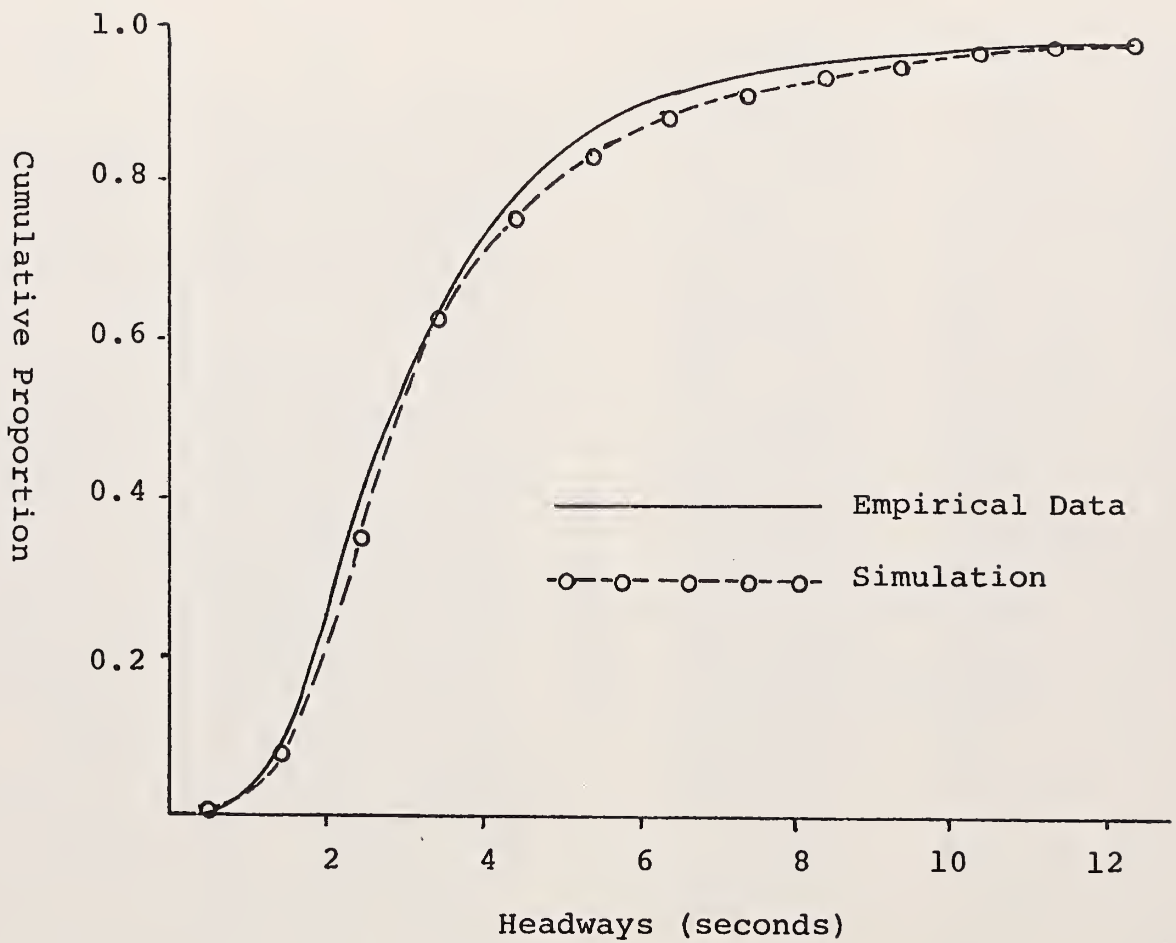


Figure 41: Los Angeles Headways
Detector #56 Shoulder Lane

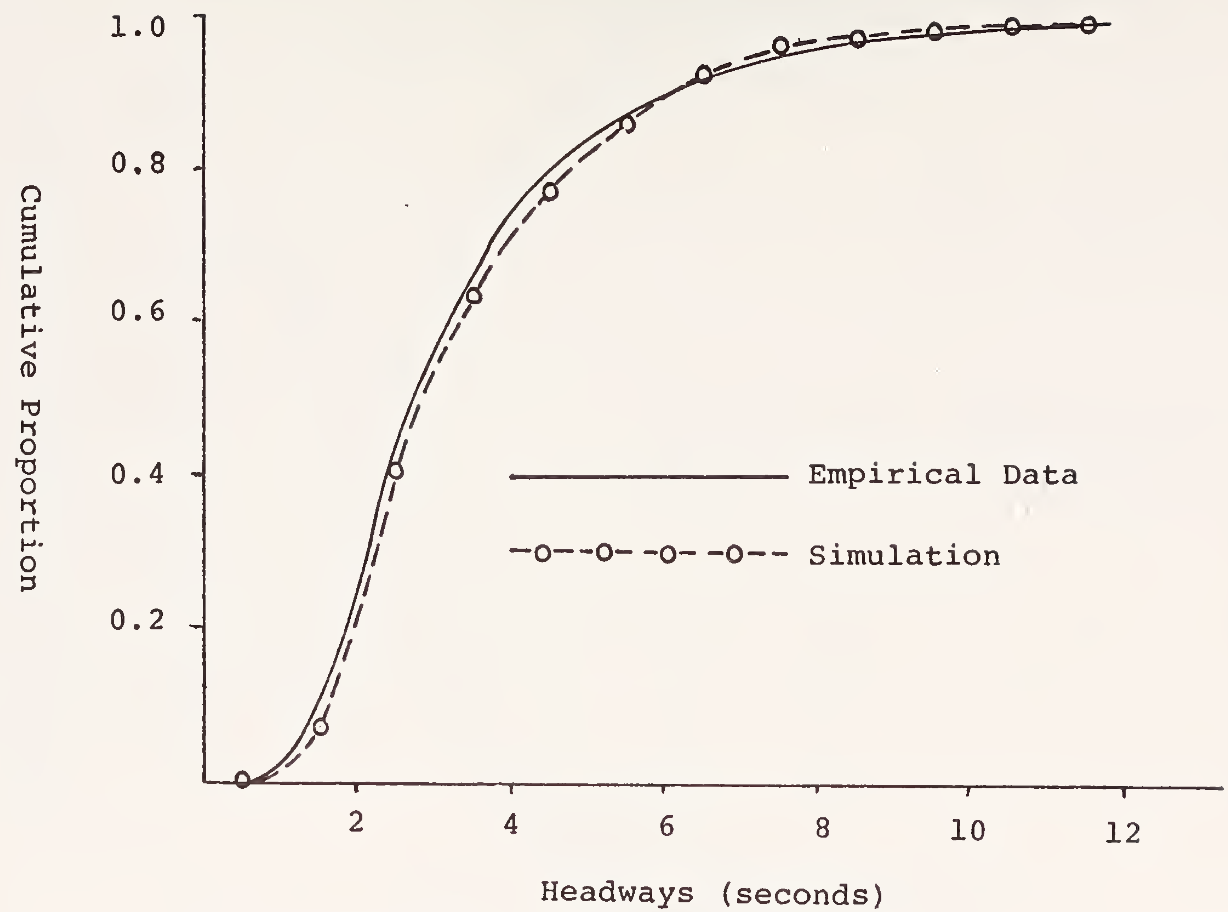


Figure 42: Los Angeles Headways
Detector #55 Next to Shoulder Lane

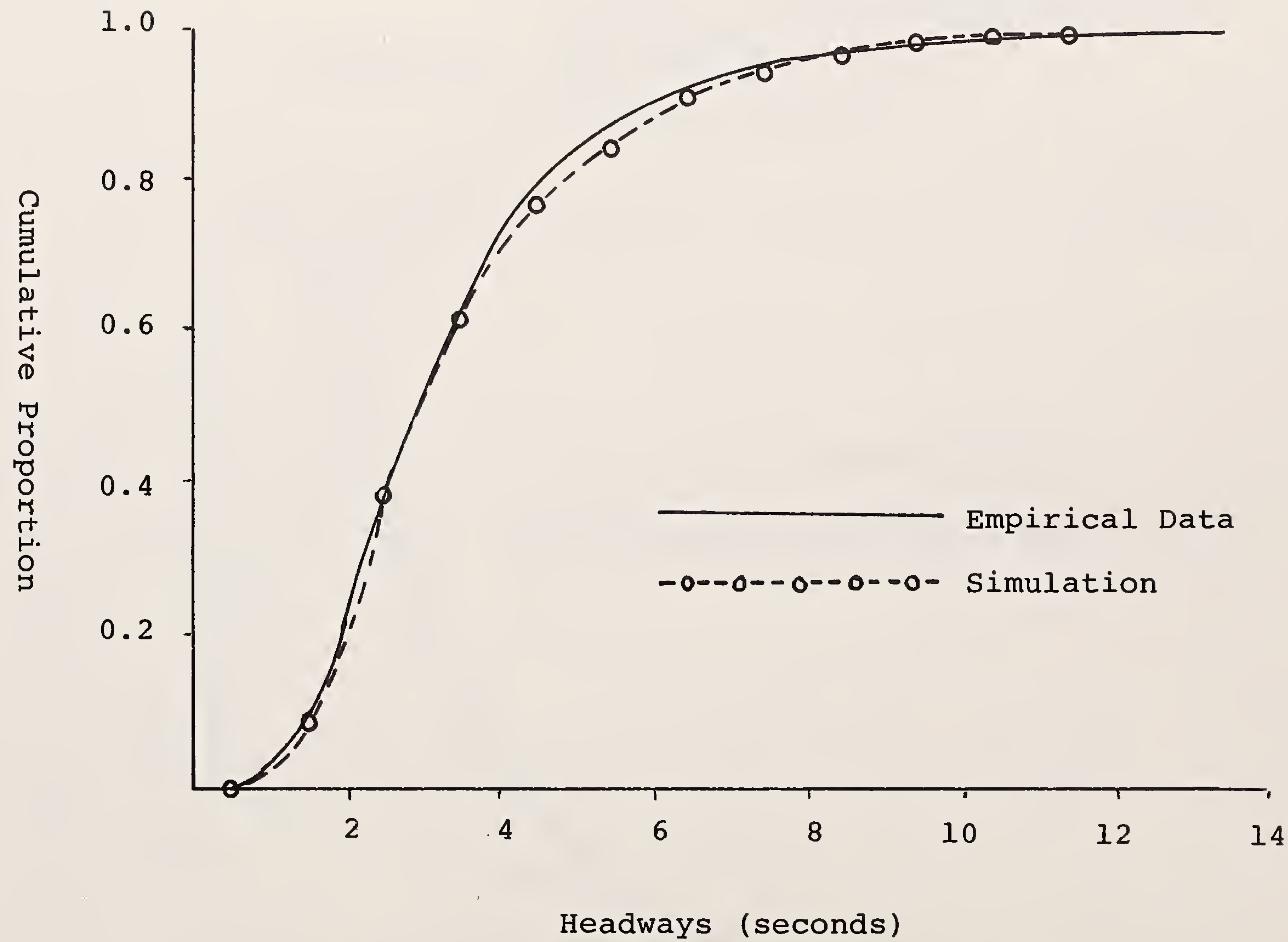


Figure 43: Los Angeles Headways
Detector #54 Next to Median Lane

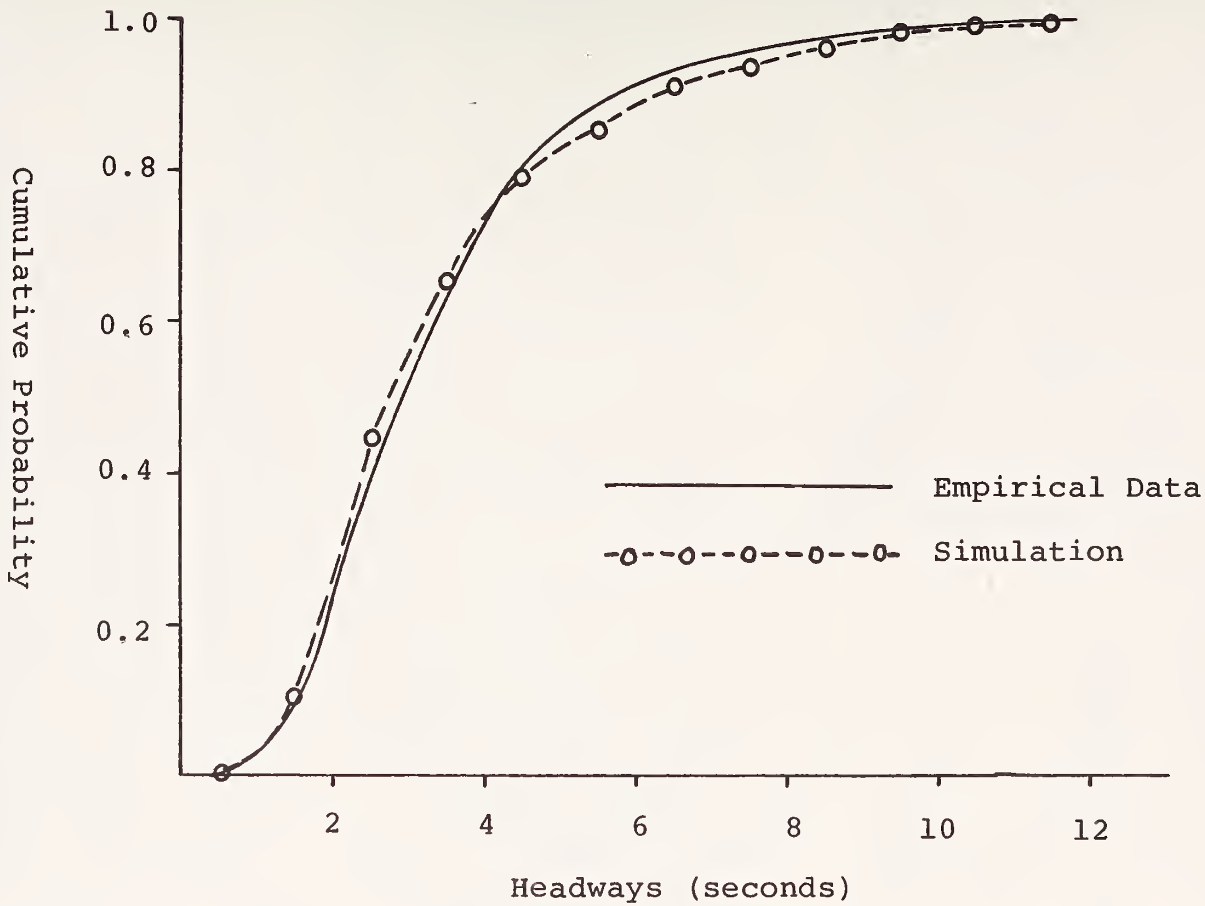


Figure 44: Los Angeles Headways
Detector #53 Median Lane

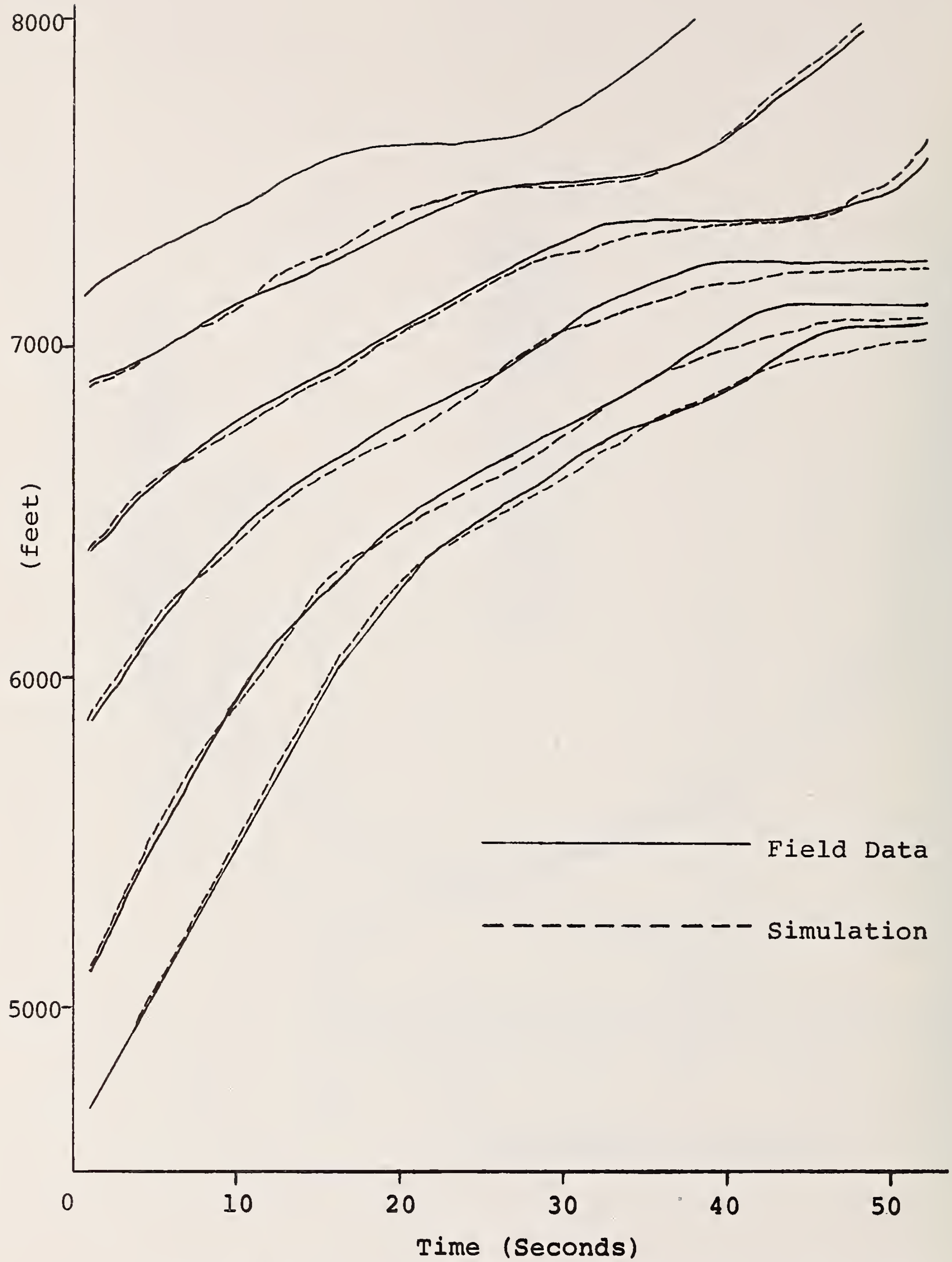


Figure 45: Ohio State Vehicle Trajectories Platoon of Twenty Three Vehicles Showing Paths of Vehicles Numbers 1, 5, 10, 15, 20, and 23.

examining the trajectories in detail, it was noticed that even for this comparatively short time period, individual drivers tended to change their "type" of car-following behavior; i.e., their desired following distance.

Nevertheless, despite these latter factors and a lack of knowledge as to the local geometrics that create this bottleneck, this simulation agreed most satisfactorily with the empirical base.

Other platoons were run for the free flow trajectory sections and in these cases the simulation-empirical match was so close as to be barely differentiable at a level of detail as given in Figure 45.

8. SUMMARY

The program design described in the preceding sections is implemented in a CDC 7600 computer at the Brookhaven National Laboratory, Upton, New York. This implementation includes the adaption of the component models, described in Sections 5 through 7, which were originally programmed for a DEC computer system at the University of Pittsburgh. The simulation model is also operational on an IBM 360 computer system, similar to that at the FHWA computer facility in Washington. This development procedure ensures that the INTRAS model may be exercised on a variety of computer systems, as has its predecessor, UTCS-1.

Validation of the INTRAS simulation model (as reported in Volume III) is accomplished by comparison of simulated detector outputs with the closely spaced detector data base from the Los Angeles freeway system. The high density of detector stations (600-foot separation), in this data base, makes it possible to rigorously test the INTRAS model's ability to replicate abrupt longitudinal changes in traffic performance, characteristic of congested flow conditions. Comparisons are also performed of model performance with on-ramp field data gathered in the Washington, D.C. vicinity.

In addition, the PINY data sets used for component validation (Section 7) are reapplied to testing of the integrated model to ensure that component performance is not affected by the integration process.

The results of validation testing, as well as exercises performed to evaluate and demonstrate the INTRAS incident detection capabilities, are described in Volume III.

