THE DEVELOPMENT OF A DIGITAL SIMULATOR FOR
THE ANALYSIS OF FREEWAY TRAFFIC PHENOMENA

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INTRODUCTION

Since the beginning of the Machine Age, no development has had an impact of such tremendous magnitude as has the ever increasing use of motorized transportation. Over the last few decades a steady attempt has been made to design highways to conform to the needs of modern traffic. Freeways are the ultimate result of this attempt.

The multilane freeways of today have brought the urban and commercial areas much closer to each other; and they have compressed the distances between recreation areas, sea and mountain resorts, the cultural and political centers and the dwellings. In other words, freeways are now essential in order to keep pace with the growing demand for mobility in present day life which is based on a new scale established by motorized transportation.

A freeway may be defined as a divided arterial highway, for through traffic, with full control of access. A freeway traffic system mainly consists of several through lanes to accommodate the high speed traffic stream, and a number of on and off-ramps through which vehicles may enter or leave the freeway.

In recent years the demand for freeway-type facilities has increased many fold. In order to provide
for the convenient and efficient transportation of persons and goods substantial capital outlays have been made for the construction of thousands of miles of these facilities. As the construction program for building more and more miles of freeways throughout the country has gained momentum, traffic engineers have become concerned with the lack of knowledge about the characteristics of freeway traffic phenomenon. This deficiency of knowledge has so far made it difficult for the traffic engineers to develop an efficient design for the proposed system, or to suggest the necessary modifications to be undertaken in an already existing system in order to correct the traffic problems associated with it.

So far as the functional aspects of the planning and design of a freeway traffic system are concerned, some of the problems that remain yet to be solved include:

1. the optimum distances between interchange areas,
2. the length of acceleration lanes required for direct on-ramps,
3. the location of exit signs upstream from off-ramps,
4. the operational impact of various traffic volumes and the presence of commercial vehicles in the freeway lanes and on the on-ramps,
5. the effect of maximum and minimum speed
limits,
6. the effect of left hand on-ramps and off-ramps on the operational characteristics of the traffic stream,
7. the effect of grades,
8. the design of merging and diverging areas including weave sections,
9. the relative efficiency of alternate route design proposals.

The criteria for the solution of these problems depend on analyses of traffic movements in the system. For example, the optimum distances between interchanges could be obtained by locating them at various distances and then evaluating respectively the quality of traffic flow derived or the turbulence resulting in the traffic stream near the merging and/or diverging areas. This requires a tool by means of which the operation of the freeway can be analyzed as a system. By varying the input parameters of this system the resulting performances could be evaluated thus enabling one to arrive at an optimum design. Such a tool could be provided if a general model to represent the complex traffic problem of a freeway system could be developed, thus making possible the study of traffic characteristics in the laboratory rather than in the field.

Theories of Traffic Flow

Over the last few decades various theories and
techniques have been put forward to describe and to ana-
lyze the flow of a vehicular traffic stream. It is pos-
sible to broadly categorize these theories and techniques
under the following four major headings:

1. analytical or deterministic models,
2. statistical or probabilistic models,
3. continuum or hydrodynamic models,
4. Monte Carlo simulation models.

In the first type of model two factors are considered—
the motion of isolated vehicles and the interference of
vehicles with each other. These factors are described in
terms of the geometric and physical characteristics of the
vehicle and the assumed behavior of the driver. Car-
following theory is an example of an analytical model (8, 29, 47, 74) in which the traffic stream is depicted as a
group of vehicles, that interact with one another and are
influenced by their environment. Each vehicle either ac-
celerates, decelerates, or remains at the same speed as it
follows another vehicle in the same lane. Thus this
theory describes the acceleration and deceleration pat-
terns of a platoon of vehicles travelling in the same di-
rection, and the flows resulting when the vehicles in the
platoon are controlled in various ways. In other words,
when specific values for vehicle characteristics such as
velocity and acceleration are known, and driver character-
istics such as following behavior are postulated, it is pos-
sible to describe the motion of a group of vehicles in one
lane.
The second category of models is based upon the concept that vehicle and driver characteristics vary along the highway. These variable phenomena of traffic have given rise to the stochastic approach in which the methods of probability and statistics are employed. In this approach the theory of queues is utilized to predict delay and queueing characteristics associated with signalized and unsignalized intersections, the on-ramp merging process and passing maneuvers on two-lane highways, etc. (65, 66, 67, 70, 84, 85, 86). This theory, in general, is inadequate to portray the complex nature of traffic flow such as that which takes place on a freeway, because it can only be applied when vehicles have essentially the same speed and when all vehicles enter the system at one particular point. However, it should be noted that queueing theory has been employed satisfactorily in cases where traffic is actually queued, velocity is uniform, and the driver has only a few maneuvering decisions.