APPENDIX A

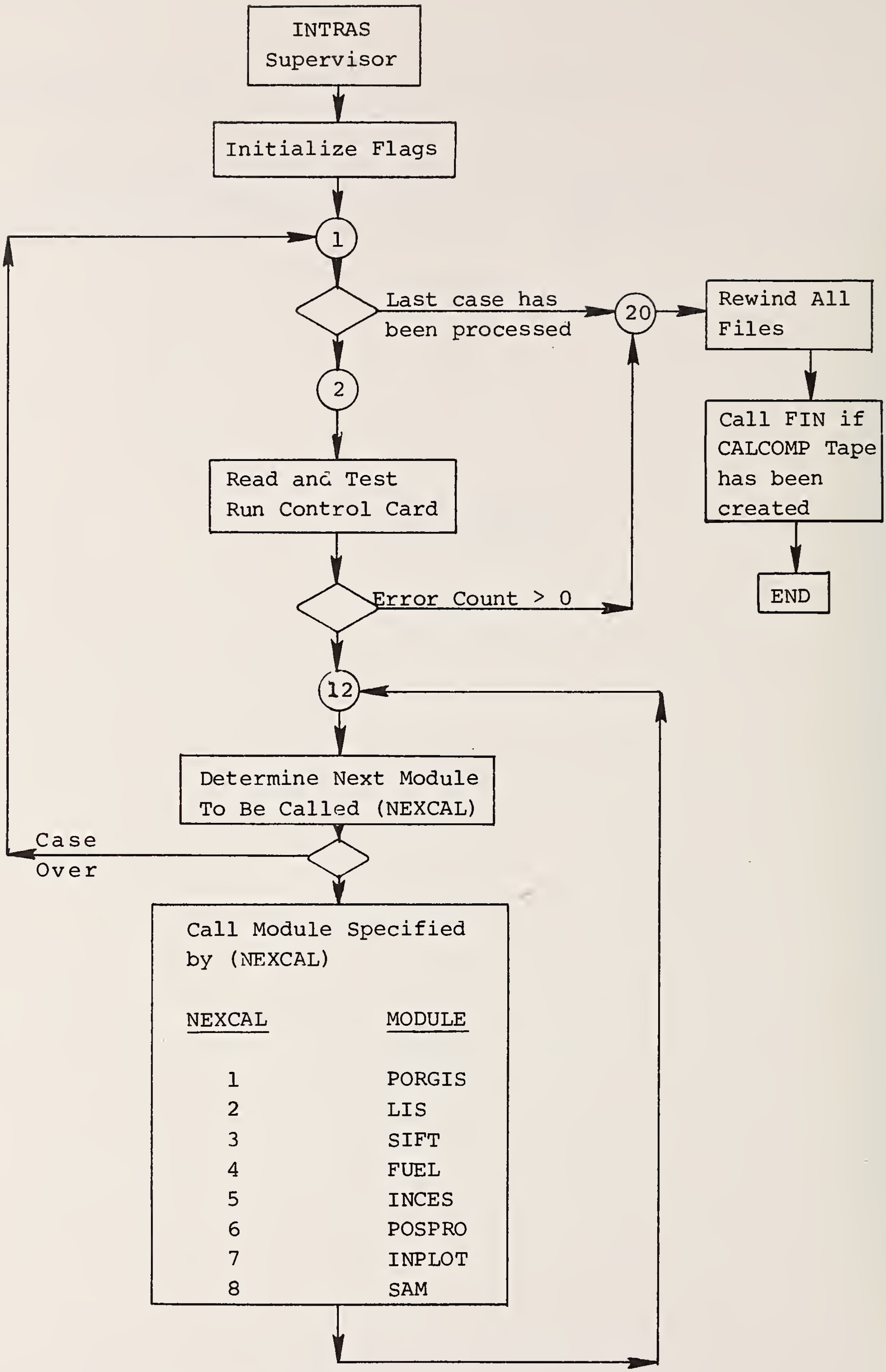


Figure 46: INTRAS Supervisor Logic

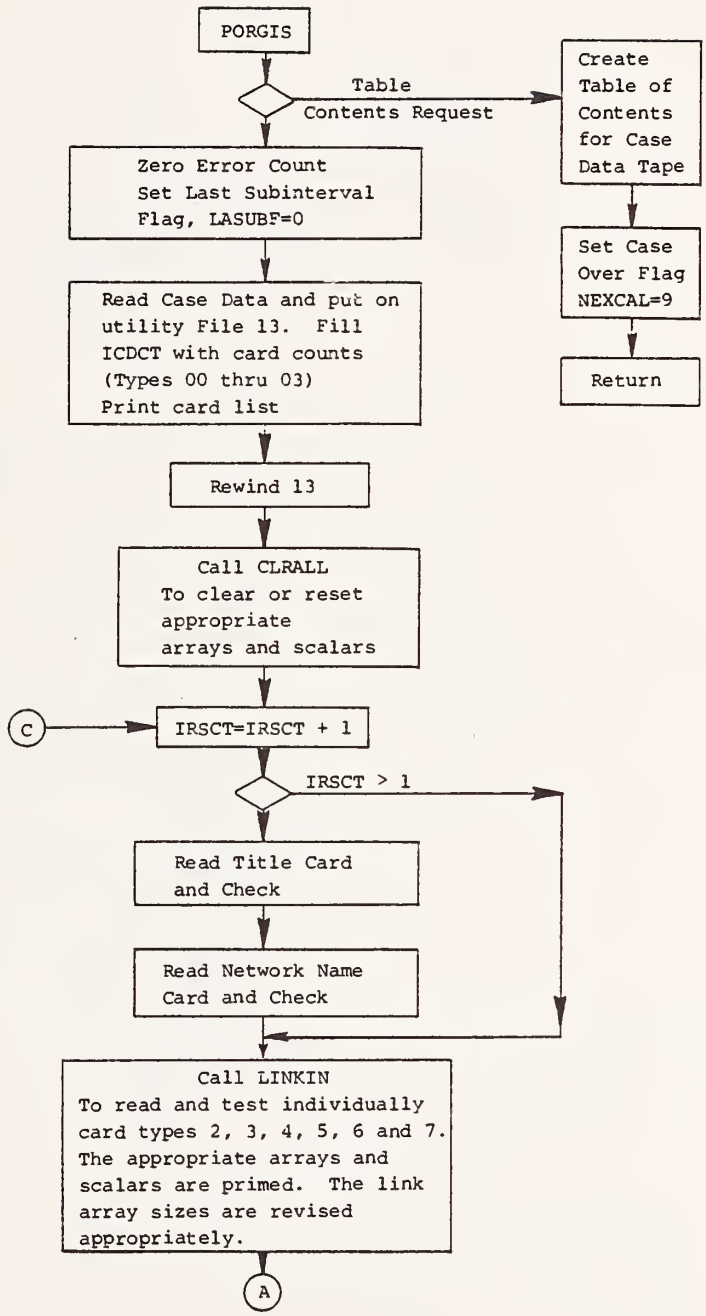


Figure 47: PORGIS Module Logic

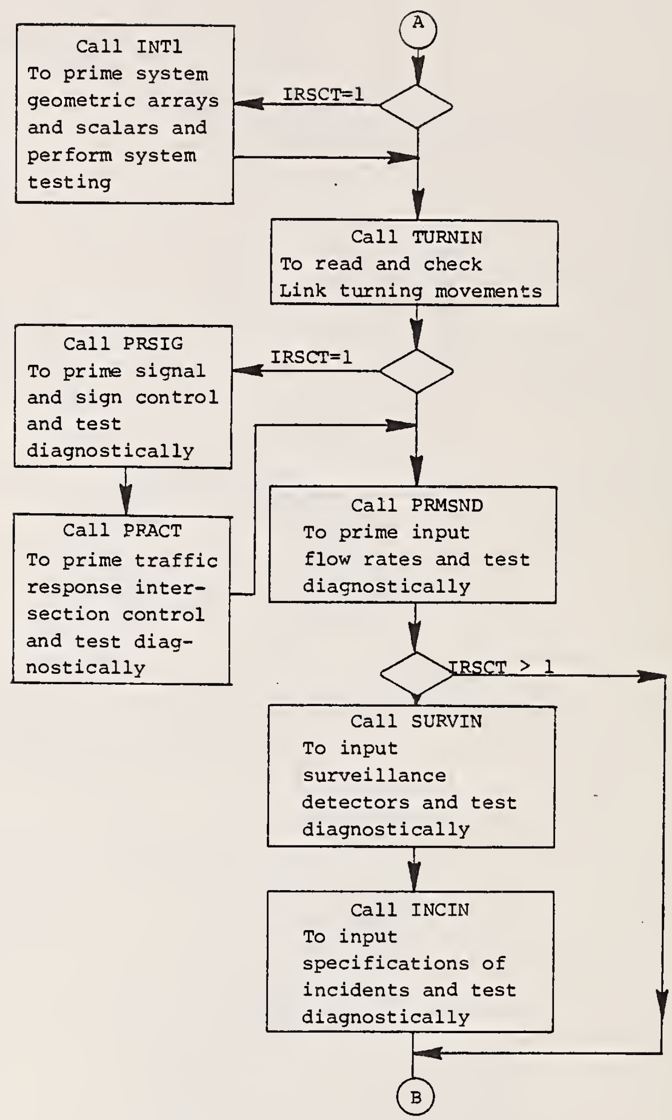


Figure 47 (continued)

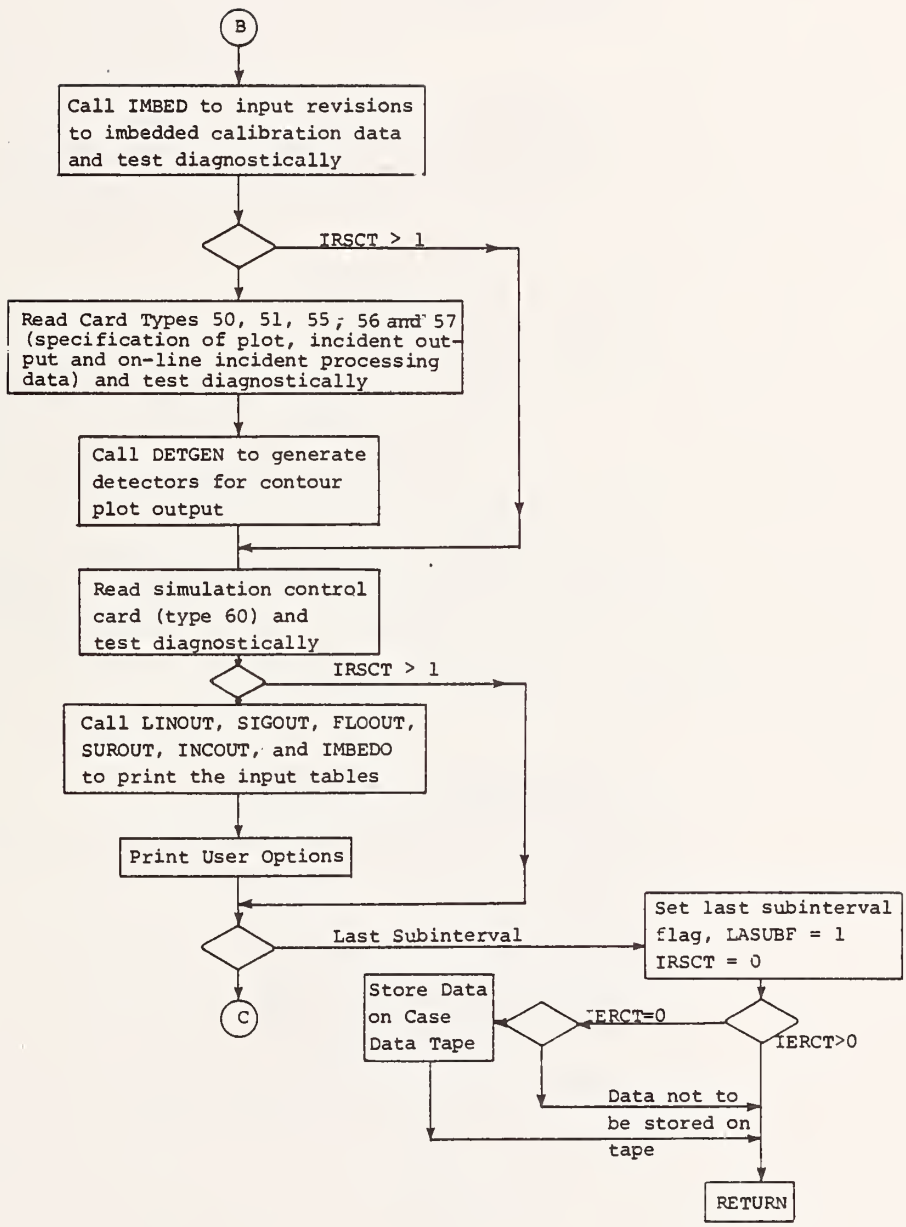


Figure 47 (concluded)