In the third category of models, the theory of traffic flow is approached in terms of fluid or hydrodynamic flows (39, 62, 68, 87). Traffic has been considered as a compressible fluid having a particular density or concentration and a particular fluid velocity. The equation expressing the conservation of matter serves as the basis for empirical relations between flow and concentration on particular highways. This theory has been utilized to describe traffic characteristics under Bottle-
neck situations on one-lane sections of highway.

The fourth and last type of model is more a technique than a theory. In general, it is based on methods of synthetic random sampling of probability distributions that depict traffic flow phenomena in real world traffic situations. The first three approaches are limited by the fact that they basically describe vehicles in one-lane, one-way streams. Thus overtaking and passing maneuvers cannot be described by these models. A more comprehensive model is essential for purposes of describing flow on multi-lane highways. While such a general model may combine one or more of the above theories to depict the micro-aspects of some special situations, the basic structure of the model can only be developed by the technique of Monte Carlo simulation so as to create a dynamic representation of a real world situation. This is achieved by building a computer model that can be dynamically processed. The computer model essentially consists of several component mathematical models that describe the operating characteristics of the driver-vehicle combination in freeway traffic flow. The rapid development of computer software, along with the advent of high-speed computers in recent years, has made it possible to develop a simulation model of the complex freeway system.

In a freeway simulation model a vehicle is allowed to maneuver through the system according to predetermined decisions. These decisions will reflect actual
traffic behavior under certain probable conditions. Since such a model can provide any information about the stream at any point of the freeway at any instant or period of time, it is extremely helpful for a traffic engineer to employ it in experimentation directed at achieving optimum freeway design. Due to the reproducible character of the computer model, the results rendered by any changes in operating conditions can be tested with ease simply by changing the input parameters such as traffic volume, speed information, or freeway geometry, etc. The respective effects on the traffic flow can be evaluated by noting the changes in the computer output of the model in terms of qualitative measures of characteristics such as travel time along the section, service time on on-ramp merging area, speed-volume relationship, weaving, etc. Thus such a computer model provides a ready means for controlled experimentation that is impossible to perform with real traffic. Hence, it is obvious that a computer simulator holds an immense prospect in the field of freeway traffic control and operations.

**Purpose and Scope of Study**

The purpose of this study was three-fold:

1. to develop representative models for the various components of a simulator,
2. to develop a general simulation program for a freeway traffic system,
3. to evaluate the predicted performance of the proposed simulation model.

In the first phase of the study the various components of the proposed freeway simulator were identified and their respective models were developed on the basis of actual behavior of traffic observed in the field. The second phase was directed toward the development of the simulator. The simulator was built as a general model with respect to geometric configuration and other input information such as total traffic volume of the freeway, speed distribution, percentage of commercial vehicles in the stream, etc. The proposed model was developed for five freeway lanes, four on-ramps and six off-ramps. The maximum length of a freeway section that can be simulated was set at three and one-half miles with both right and left hand on-ramps. However, with proper consideration for computer storage capacity, any of these numbers can be changed in the input information in order to apply the model to particular freeway sections. The final phase of the study was directed at the evaluation of the predicted performance of the proposed model. This evaluation was accomplished using data already available from several traffic studies that had been conducted on other freeway facilities.
CHAPTER TWO

REVIEW OF COMPUTER SIMULATION OF VEHICULAR TRAFFIC FLOW

Computer simulation has brought traffic systems into the laboratory under practically limitless conditions. Because of the obvious advantages, computer simulation of vehicular traffic has attracted considerable interest among traffic engineers in recent years. Since the last World War computers have been used increasingly to expeditiously analyze problems that apparently did not lend themselves to expression in any other known mathematical form. This trend has gained tremendous momentum during the last few years with the appearance of high-speed computers. It was only during the middle of the nineteen-fifties that any work in traffic simulation was started.

Types of Computer Simulation

Simulation of traffic flow has been attempted in two types of computers—analogue and digital. Thus the simulation technique can be characterized either as analogue or digital according to the method of model formulation and the type of computer used. The distinction between these two types of computers is easily explained;
analog devices measure, whereas digital devices count. To be precise, the fundamental distinction between analog and digital computers is essentially the mathematical distinction between the continuous variable and the discrete variable.

**Analog Simulation**

Analog simulators using electric analogies have been proposed for the analysis of traffic at intersections (63). In such a simulator the parts of the system must be simulated simultaneously using one or more components in the computer for each component, or function, of the simulator. This requires the addition of more elements in the computer as the functions or components of the simulator increase. Apart from being expensive, such an addition is restricted by practical limitations. Also, it is not possible to employ stochastic variation in the elements to be simulated on such a computer. Moreover, the accuracy of an analog computer is dependent on the accuracy of its physical components. In general, analog simulation of vehicular traffic does not appear to be advantageous.

**Digital Simulation**

Unlike analog computers, digital computers handle the components or functions of the simulation one after another. While the analog simulator requires that all the
mathematical modes in the simulation must be expressed in the form of differential equations, the digital simulator commands no such restriction and used models described in logical words rather just in mathematical terms. Furthermore, the digital simulator offers a tremendous flexibility in model formulation.

The first work regarding the digital simulation of vehicular traffic flow appeared in 1956 (31, 38, 91). Since then several investigators have worked on different aspects of traffic problems utilizing electronic digital computers. The early models were limited in the complexity of the system simulated. Since the actual behavior of traffic in a particular system was not known to the extent that it is today many empirical assumptions were made. The physical limitations of contemporary computers in regard to both software and hardware also hampered the efficiency of the initial models. However, in recent years considerable progress has taken place both in the field of traffic engineering and in that of computer science. Many aspects of traffic flow theory, unknown to early investigators, have been formulated. Thus, for example, while early models used only one or two fixed velocities for the vehicles and allowed little flexibility in traffic behavior, later models have shown more sophistication in describing the continuity of traffic action.
as well as in describing driver behavior patterns. Along with this trend, the storage capability and the speed of digital computers have increased many fold. The development of simpler and more flexible programming language has also aided later investigators. Thus in recent years, the cross-fertilization of the two branches of science—traffic engineering and computer technology—has yielded an opportunity for more realistic traffic simulation.

**Historical Development of Digital Simulation of Vehicular Traffic**

In 1956 three digital simulators were reported in the literature. Oerlough (31) discussed the simulation of freeway traffic flow. A two lane section of one-quarter mile freeway without any on or off-ramps was the subject of his research. An additional one-sixteenth mile was added at each end of the section to eliminate the end effects. For the purpose of depicting the vehicles in the model a technique of physical representation was used. In order to measure the effectiveness of the model the delays and the number of lane changes were studied. But the results obtained were not compared with any field data because such data was not readily available.

Goode, Pollmar, and Wright (37, 38) developed a simulation model for a signalized intersection with two lanes in each direction. In this model the vehicles either turned right or left, or went straight ahead ac-
cording to some given distributions. In any event, chang-
ing from one lane to another was not allowed. The ve-
hicles were generated into the system on the basis of a
Poisson Distribution. In order to study the flow of traffic
resulting from the model, the average delay of the ve-
hicles in the intersection was computed under varying
conditions. In a later IBM 704 version of the model, a
dynamic picture of the intersection traffic flow was dis-
played on an output scope.