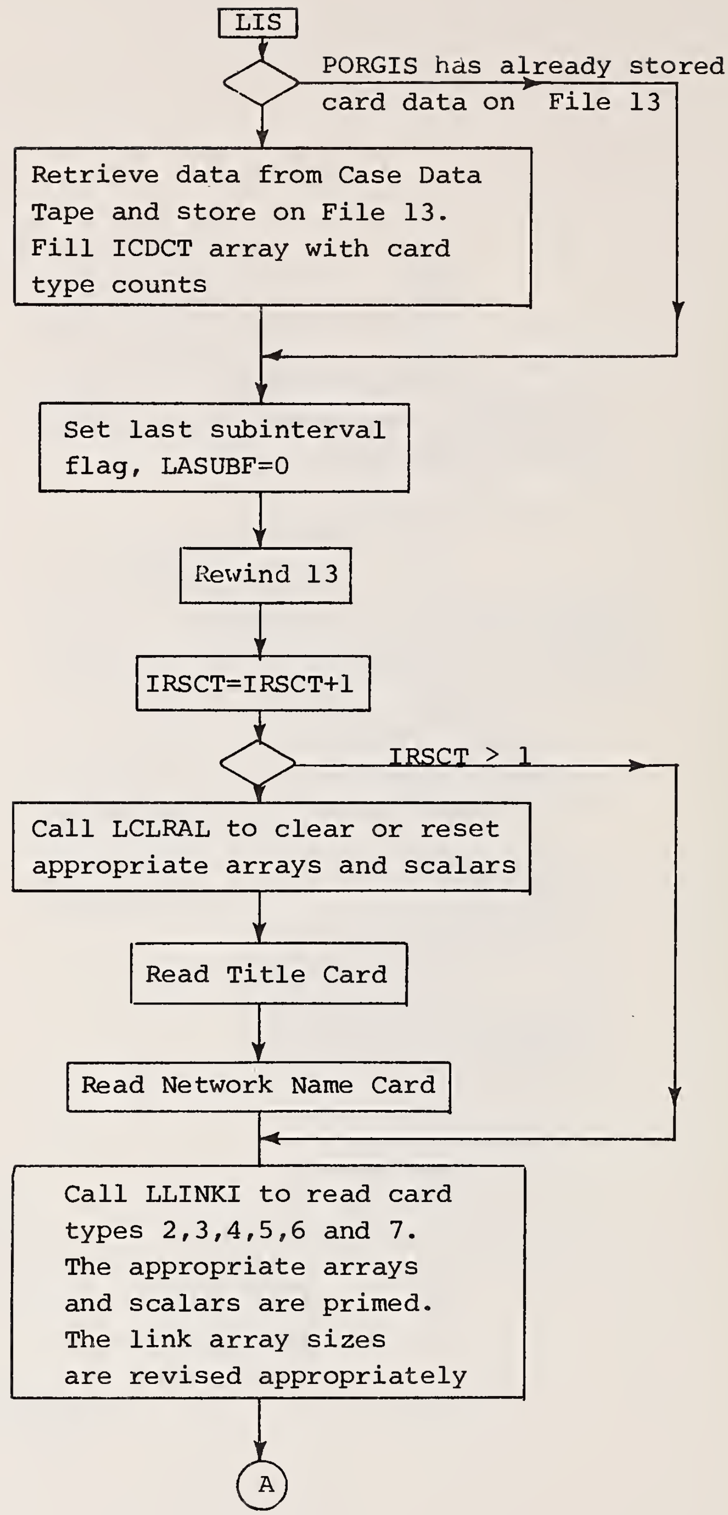


Figure 48: LIS Module Logic

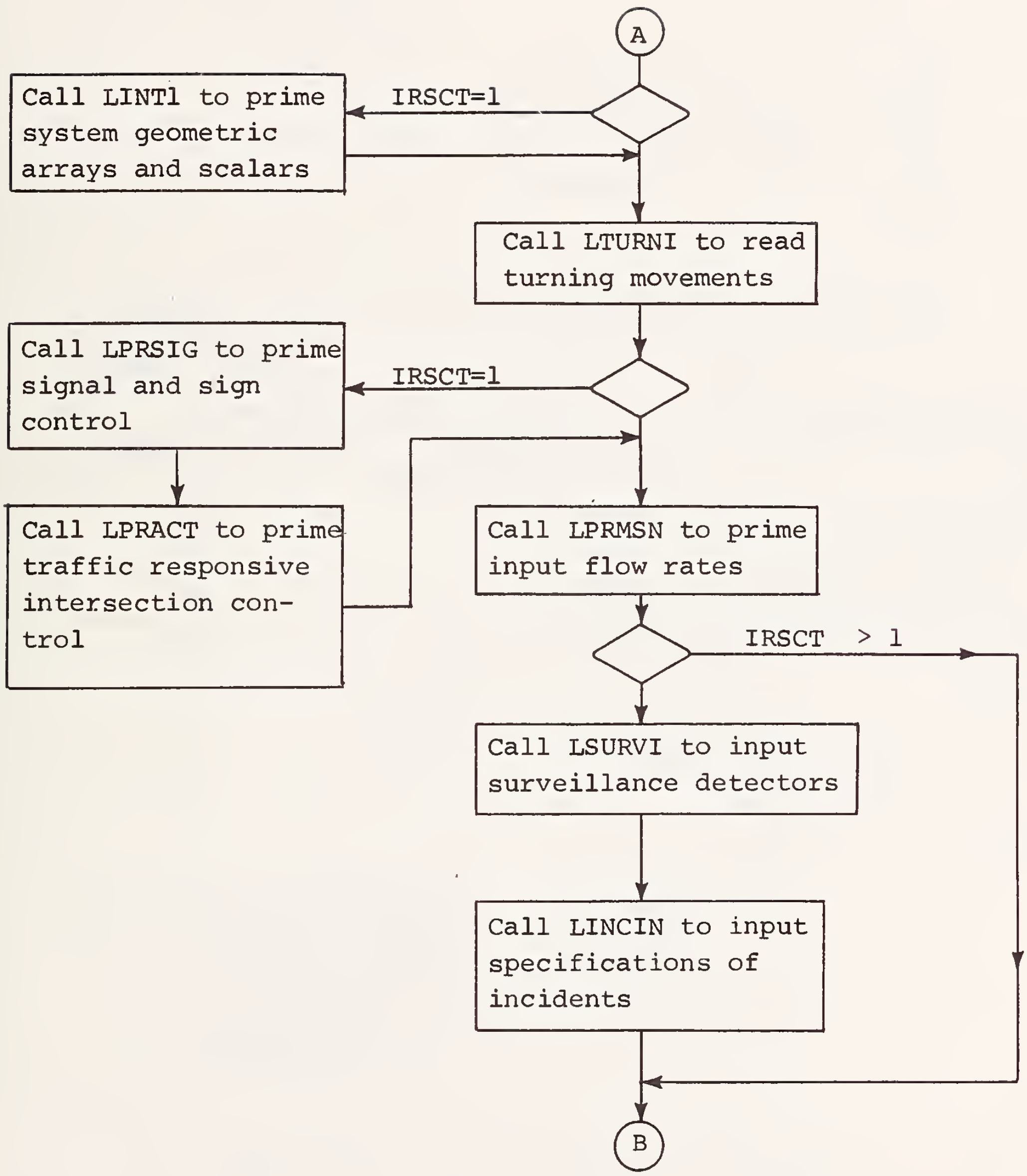


Figure 48: LIS Module Logic (continued)

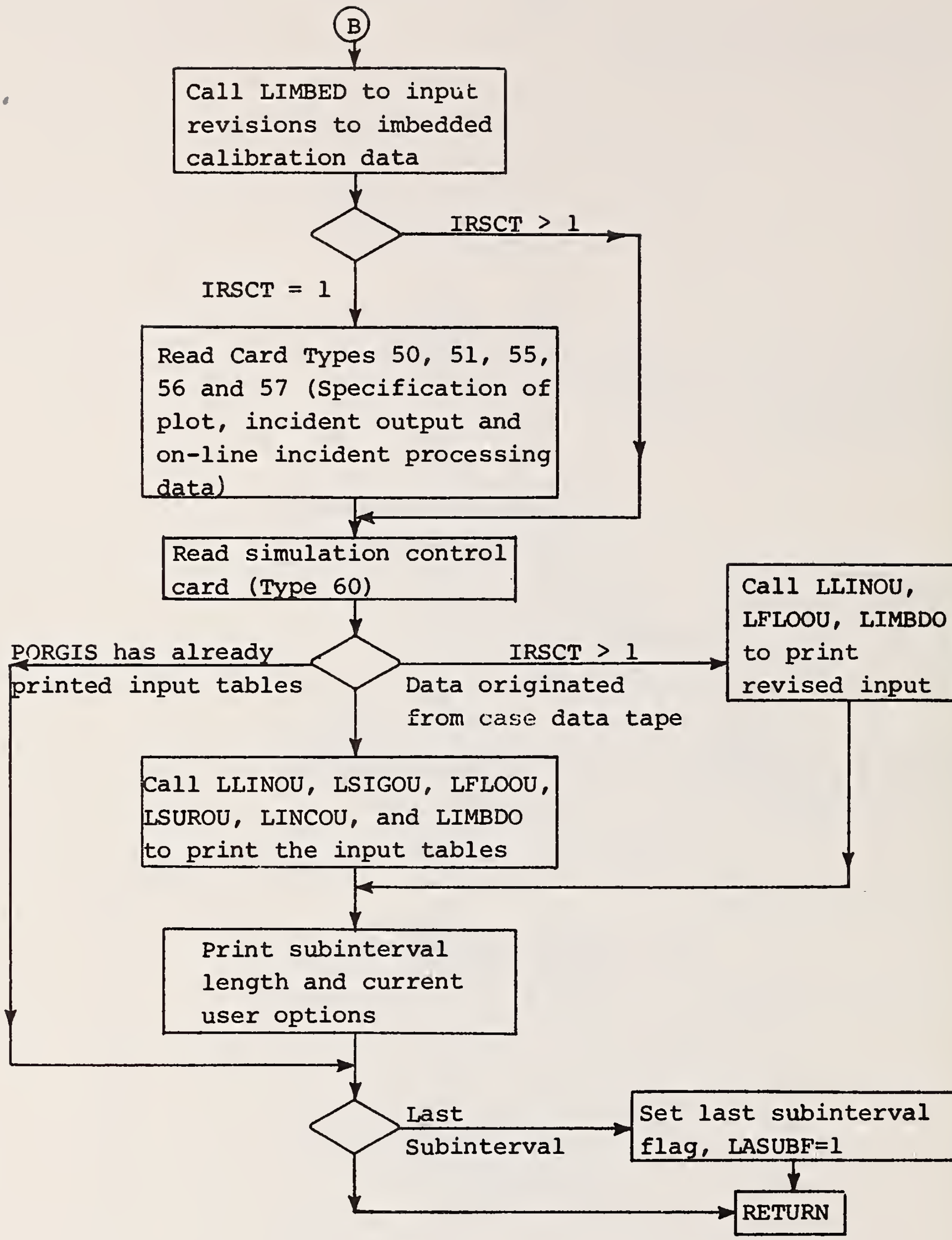


Figure 48: LIS Module Logic (concluded)