Wong (91) discussed the simulation of a very small
portion of a twelve-lane boulevard with six lanes each
way. A special feature of the study section was the pro-
vision of the left turn area between the median lanes. The
vehicles in the system were allowed to move left, right
or straight ahead. The rules of operation were arbitrar-
ily assumed and the performance of the model was judged
in terms of the distributions of transit times through the
system.

However, these early simulators were based on
very generalised assumptions and arbitrary rules of traf-
fic behavior. Nevertheless, they successfully establish-
ed the possibility of using digital simulation for solving
traffic problems.

The next major research effort in the develop-
ment of digital traffic simulation was reported by the
Midwest Research Institute in co-operation with the Bureau
of Public Roads. Perchonok, Levy, Glickstein and Findley
(35, 58, 73) utilized the technique of digital simulation to analyze freeway interchange design problems. They considered a section of freeway 17,000 feet in length with two on-ramps and two off-ramps. The simulation model was based on the statistical analysis of actual traffic data collected at a number of freeway locations. This type of analysis contributed to the development of comparatively more realistic component models. On the basis of actual data the models were developed to describe the relationship between (a) the total volume in one direction and the vehicle distribution in the lanes, (b) the average velocity and total traffic volume, and (c) the exiting vehicle distributions and distance from the off-ramp. Moreover, information was obtained to describe gap acceptance by merging vehicles from the on-ramps; and the relations to describe the velocity distributions in each lane at various traffic volumes were also explored. This work resulted in a model for the study of freeway traffic phenomenon. The model served as a mechanism for examining the effect of inter-ramp spacings and for analyzing the effect of various parameters such as total traffic volume, speed distribution, and lane changing, on freeway operations. Because this simulator was constructed as a general model it was useful as a tool for evaluating alternate design criteria. However, many of the decisions in the model were based on empirical relationships and arbitrary, rational judgement.
Helly (45, 46) used the digital simulation technique to study bottleneck situations in a single-lane traffic flow. He simulated the behavior of a platoon of vehicles using a car-following equation in which the acceleration of each driver was a function of his headway, his velocity difference from the car ahead of him, and other factors such as the error in judgement, perception error, and ability to extrapolate. Helly fitted the parameters of the model to data observed in a tunnel traffic and evaluated the resulting realism of the model with respect to the propagation of shock waves, flow-density relationship, and platooning.

Subsequent work by Wohl (90) served primarily as an objective appraisal of the application of simulation to traffic engineering. As an example he described a simulation program for a freeway merging area. For various combinations of shoulder lane and on-ramp volume the ramp vehicle delay data was computed in order to ascertain the capacity of the entering ramp. The problem of determining freeway on-ramp capacity was also the subject of a later study by Dawson (16, 18). A simulation model was developed to depict the flow of traffic on a freeway ramp. Quantitative measurements of delays and queue lengths of ramp vehicles under various combinations of shoulder lane and ramp volumes were then evaluated to determine on-ramp capacities.

Subsequently consideration was directed at the
analysis of traffic operations at urban intersections using simulation. Stark (81) constructed a model to simulate the flow of traffic on a nine block section of a city street with seven traffic lights and three stop signs. The vehicles in the model were allowed to accelerate, decelerate or to pass according to prescribed rules of operation. Like the work of Goode, et al. (38), an important feature of the output of this model was that the simulated movement of vehicles was output on an oscilloscope and was photographed at the end of constant increments in time so that the simulated operations could be viewed as moving pictures. Lewis (60, 61) developed a simulation model to determine volume warrants for intersection control. The study area consisted of a four-legged, right-angle intersection at which a low-volume, minor arterial street crossed a high-volume major arterial street. The delays encountered by the vehicles in the intersection were used as criteria for establishing volume warrents. The intersection controls considered included a semi-actuated signal and a stop-sign. A concurrent study by Kell (51, 52, 53) was directed at the simulation of traffic operations in an intersection of two, two-lane, two-way streets. Here again, both a stop sign model and a traffic signal model were studied to determine the relationship between vehicular delays and approach volumes. The effect of signal settings on traffic movement and delays was investigated by Katz (50). For this purpose he
developed a simulator to describe the movement of urban traffic in a network. Valton (88) also utilized the technique of simulation for predicting the performance of a system of urban road networks. The parameters of this model included the geometric layout of the system, the traffic controls, the spacing properties of the traffic, and the time-dependent origin and destination pattern of the traffic. The evaluation of the performance of the system was accomplished in terms of the simulated delays in the system.