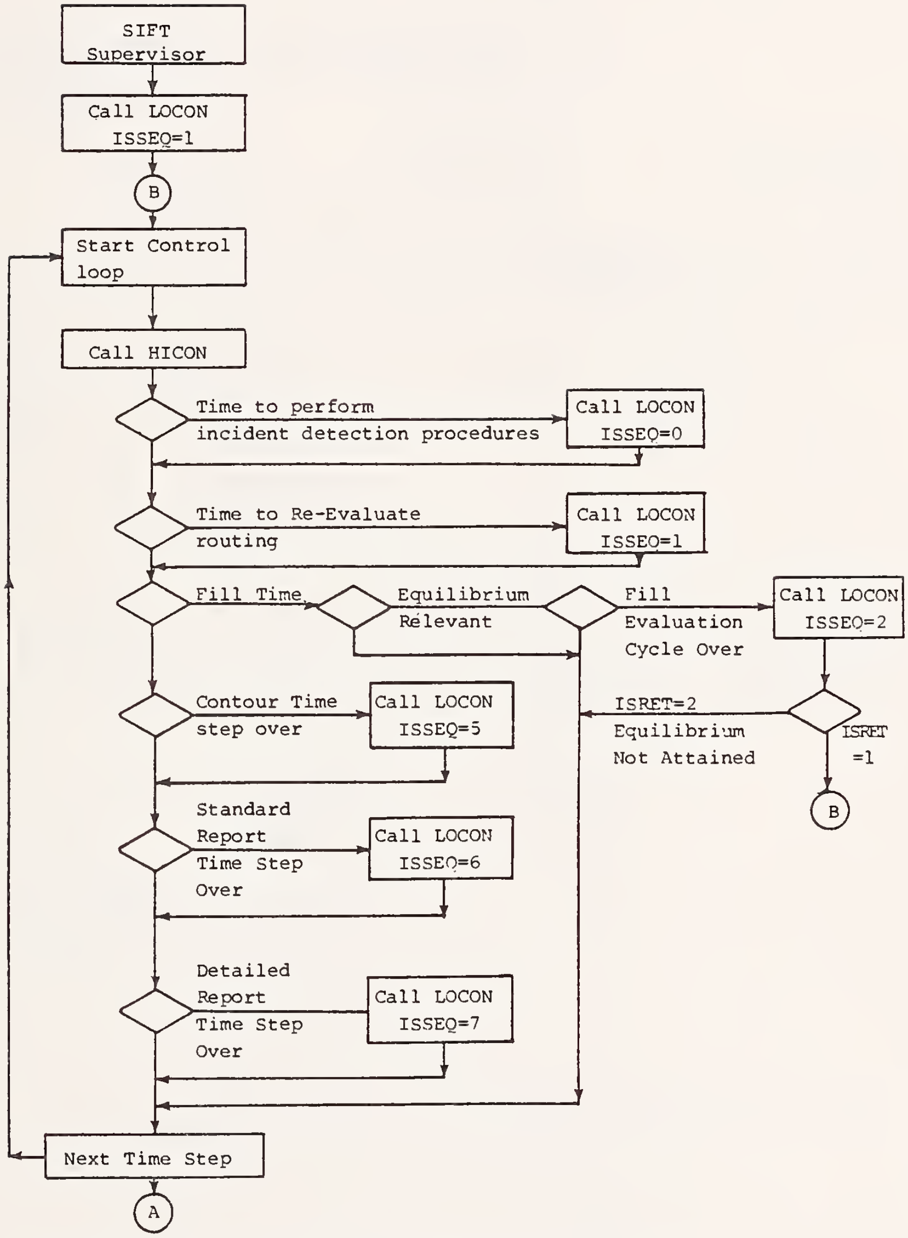


Figure 49: SIFT Supervisor Logic

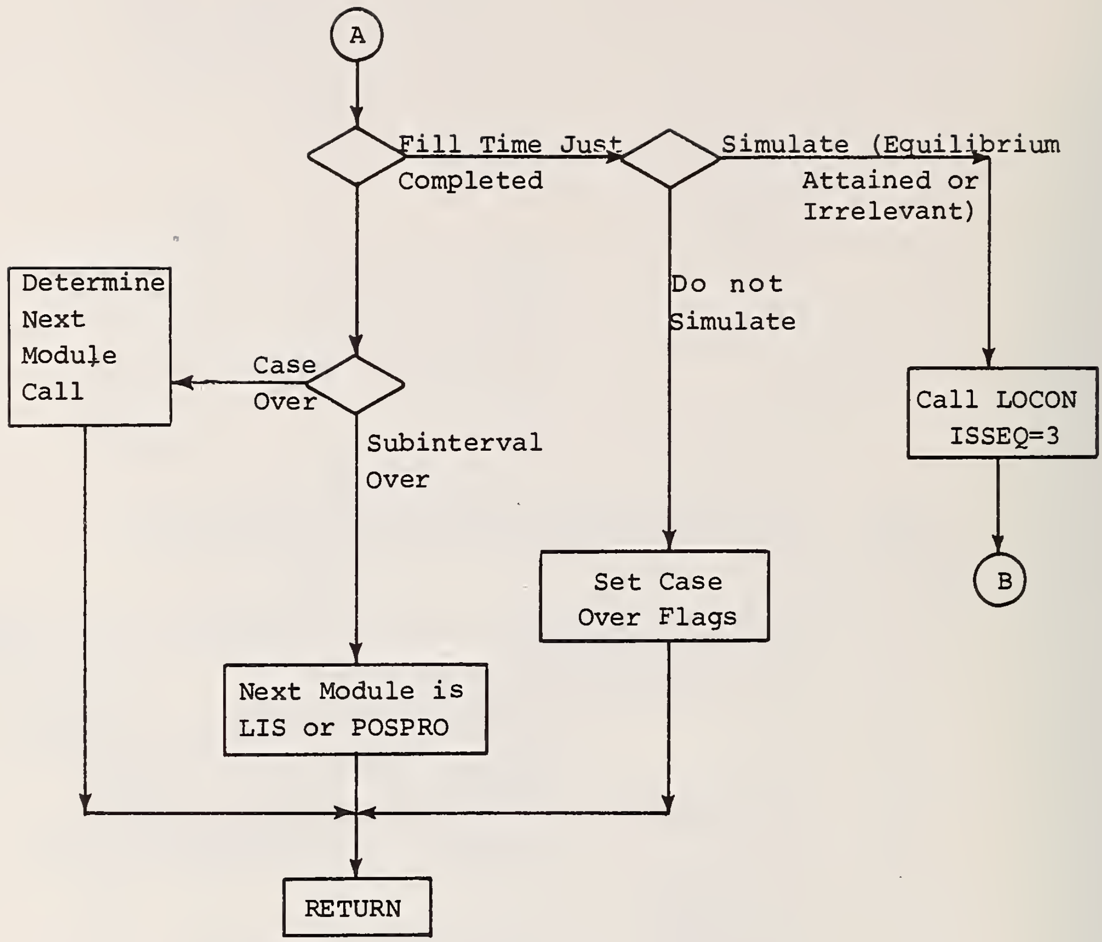


Figure 49: SIFT Supervisor Logic (continued)

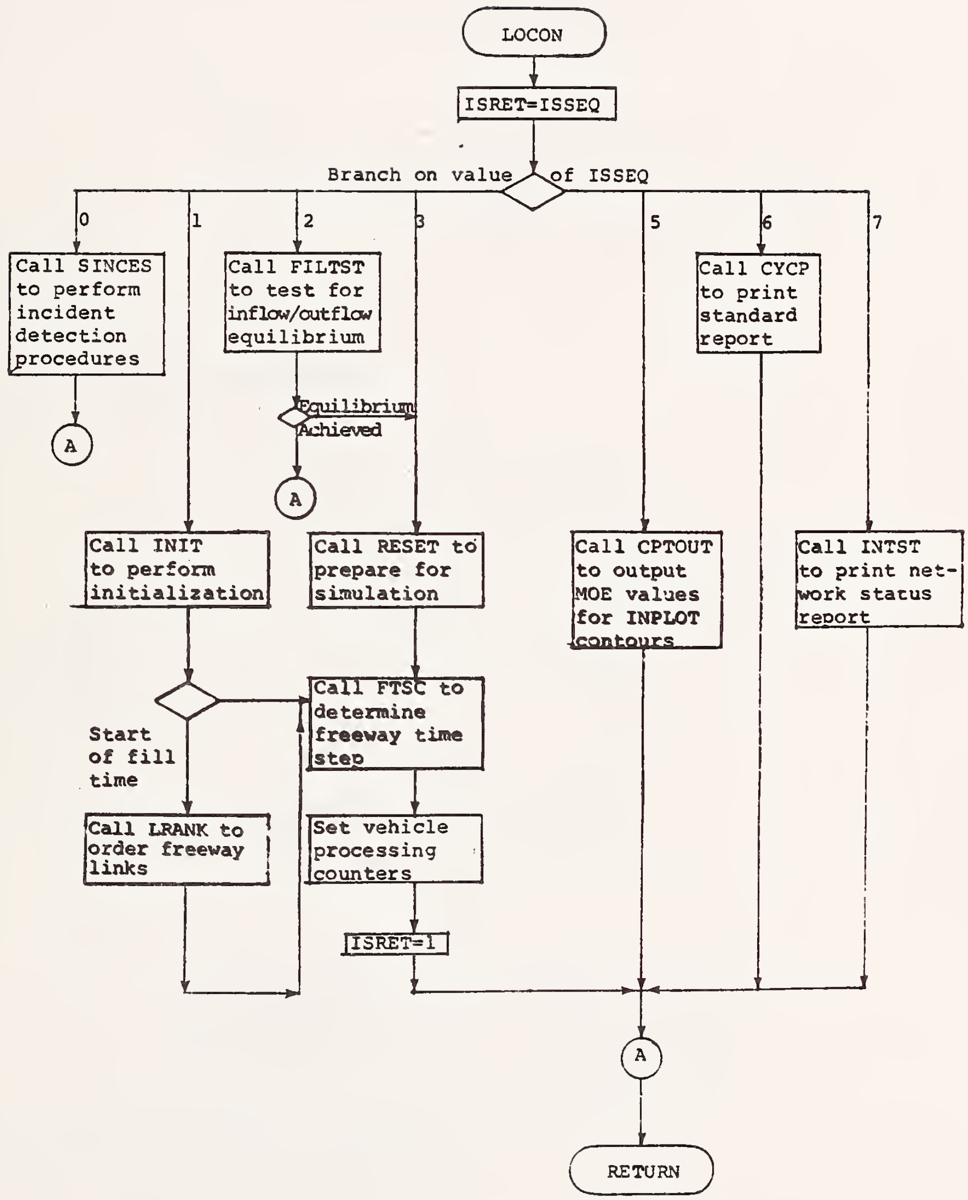


Figure 50: LOCON Suboverlay Logic

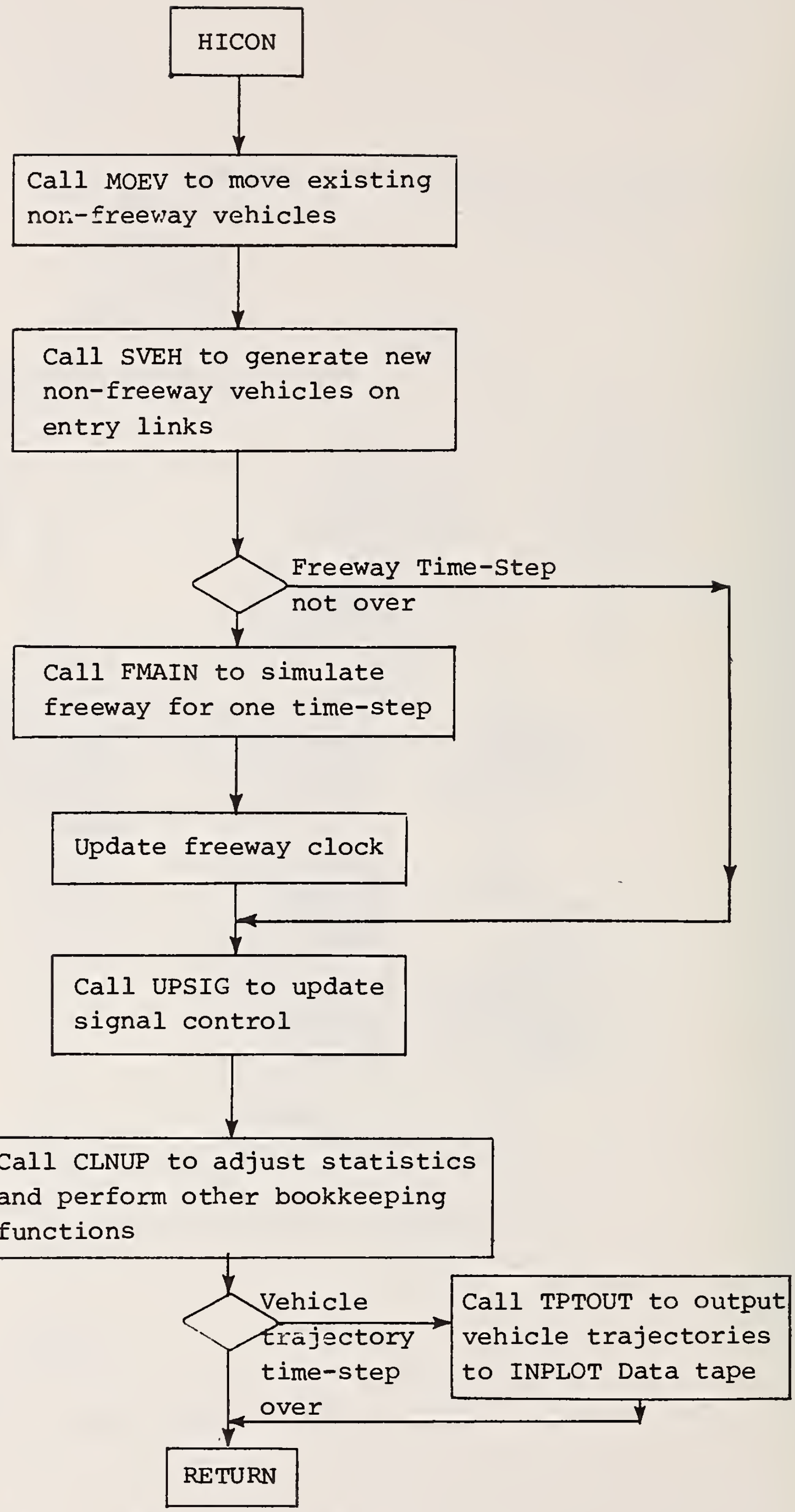


Figure 51: HICON Suboverlay Logic

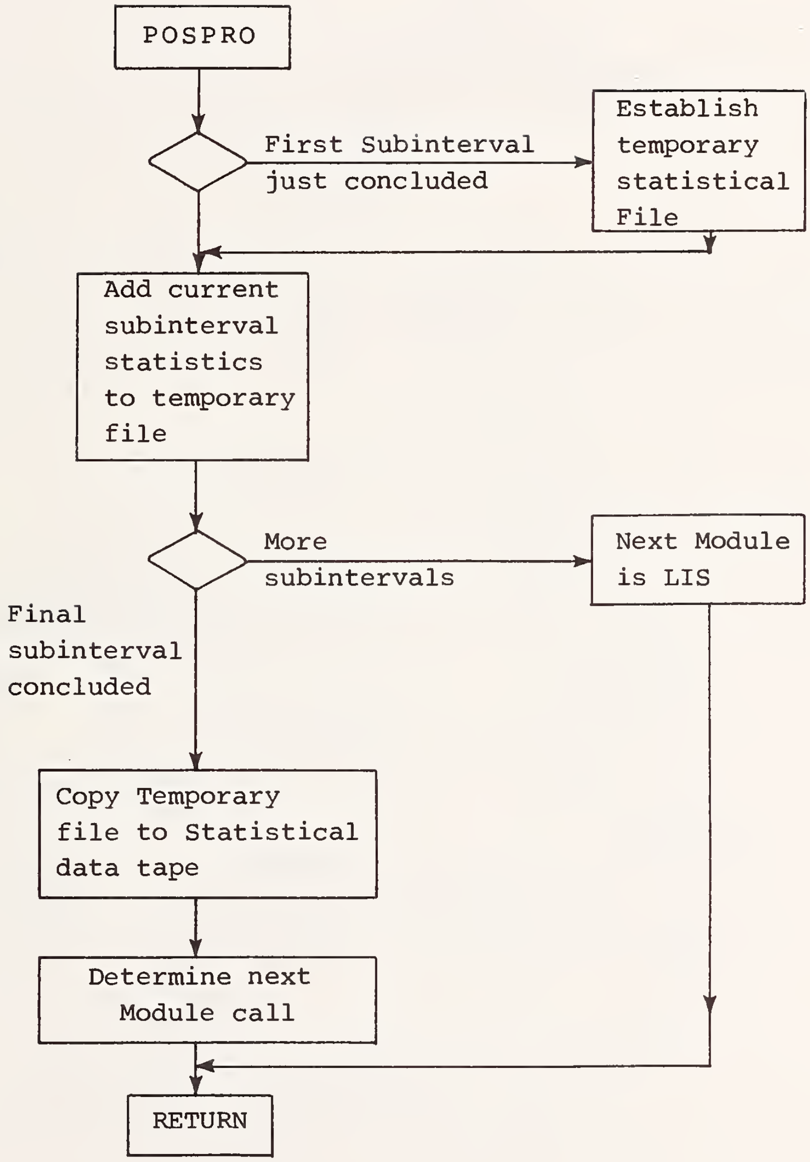


Figure 52 : POSPRO Module Logic

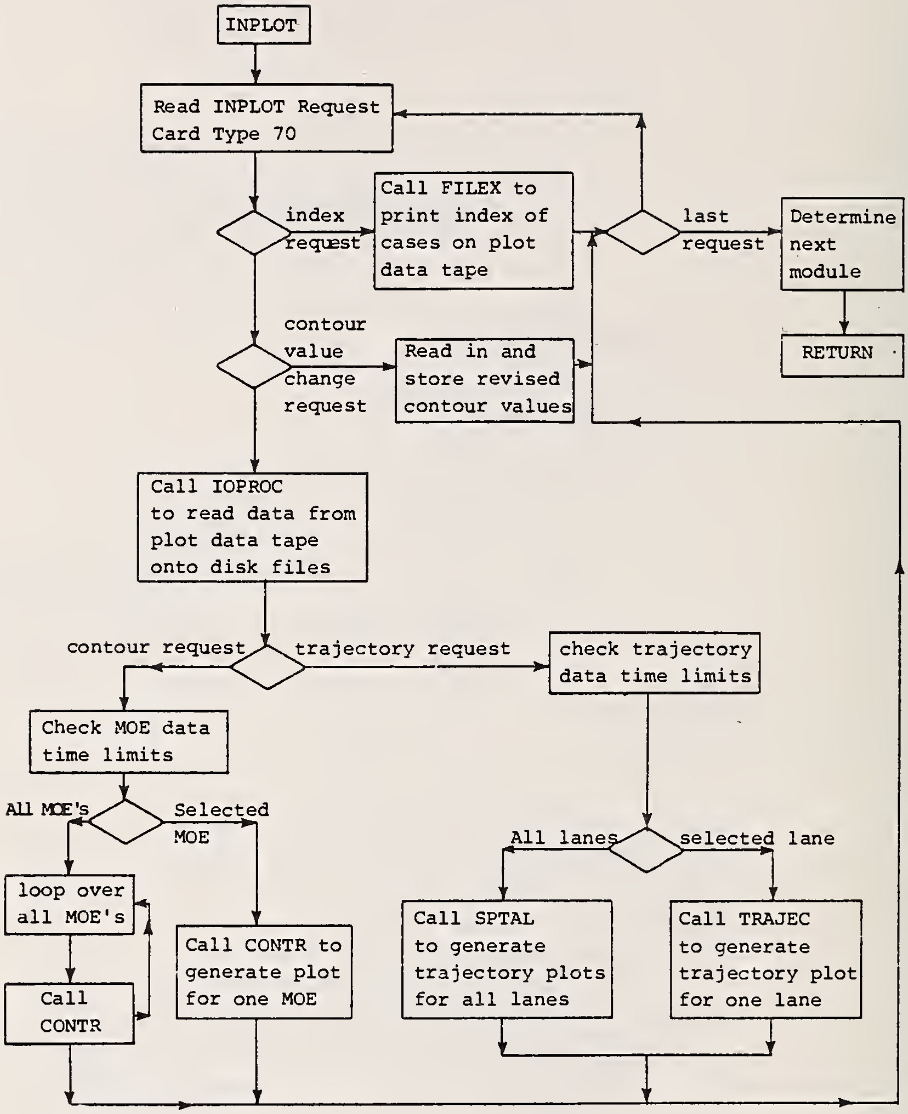


Figure 53: INPLOT Module Logic

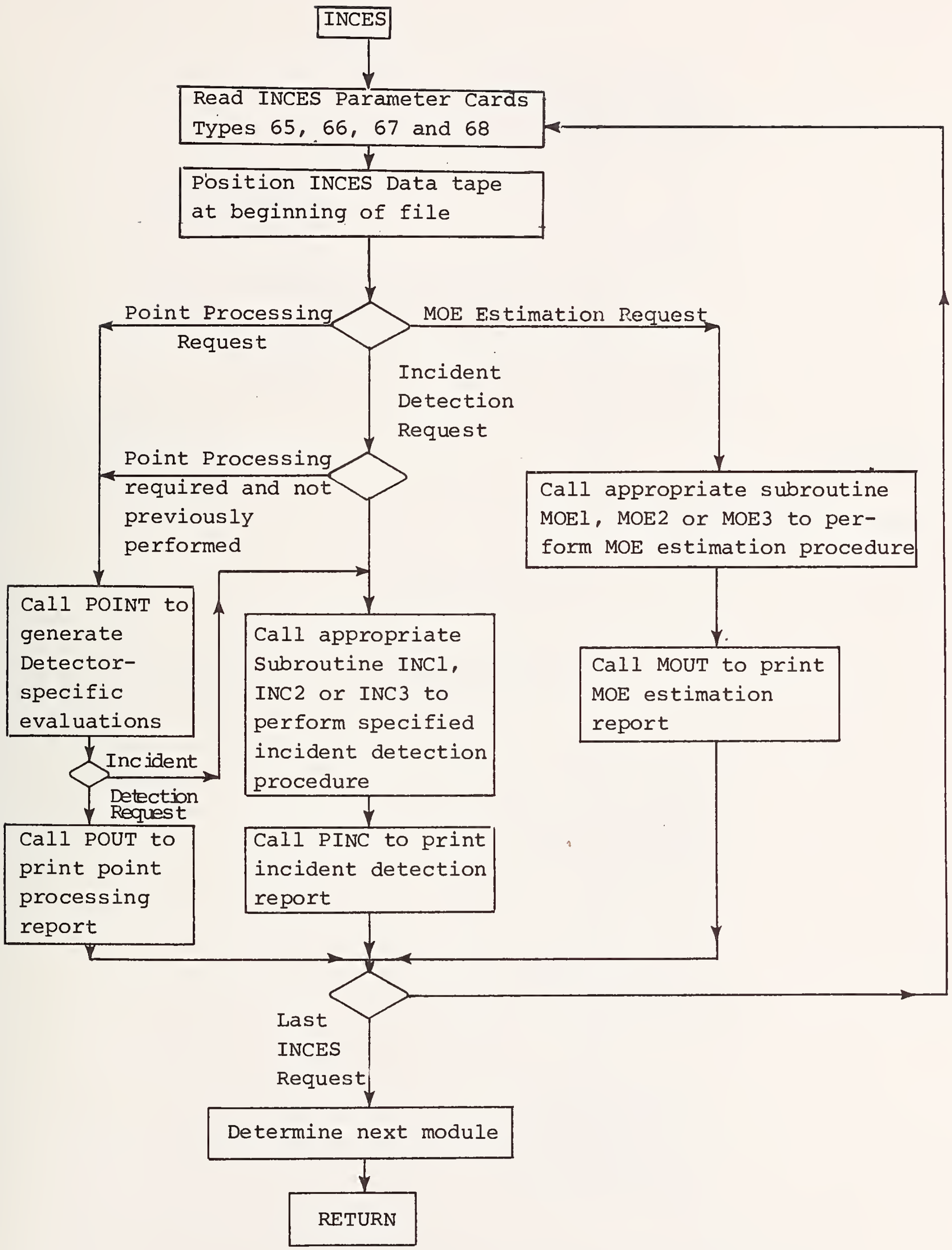


Figure 54 : INCES Module Logic

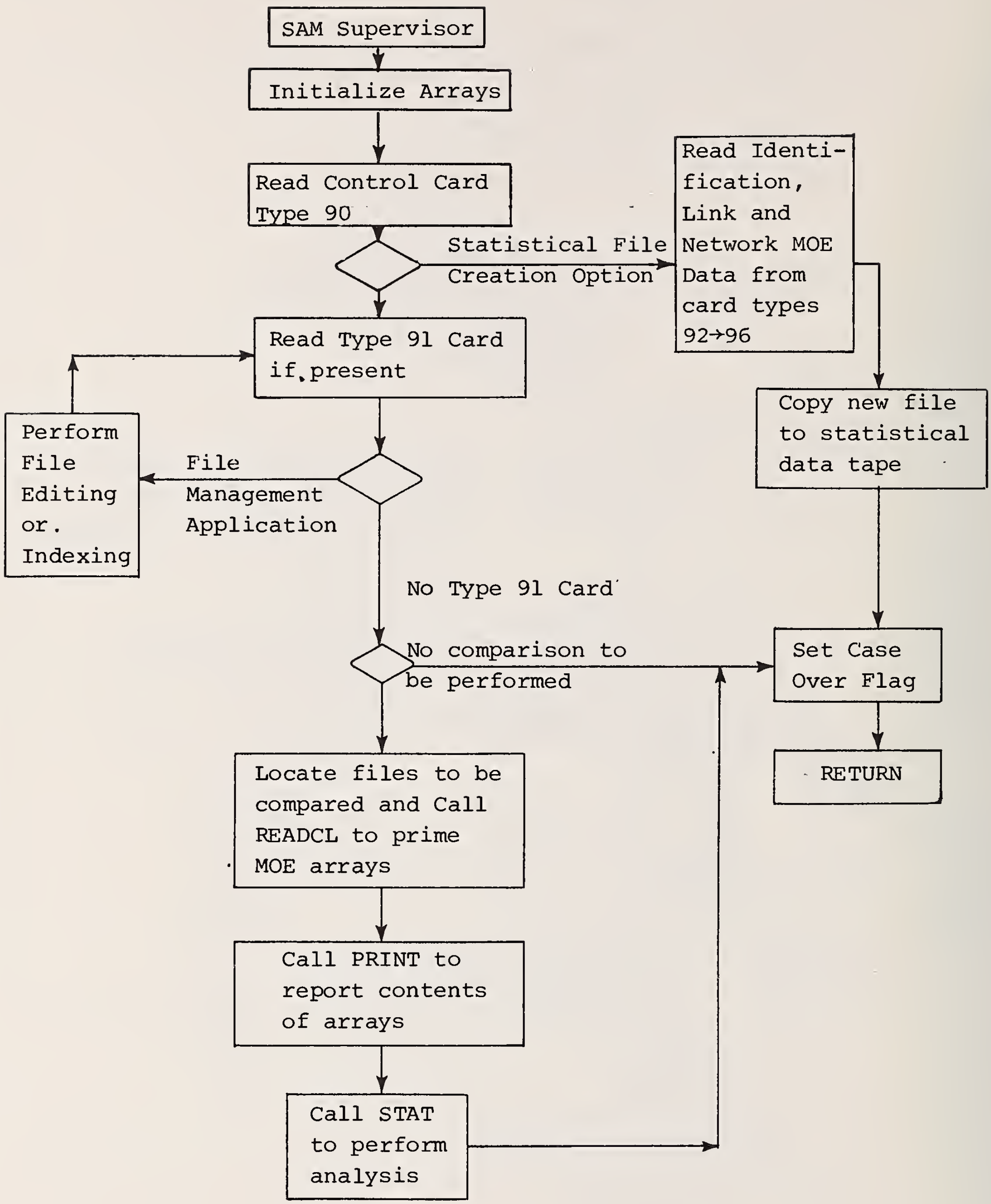


Figure 55: SAM Module Logical Flow

Appendix B

The PITT Car-Following Model

1. Symbols Used

All dimensions are feet and/or seconds

k = car following parameter (driver sensitivity)
L = length of the leading vehicle
T = time scanning interval
c = lag (the reaction time which is always < T)
e = maximum emergency deceleration
x = position of leader at time t
u = speed of leader at time t
y = position of follower at time t
v = speed of follower at time t
a = acceleration of follower in the interval (t,t+T)
x* = position of leader at time t+T
u* = speed of leader at time t+T
y* = position of follower at time t+T
v* = speed of follower at time t+T
b = constant

2. The Car-Following Model

The basic assumption is that the following vehicle will try to maintain a space headway equal to

$$L+10+kv+bk(u-v)^2 \qquad (1)$$

For the current calculation for the follower we are given x*, u*, y, v and we must calculate a. The desired position at time t+T is given by (1) as

$$x^*-y^* = L+10+kv^*+bk(u^*-v^*)^2 \qquad (2)$$

but $y^* = y+vT+aT^2/2$ and $v^* = v+aT$ and thus expression (2) becomes

$$x^*-(y+vT+aT^2/2)=L+10+k(v+aT)+bk(u^*-v)^2 \qquad (3)$$

(Note: Since the term $(u-v)^2$ is small we have used the approximation $v^* = v$. Any difference is taken care of by the calibration of b. The increased calculation required to use v^* is not warranted.)