The investigation of interchange design criteria was the object of two more recent simulation studies. Richard, Baker and Sheldon (75) attempted to establish optimum requirements for interchange design in terms of (a) the distance between nose points of adjacent loops on a clover leaf interchange, (b) the distance between interchanges, and (c) the length of acceleration lane required for a direct on-ramp. However, the proposed model was based on many arbitrary assumptions about the traffic behavior and no firm conclusion was drawn about the validity of the simulator performance. On the other hand, the simulation study conducted by Gafarian, Hayes and Mosher (28) emphasized the validation problem of the simulator. In their study a freeway diamond interchange was considered and unlike the other models the simulator was built on a macroscopic approach.

Since the development of car-following theory by
Gazis, Herman, and Potts (29) in 1959, several researchers have shown considerable interest in this approach. In a recent simulation study, Fox and Lehman (27) employed a car-following model as a basis for evaluating several driver and vehicle characteristics in single lane traffic. A trial and error method was adopted to determine the optimum values for the parameters utilized in the model.

The technique of digital simulation was also used to investigate the psychophysical characteristics of drivers in a traffic stream. Braunstein, Laughey and Siegfried (6) developed a digital computer model to simulate the behavior of the individual driver in an expressway traffic situation. A series of actual experiments in a highway situation were conducted and the verbal reports of the subjects were recorded. On the basis of these data a driving simulation model was built to establish the levels of various decision functions and parameters in a car-following situation. In another study Howat (49) investigated the driver-vehicle characteristics with respect to overtaking, following, and passing in a freeway traffic situation, and developed a decision table to determine driver behavior.

The most recent simulation study was reported by Buhr, Meserole, and Drew (7). The model was developed to simulate traffic on a section of freeway with a maximum of two exit ramps. The total number of freeway lanes
and on-ramps was limited inclusively to six. The maximum number of vehicles that could be allowed in the system at any time interval was five hundred. Though this model was more sophisticated than the initial ones, it still does not qualify as a universal model because of several gross assumptions regarding driver-vehicle characteristics.

It should be noted that all the simulation models described thus far fall into three major categories:

1. single lane or car-following models,
2. urban arterials or intersection models, and
3. freeway system models.
CHAPTER THREE

DISCUSSION OF PREVIOUS STUDIES ON
FREEWAY SIMULATION MODELS

Basically, a freeway simulation model is an abstraction, in mathematical form, of the various characteristics of the freeway system including the roadway, the vehicle, the driver, and the traffic and environmental conditions. The simulation of the real world system is effected by the dynamic solution of the inter-related components of the abstracted system on a digital computer. The operations involved in this process include mainly, the introduction of vehicles into the system, the movement of vehicles, or vehicle-driver units, through the system according to given rules of operation, and the removal of the vehicles from the system. Because a digital computer, unlike an analog computer, is a sequential processor, all of the operations cannot take place simultaneously. In fact even individual events cannot be processed continuously throughout the full life of the event. Hence both the distance and time along the system are quantified, and the operations of the component models are scanned successively according to established rules.
for operation. The scanning process can be executed as a periodic process, or it can be executed only upon the occurrence of a significant event. In "periodic scanning" the entire system is scanned once during each established unit of time—for example, one second—and the vehicles are advanced an appropriate distance for that time period. On the other hand, in "event scanning," the system is scanned and updated only at those critical points in time when significant events occur.