Expression (3) gives

$$a = 2[x^*-y-L-10-v(k+T)-bk(u^*-v)^2]/[T^2+2kT] \qquad (4)$$

This is the basic car following relationship. The term involving constant b was introduced to allow for high relative closing speed behavior observed empirically. The value of b has been calibrated to

$$b = \begin{cases} 0.10 & \text{for } (u-v) \leq 10 \\ 0 & \text{for } (u-v) > 10 \end{cases} \qquad (5)$$

The driver reaction time c is introduced into the car following equations, after a has been calculated, when the new speed and position are defined

$$v^* = v+a(T-c)$$

and $$y^* = y+vT+a(T-c)^2/2$$

where $c < T$

3. Derivation of the Emergency Constraint

This constraint overrides the car following rules to prevent collisions. The basic concept provides that the following vehicle can stop safely behind its leading vehicle under the following conditions:

(1) The leader decelerates to a stop at the maximum emergency deceleration.

(2) The follower starting at the lag time c later decelerates to a stop behind the leader at a deceleration rate within the maximum emergency deceleration limit.

If the leader stops at maximum deceleration then $u^* = 0$ and

$$x^* = x+u^2/2e \tag{6}$$

The follower also stopping at maximum deceleration will give

$$y^* = y+cv+v^2/2e \tag{7}$$

Since the headway between the vehicles must exceed the length of the leader, expressions (6) and (7) give

$$x^*-y^* = x-y+(u^2-v^2)/2e-cv \geq L$$

and therefore, in general, we have

$$x-y \geq L+cv+(v^2-u^2)/2e \tag{8}$$

but $x-y \geq L$ for all u, v and thus expression (8) holds only if

$$cv+(v^2-u^2)/2e \geq 0$$

or

$$v \geq (u^2+e^2c^2)^{1/2} -ec$$

The basic headway constraint is therefore

$$\begin{aligned} &x-y \geq L+cv+(v^2-u^2)/2e && \text{if } v \geq (u^2+e^2c^2)^{1/2}-ec \\ \text{and } &x-y \geq L && \text{if } v < (u^2+e^2c^2)^{1/2} -ec \end{aligned} \tag{9}$$

Suppose that x^*, u^*, y, v, T are given, then the acceleration a of the follower for the time period (t, t+T) must be determined such that the headway constraint is not violated.

Two possible cases can arise.

1. The follower has a speed $v^* > 0$ at time t+T

2. The follower comes to a stop during the interval $(t, t+T)$. Let this occur at time $t+pT$ where $0 < p \leq 1$.

Case 1:
$$v^* = v+a(T-c)$$
$$y^* = y+vT+a(T-c)^2/2 \tag{10}$$

Case 2:
$$v^* = v+a(pT-c)=0$$
$$y^* = y-v^2/2a \tag{11}$$

Substituting now for v^*, y^* in expression (9)

$$x^*-y^* \geq L+cv^*+(v^{*2}-u^{*2})/2e \quad \text{if } v^* \geq (u^{*2}+e^2c^2)^{1/2} -ec$$
$$x^*-y^* \geq L \quad \text{if } v^* < (u^{*2}+e^2c^2)^{1/2} -ec \tag{12}$$

and from expressions (10), (11) and (12)

$$x^*-y-vT-a(T-c)^2/2 \geq L+cv+ca(T-c)+[(\{v+a(T-c)\}^2 - u^{*2}]/2e$$

when $v^* \geq (u^{*2}+e^2c^2)^{1/2} -ec > 0$

and $x^*-y-vT-a(T-c)^2/2 \geq L$

when $0 < v^* < (u^{*2}+e^2c^2)^{1/2} -ec$

and $x^*-y+v^2/2a \geq L$

when $v^* = 0$

or

$$-a^2[(T-c)^2/2e]-a[(T-c)^2/2 + c(T-c) + 2v(T-c)/2e]$$
$$+ [x^*-y-vT-L-cv-(v^2-u^{*2}/2e] \geq 0$$

when

$$v^* \geq (u^{*2} + e^2c^2)^{1/2} -ec > 0 \tag{13}$$

and $$-a[(T-c)^2/2] + x^*-y-vT-L \geq 0 \tag{13}$$

when $$0 < v^* < (u^{*2}+e^2c^2)^{1/2}-ec \tag{14}$$

and $$a \leq -v^2/2(x^*-y-L)$$

$$\text{when } v^*=0 \tag{15}$$

Expression (13) reduces to

$$a^2+a[e+2ec/(T-c)+2v/(T-c)]-(2e/(T-c)^2)[x^*-y-vT-L-cv-(v^2-u^{*2})/2e] \geq 0$$

and this gives

$$a < -B/2 + [B^2+4C]^{1/2}/2 \tag{16}$$

where $B = e+2(ec+v)/(T-c)$

and $C = \{2e/(T-c)^2\}[x^*-y-vT-L-cv-(v^2-y^{*2})/2e]$

The condition $v^* \geq (u^{*2}+e^2c^2)^{1/2}-ec > 0$ reduces to

$$v+a(T-c) \geq (u^{*2}e^2c^2)^{1/2}-ec > 0$$

or

$$a \geq [(u^{*2}+e^2c^2)^{1/2}-ec-v]/(T-c) > 0 \tag{17}$$

Expression (14) recuces to

$$a \leq 2[x^*-y-vT-L]/(T-c)^2$$

$$\text{provided } 0 < v+a(T-c) < (u^{*2}+e^2c^2)^{1/2}-ec \tag{18}$$

or

$$-v/(T-c) < a < [(u^{*2}+e^2c^2)^{1/2}-ec-v]/(T-c)$$

Expression (15) reduces to

$$a \leq -v^2/2(x^*-y-L) \qquad (19)$$

provided $a \leq -v/(T-c)$

Expressions (16), (17), (18), and (19) are the constraints which determine the following vehicle's acceleration which must be maintained to satisfy the emergency non-collision conditions.

Provided the vehicles are in a safe position at time t, then the above constaint set will be sufficient for the vehicles at time t+T. In particular, B^2+4C is always positive and thus the acceleration given by expression (16) has a real value.

The emergency constraint, however, is also used in the lane changing mechanism where the vehicles (in adjacent lanes) may not be in a safe position relative to each other in a longitudinal sense. In this case the following can occur:

(1) The above constraint set provides a real acceleration but it is < e and thus the lane change is not initiated.

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

(3) In the case $u^* = 0$ and $x^*-y \leq L$, then expression (19) operates and gives a spurious result. Thus expression (19) is modified for lane changing such that the lane change cannot be initiated if

$$v^*=0 \text{ and } x^*-y-L < 0 \qquad (20)$$

Once again this occurs only if the two vehicles are in an unsafe relative position for occupying the same lane.

Appendix C

ANNOTATED BIBLIOGRAPHY

1. Car-Following Models

Bexelius Sten, "An Extended Model for Car Following", Transportation Research, Vol. 2, No. 1, March 1968.

This paper attempts to refine the basic car following models by assuming that every driver reacts to several of the preceding vehicles. A model is suggested and discussed and a stability criterion is found. It is pointed out that the "reciprocal-spacing-model" gives a critical velocity below which flow is unstable. It is assumed that to load a road section to its theoretical capacity, the corresponding optimum velocity must be in the stable range. Based on this assumption, maximum flow is limited by S/2T, where S is a constant depending on the ratio of sensitivity coefficients and T is response time.

D. E. Blumenfeld and G. H. Weiss, "Gap Stability in the Light of Car Following Theory", Transportation Research, Vol. 7, No. 2, June 1973.

This article presents an elaboration upon a basic car-following model with acceleration noise for predicting the statistical properties of a gap measured at two points in a traffic stream. If the noise term is assumed to be Gaussian, then, in a linear theory, the gap itself will have a Gaussian distribution. The variance can be calculated, and the resulting theoretical description reproduces some of the features found earlier in experimental measurements by J. H. Buhr.

A. D. May and E. Keller, "Non-Integer Car-Following Models", Highway Research Record No. 199, 1967.

This paper consists of four major parts. First, a brief background is given of microscopic and macroscopic theories of traffic flow, with special emphasis on their interrelationships. Second, a comprehensive matrix is developed which results in the set of steady-state flow equations, which includes the major macroscopic and microscopic theories. Third, analytical techniques are developed for evaluating the various theories on the basis of experimental data. The last section deals with the investigation of a continuum of non-integer car-following models for the development of deterministic flow models describing the inter-relationships between flow characteristics.

G. F. Newell, "Nonlinear Effects in the Dynamics of Car-Following", Operations Research, Vol. 2, No. 9, 1961.

The purpose of this paper is to show that with a non-linear car-following model of the type, $V_j(t)=G_j [X_{j-1}(t-\Delta)-X_j(t-\Delta)]$, it is possible to incorporate into a single theory all the results previously derived for linear car-following models and the nonlinear phenomena previously obtained from continuum theories. Thus, the model includes most that has been contained in prior models for dense traffic flow. In addition, it allows the investigation of such things as the development of shocks, shock profiles, the range of validity of previous theories and the spreading of an acceleration wave.

It is assumed in this model that the velocity of a car at time, t, is some nonlinear function of the space headway at time, $t-\Delta$, so the equations of motion for a sequence of cars consists of a set of differential difference equations. The author argues that there is a special family of velocity-headway relations that agrees well with experimental data for steady flow and that also gives differential equations which can be solved explicitly for $\Delta=0$. Exact solutions of these latter equations show that a small amplitude disturbance propagates through a series of cars in the manner described by the various theories.

T. H. Rockewll, R. L. Ernst and A. Hanken, "Sensitivity Analysis of Emprically Derived Car-Following Models", Transportation Research, Vol. 2, No. 4, 1968.

This effort examines the sensitivity of empirically derived regression models of car-following. Data were collected from coupled two-car units (a lead car and a following car) in light traffic and in dense expressway traffic. Inter-vehicular spacing and velocities and accelerations for each of the cars were obtained. The sensitivities of these variables to the operating conditions were modelled. Delays in the variables were investigated using a computer simulation with empirical data. The principal findings were (1) overall, car-following is quite linear, (2) the goodness of fit of any model is influenced by stream velocity and time delays. These results are discussed in terms of the generality of car-following models with respect to the driving population.

W. E. Wilhelm and J. W. Schmidt, "Review of Car-Following Theory", Transportation Engineering Journal of the American Society of Civil Engineers, Vol. 99, No. T.E.4, 1973.

The authors indicate here that the steadily increasing volumes of traffic and the accompanying concern for safety have spawned the need for a thorough understanding of the dynamic characteristics of vehicular flow. A number of theories, approximately 30 models in all, have been advanced in the attempt to provide such a mathematical description of highway traffic.

The appeal of this article is the brief history of car-following models and a rather comprehensive bibliography of closely associated work.

2. Traffic Simulation Models

J. H. Buhr, T. C. Meserole and D. Drew, "A Digital Simulation Program of a Section of Freeway with Entrance and Exit Ramps", Highway Research Record No. 250, 1968.

This paper describes a computer program developed for the simulation of a section of freeway, including several exit and entrance ramps. The program allows for the simulation of the traffic operation under different modes of entrance ramp control. These are fixed-rate metering, demand-capacity metering, gap-acceptance control and no control. The computer logic and simulation techniques are discussed in detail. Limited output of the program is presented as evidence of the feasibility and realism of the simulation model.

Connecticut Department of Transportation, "Traffic Flow Simulation Model", 1969.