Gerlough's (31) study can be considered as the pioneer work in freeway simulation. Although the resulting model did not prove to be useful as a design tool, the study firmly established the potential value of digital simulation as a technique for analyzing freeway traffic phenomena. Gerlough's work was concerned more with the techniques of freeway simulation than with the actual application of the models to design problems. The same can also be said of Wong's work (91). Perchonok, Levy, Glickstein and Findley (35, 36, 56, 73) of the Midwest Research Institute were the first researchers to apply the techniques of digital simulation to the analysis of a design problem. Since then several investigators have utilized digital simulation as a freeway design tool. However, most of the effort has been focused on building realism into the proposed models. Buhr, et al. (7), of the Texas Transportation Institute, and Gafarian, et al. (28), of System Development Corpora-
tion have made some progress toward this goal.

**Gerlough's Study**

Gerlough (31) constructed a digital model to simulate flow on a simple freeway section consisting of only two through lanes without any merging or diverging areas. The general structure of the simulation model was developed on the basis of the following rules of operation:

1. Vehicles are generated at the beginning of the study area according to a given headway distribution.
2. Each vehicle entering the system is randomly assigned a desired speed from a known speed distribution.
3. Each vehicle is processed through the system at its desired speed, when possible; and in no case can it travel at a speed higher than the assigned desired speed.
4. A vehicle is maintained in the shoulder lane, if possible.
5. A vehicle is processed at a particular speed unless it encounters a slower vehicle ahead. In such a case, the vehicle will attempt to change to the left lane, overtake the slower vehicle and then come
back to the shoulder lane again. If lane changing is not permissible, the vehicle will decelerate to the speed of the slower vehicle ahead.

6. To create an image of movement of vehicles in the computer both distance and time are quantified.

Gerlough discussed several techniques for the representation of vehicles in the computer. Both physical and mathematical representations were presented along with the associated advantages and disadvantages.

The following figures of merit were suggested as criteria for the evaluation of simulation models:

1. average transit time through the system,
2. percent of vehicles travelling at speeds below their desired speeds or the time lost for this,
3. average delay in the system,
4. number of lane changes per unit time.

The model developed by Gerlough was not adequate to realistically represent a freeway traffic situation, because the rules of operation were too simplified, and the geometric configuration was too limited. Furthermore, Gerlough did not validate the performance of the proposed model.
Wong’s Study

Wong’s (91) study, like that of Gerlough, was involved more with the exploration of simulation techniques rather than the development of a realistic model. As an example, he proposed a simulation model for a twelve-lane boulevard with six lanes in each direction. Wong suggested that a vehicular traffic simulation model should include several essentially independent parts to afford descriptions of:

1. the road system,
2. the control systems,
3. car and/or driver behavior, and
4. data handling.

As in Gerlough’s investigation, both the distance and the time within the system were quantified. The study area was divided into a number of blocks each eighteen feet in length. The overall system was updated at one second time intervals. Vehicular speeds were assigned at discrete levels each 12.5 m.p.h. apart. The generation of vehicles into the system was effected by sampling a random number from a uniform distribution of random numbers and comparing it with a predetermined constant value. If this random number was less than a given value, a vehicle was generated. The assignment of speed levels to the vehicles and the decision process to change lanes were also accomplished by random sampling processes. The object of this simulation work was the analysis of vehicle
transit times through the system. Several transit time distributions were obtained by varying the predetermined constants that were used to generate vehicles or to make lane-change decisions.

Wong's model was based on rather arbitrary rules for vehicle-driver behavior, and therefore it was not validated for the purpose of studying freeway design problems.

Midwest Research Institute's Study

Perchonok, Levy, Glickstein and Findley (35, 58, 73) attempted to develop a general simulation model that could be applied to freeway interchange design problems. They were able to simulate a freeway section with three lanes in each direction with both on and off-ramps. A schematic diagram of the study area matrix is given in Figure 1. The input factors considered in their initial model included:

1. volume of entering and exiting vehicles,
2. distribution of vehicles between lanes,
3. velocity distribution of vehicles,
4. gap acceptance distribution of merging and weaving vehicles,
5. acceleration of entering vehicles,
6. deceleration of exiting vehicles, and
7. distribution of exiting vehicles between lanes.
Direction of Flow

Block 3999
Block 3998
Block 2999
Block 2998
Block 1999
Block 1998

I

Lane 3
Lane 2
Lane 1
Lane 5

Where
A = Ramp Input Location
B = Nose of On-Ramp
C = End of Acceleration Lane
D = Beginning of Deceleration Lane
E = Nose of Off-Ramp
F = Off-Ramp Output Location
T = Through Lane Input
O = Through Lane Output

FIG. 1. GEOMETRIC LAYOUT OF MIDWEST RESEARCH INSTITUTE'S STUDY
The following performance characteristics were provided as output:

1. volume of vehicles traversing the system in each lane,
2. volume of vehicles entering the freeway from each on-ramp,
3. volume of vehicles exiting the system at each off-ramp,
4. number of vehicles stopping on the acceleration lane,
5. length of queues on acceleration lanes,
6. number of vehicles that desire to exit but cannot,
7. distribution of through-vehicle traverse times,
8. distribution of ramp-vehicle traverse times,
9. average vehicle velocity in each lane, and
10. number of lane changes between adjacent through lanes.

Upon continuation of their research effort, the Midwest Research Institute improved the model initially developed. Kobett and Levy (56) altered and restructured the early version to improve its effectiveness. The
input information required for the revised version included:

1. Roadway information
   a. number of through lanes,
   b. analysis length and warm-up length,
   c. location and details of ramps,
   d. position of check locations,
   e. off-ramp exit decision locations.

2. Vehicle-driver information
   a. traffic volume for each through lane, on-ramp and off-ramp including the percentage of commercial vehicles in each stream,
   b. desired velocity for both passenger and commercial vehicles at each through lane, each on-ramp and each off-ramp—either a complete table or the mean and standard deviation of a normal distribution for each case,
   c. desired following distances for both passenger and commercial vehicles—either a complete table or the mean and standard deviation of normal distributions,
   d. acceptable time gap parameters for
vehicles on the through lanes, vehicles moving on the on-ramps and vehicles stopped on the on-ramps,
e. acceleration rates for both passenger and commercial vehicles,
f. minimum and maximum deceleration rates,
g. vehicle length for both passenger and commercial vehicles,
h. space gap parameters for the merging and weaving process,
i. on-ramp velocity factor—the ratio of desired velocity in the through lanes to desired velocity on the ramp.

The simulator program was subdivided into three parts, that provided the control logic for:

- vehicles on through lanes,
- vehicles on on-ramps, and
- vehicles on off-ramps.

The movement of vehicles along the freeway was based upon the assumption that vehicles attempt to travel at a desired velocity with a following distance not less than \((\text{DFD/\text{DV}}) \cdot V\); where \(\text{DFD}\) is the desired following distance, \(\text{DV}\) is the desired velocity, and \(V\) is the current velocity of a particular vehicle.
The output information provided by the model included:

1. distribution of transit times for all vehicles that pass through the simulated section,
2. distribution of vehicle velocities at every check location,
3. number of weaves between adjacent lanes,
4. length of queue on each on-ramp,
5. number of velocity changes occurring in each lane,
6. number of vehicles unable to exit at each off-ramp,
7. number of vehicles exceeding the specified maximum acceleration.

In another project in cooperation with the U.S. Department of Public Health, the Midwest Research Institute developed a simulation model to study accidents in a freeway environment. St. John (76) concentrated on following and overtaking maneuvers to identify the risk situations. Because the model was developed explicitly for the purpose of studying the accident phenomena, it is not usable as a general-purpose freeway design tool.