This work represents a progress report on a flow simulation model which was being developed for highway engineers as a tool for investigating, evaluating, and solving expressway design problems. The model simulates vehicle flow on freeway-type facilities, including all elements of design and operation that affect flow and capacity. The effect of grades and curvature, sign spacing, and lamp placement are included. The model is based on the premise that each vehicle in the traffic stream has a desired speed that motivates its actions. The UNIVAC Model is capable of simulating a five-mile section of expressway, seven lanes directional, with ten on-ramps and ten off-ramps. The vehicle characteristics which seem to have significant effect on the model are: gap acceptance, desired speed, headway preference, and acceleration and deceleration. The model was calibrated by varying these input components until the results fell within reasonable statistical range of duplicating actual field observations.

M. J. Craft and J. L. Smith, "Road Traffic Simulation", Plessey Communication Journal, Vol. 1, No. 2, 1967.

This article reviews simulation work in the road traffic field and discusses a computer program which has been written to simulate traffic passing through a sequence of linked traffic signals. By adjustment of the input parameters, a wide variety of traffic situations can be studied. The timing of the signals, the number of phases and the corresponding traffic movements, the volume of through traffic and of traffic turning into and out of the intersections, can all be specified by the user, as can the speed distributions and other aspects of traffic behavior. The output gives the traffic flows achieved and the delays incurred at each stop line. The method was tested by comparison with actual observations of a real life situation, and it is shown how the program may be used to compare the merits of various signal timings, and to study the effect of changes in traffic behavior.

L. Eisenberg and E. Kaplan, "An Investigation of Car-Following Model Using Continuous System Model Program (CSMP) Techniques", Pennsylvania University Transportation Studies Center, Project No. Urt-8, June 1971.

Quantitative methods for modeling car-following dynamics are explored. The behavior of grouped road vehicles is predicted according to empirical relationships between vehicle performance specifications, roadway surface conditions and driver characteristics. By development of mathematical equations to correlate these variables, traffic dynamics can be simulated without field experiments. The concept of traffic simulation is described in detail along with various stages of model building. The basis of the car-following simulation is the continuous system modeling program (CSMP), a special computer program developed to integrate various hypothetical conditions. Computer printouts are contained in the paper which reveal the effectiveness of the CSMP in actual operation. It is concluded that traffic flow may be better understood from the viewpoint of dynamic simulation modeling.

Fox and G. Lehman, "A Digital Simulation of Car Following and Overtaking", Highway Research Record No. 199, 1967.

This article introduces a model representing the single lane no-passing driving situation and was formulated and run on a digital computer. Although the model involves the use of conventional car-following equation, the simulation also includes human factors, such as reaction time lag, driver sensitivity, and the threshold of detection of relative velocity. The model allows for variation of these characteristics both between drivers and overtime for each individual driver. The study was directed to the accident prevention problem with the aim of determining the critical parameters of the driving situation, and of ascertaining the ranges of values of these parameters which define a safe or stable driving situation.

G. W. Harju, "An Advanced Computer Concept for Freeway Traffic Flow Modeling", presented at the Summer Simulation Conference in San Diego, Calif., June 1972.

This work introduces a freeway network traffic flow simulation system developed by the Aerospace Corporation which can accept any freeway road configuration under any possible traffic conditions. Complex freeway interchanges, lengthy networks with any number of on-ramps and off-ramps, and intricate weaving sections connecting on-ramps and off-ramps can be handled by this program. The input module was designed to accept freeway geometry identical to the conventions used on the freeway designer's coordinate control maps. A unique feature of the model is the optional capability to produce computer generated traffic flow movies of any specific subarea of the network under simulation. The movies appear as stationary overhead aerial shots and are used for detailed flow analysis, program debugging, and as an aid during the computer program validation process. Other features include any type of traffic control system, and grade and curve effects. The simulation is microscopic with random assignment of individual driver attributes. Detailed programming has produced optimum execution times and the size of the freeway network being simulated is restricted only by the computer capacity.

D. R. Korbett, "Digital Simulation Model of Freeway Traffic Volume 1: Model Description", Final Report prepared for the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, Contract No. CPR-11-3661, January 1966-November 1968.

This report describes the freeway simulation model developed at the Midwest Research Institute over a number of years. A typical general logic is used with vehicles attempting to travel at their desired speeds and changing lanes to avoid slower vehicles or enter or leave the freeway. The car-following algorithm is a fail-safe type formulation which is rather complex and includes several parameters to be calibrated. The lane changing mechanism operates on the decelerations that are required of the changing vehicle and its new follower. If these decelerations are below a certain threshold (termed the acceptable risk), the lane change proceeds with the vehicle changing lanes over one time period (one second). For vehicles making forced changes, a capability to scan several potential gaps to change into is included. The simulation includes variable driver and vehicle characteristics and has been running successfully although with a rather long computer running time.

U. Larsson and R. Ludin, Urban Traffic Simulation, Gothenburg Studies in Business Administration, Basagatan 3, Gotenborg, 1971.

The stated purpose of the book is first to sketch a systems approach to be applied in studies of urban traffic systems. Second, to supply a "philosophy" for simulation model formulation, and third to present a digital simulation model to use for the determination of signal programs for traffic signal systems in an urban environment. The basic version of the model is applicable to pretimed signal systems while the expanded version, formulated by Ake Lindstrom, is applicable for traffic actuated control.

Topics included in this book include a discussion of a systems approach to urban traffic planning and control. This involves the development of a hierarchy of urban traffic systems, various control techniques, strategies vs. tactics and a working definition of an urban traffic system.

Also included is a brief history and the presentation of characteristics associated with traffic simulation models, such as actual traffic situations, time-keeping, representing the system and the Fortran computer oriented characteristics.

Finally, the basic model is described in terms of modules and elements; the use of code numbers, and the use of matrices. Representation schemes are given for the control system, the vehicles and various events. Some attention is devoted to submodels such as for queue discharges, vehicle generation and link passage, in addition to a discussion of efficiency criteria.

S. D. Leland, "A General Traffic Flow Simulation Model for Freeway Operation", Connecticut Department of Transportation in 1970 and by the U.S. Bureau of Public Roads in 1969.

A freeway traffic simulation model is presented together with a user's manual. The major portion of the paper is devoted to the validation effort. The principal goal of the project was to develop a model capable of simulating vehicle flow on freeway facilities including elements of design and operation that affect vehicle flow and capacity. The logic of the resultant model is discussed in detail with typical values given for the various driver characteristics that are required as input. Model implementation is illustrated with simulation of two freeway sections. One, a weaving section with several design alternatives, and two, a complex mile section of urban freeway with five off-ramps and multiple weaving sections. The model capacity is a five-mile section of expressway with up to seven lanes directionally, ten on-ramps, and ten off-ramps with up to 1000 vehicles in the system at any one time. The program takes up to three minutes to simulate one minute of real time. The vehicle characteristics considered are: gap acceptance, desired speed, headway preference, acceleration and deceleration. The principal limitation of the model appears to be that it does not relate vehicle performance to the profile of the roadway.

E. B. Lieberman, "Simulation of Corridor Traffic: The SCOT Model", Highway Research Record No. 409, 1972.

The increasing activity in controlling access to freeways for the purpose of improving traffic flow has focused on the need to develop control policies for treating the entire corridor network system. This system comprises freeway, servicing ramps, frontage road, and parallel and feeder arterials. It has been observed that ramp metering, while improving conditions on the freeway, can precipitate congestion on the grade roadways. The SCOT model was developed as an evaluative and design tool to predict the performance of alternative control policies and freeway configurations prior to field implementation. A dynamic representation of traffic flow is produced by the model. This paper describes the capabilities and prominent features of the model and some of its representative results.

E. B. Lieberman, R. D. Worrall and J. M. Bruggeman, "Logical Design and Demonstration of UTCS-1 Network Simulation Model", 1972.

A description is given of a microscopic simulation model designed as an evaluative tool for urban traffic control policies. The need for such a tool is explored, and the underlying benefits of the simulation approach are discussed. The logical structure of the model is described; the input requirements and statistical output generated by this FORTRAN-coded program are detailed, and samples are illustrated.

The requirements and objectives originally assigned to the UTCS-1 model are presented. The design of this model for the study of urban traffic flow and dynamic signal control systems was directed to satisfy the following objectives:

The model must accurately describe the real-world dynamics of urban traffic and respond to a wide variety of controls, including responsive systems actuated by an on-line digital computer; the traffic dynamics must be expressed in terms of significant traffic parameters and measures of effectiveness that characterize the performance of each component of the network; the accuracy and reliability of these results must satisfy the basic research objective of utilizing the model as a diagnostic engineering tool for the evaluation of alternative policies of traffic control, channelizations of traffic, and turning and parking restrictions, for any urban network configuration and composition of traffic, including buses.

The resulting model is a balance between considerations of sufficient detail to accurately describe the system and considerations of practical utility, such as running time and core storage restrictions of available computers. It is programmed to be acceptable to all computers regardless of manufacturer, and it requires a minimum of data acquisition and preparation.

J. H. Mathewson, D. L. Trautman and D. L. Gerlough, "Study of Traffic Flow by Simulation". This article appeared in Highway Research Proceedings No. 34, dated 1955.

The paper embraces certain philosophies and approaches in the utilization of modern computers to solve traffic problems. It concludes that computers, used as simulators, offer considerable promise in the solution of such traffic problems as investigating the effects of traffic control devices in advance of installation and predicting the effect of proposed changes on the capacity of a facility.

The concept of vehicle flow rate or, alternately distribution of gaps, finds general utility in approaches of both analysis and simulation. Ideally, the behavior of a simulator resembles that of the real situation under study by virtue of the postulates laid down by the investigator. The authors state that such a model encompasses both the structure and the dynamics of the movement of intersecting streams of vehicles in terms of flow paths, queueing, waiting, proceeding ahead and turning subject to delays caused by cross traffic and pedestrians.

Since this article represents one of the pioneering efforts in this area of research it focuses closely on the probable types of flow diagrams or algorithms which appeared feasible. The study addressed the problem as a "discrete-variable simulator" and a "continuous variable model".

K. C. Sinha and F. Dawson, "Digital Computer Simulation of Freeway Traffic Flow", Traffic Quarterly, Vol. 24, No. 2, 1970.

It is shown that the techniques of dynamic simulation on a digital computer can be well utilized in the analysis of traffic flow on multi-lane freeways. A non-technical review of the most prominent simulation models developed up to 1970 is contained in this work, as well as a discussion of the essential aspects of such models.

A comprehensive general model was developed and validated to simulate traffic flow on a freeway system with five through lanes, four on-ramps and six off-ramps. Presented in rather gross mathematical form, the model is intended somewhat as a guidepost and can be used to study traffic flow on a section of a freeway with a maximum length of 3 1/2 miles, with both right- and left-hand on-ramps.

P. Warnshuis, "Simulation of Two-Way Traffic on an Isolated Two-Lane Road", Transportation Research, Vol. 1, No. 1, 1967.

The author states that one of the open problems in traffic flow theory is to describe the flow of two-way traffic on a two-lane road. The problem offers many natural complexities such as hills, curves, intersections and speed zones. He indicates that although such factors are important from an applied standpoint, they tend to obscure the intriguing aspect of the problem: the manner in which the interaction between the two lanes affects the flow in each. As an aid to developing a theoretical description of this interaction, he has constructed a computer simulation in which the behavior of individual cars is modelled directly. The purpose of the paper is to describe this simulation and to present some numerical results obtained with it. A good basic list of terms are defined along with a clear statement of model assumptions. Model inputs are given in non-technical terms as well as ten fundamental rules governing simulated flow.

R. D. Worrall and A. G. R. Bullen, "Lane-Changing on Multi-lane Highways", Bureau of Public Roads, Federal Highway Administration, U.S. Department of Transportation, Final Report, Contract CPR 11-5228, 1969.

Although this work is quite comprehensive and relates to several modeling efforts, Chapter 4, entitled "A Simulation Model of Lane-Changing on a Multilane Highway" proves to be of particular importance to this report.

This chapter describes a digital simulation model of lane-changing behavior. The model simulates the motion of individual vehicles in a multilane traffic stream, subject to varying assumptions concerning speed and headway distributions, car-following rules and gap acceptance. The model generates as output counts of lane changes and estimates of lane-change delay, both expressed as functions of the input parameters.

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SUGGESTED TOPIC CLASSIFICATION:

A. Traffic Flow Theory
B. Car-Following Models--Math
C. Lane-Changing Models--Delays--Math
D. Simulation Techniques

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.