**System Development Corporation's Study**

Gafarian, Hayes and Mosher (28) developed a
simulation model for the analysis of freeway diamond interchanges. A schematic layout of the simulation area is given in Figure 2. The simulation program, which was structured as a macroscopic, significant event model, was divided into a sequence of four models, one of which provided the logic for the simulation of the total diamond interchange. A significant portion of the study was directed toward validation aspects. The results reported to date are for only a portion of the entire program.

Some of the input parameters that are currently required are given below:

1. Geometric characteristics,
2. Vehicle-driver performance characteristics,
   a. vehicle-driver type characteristics for velocity, acceleration, and deceleration,
   b. passing probabilities,
   c. final system and submodel velocities,
   d. density of the roadway,
   e. length and headway of vehicles.

The preliminary model resulting from this ongoing research study was partially validated against manually collected field data. These data consisted of:

1. freeway vehicle counts by the minute,
2. on-ramp vehicle counts by the minute,
FIG. 2. GEOMETRIC LAYOUT OF SYSTEM DEVELOPMENT CORPORATION'S STUDY
3. travel times through the system for freeway vehicles selected at random,
4. travel times through the system for on-ramp vehicles selected at random.

Texas Transportation Institute's Study

Buhr, Meserole and Drew (7) developed a freeway simulation model to be used in an investigation of the merging process. They were interested in the effect of traffic and geometric characteristics on merging operations and level of service. Their main objective, however, was to establish the role of digital simulation as a prospective tool for the study of freeway traffic control techniques, such as ramp metering. Consequently, an important feature of their model was the facility to simulate the merging process under various modes of on-ramp control.

A schematic layout of the simulated section is given in Figure 3. The input information essential to this simulator is listed as follows:

1. Geometric characteristics
   a. length of freeway section,
   b. number of lanes, from one to six,
   c. number of on and off-ramps, from none to five,
   d. locations and lengths of on-ramps and off-ramps,
FIG. 3. GEOMETRIC LAYOUT OF TEXAS TRANSPORTATION INSTITUTE'S STUDY
e. length of each acceleration lane,
f. location of ramp signal,
g. rate of grade,
h. locations of start and end of the grade section.

2. Traffic characteristics
   a. volumes of vehicles per hour in each lane,
   b. the proportion of vehicles in each lane that exit through each of the off-ramps,
   c. proportion of commercial vehicles in each lane.

3. Driver policy
   a. average acceleration and deceleration rates,
   b. minimum deceleration rate,
   c. maximum speed,
   d. location of exit decision stations,
   e. values of parameters for following distance and gap acceptance computations.

4. Vehicle performance
   a. maximum acceleration,
   b. maximum deceleration,

5. Program control:
a. scan interval,
b. analysis time,
c. warm-up time,
d. length of warm-up section,
e. number and location of each check station,
f. control information for plot-output.

The overall structure of this simulation program is similar to that of the Midwest Research Institute model. The basic rules for the operation of individual vehicles are governed by the comparison of the actual following distance with the desired following distance at each point in time. However, the internal bookkeeping technique contained in the Texas program is a noteworthy feature.

In addition to performance statistics such as travel times and volumes processed, the output information from this model includes time-space diagrams to display the movements of vehicles through the system in graphical form.
CHAPTER FOUR

COMPONENTS OF THE PROPOSED MODEL

The development of the proposed digital simulation model was realized in essentially two steps. First, models representing the components or the functions of the system were constructed in a mathematical format. Then, a program was written to dynamically process the component models, thereby synthesizing the changes in the state of the system. The development of the components of the proposed simulator are discussed herein.

Internal Bookkeeping

The internal bookkeeping of the system is perhaps the most important feature of a traffic simulation model. To achieve the successful operation of a simulation program, it is essential to have an efficient bookkeeping procedure that not only represents the traffic flow within the computer and keeps track of the vehicles in the system, but that accomplishes these tasks at a minimum expense in core storage and computer time.

Procedures Previously Used

In previous simulation studies several different methods were used to represent vehicular traffic flow within the computer. Gerlough (31) and Goode, et al. (38) used a
method of physical representation. In this method, the binary digits, 1 and 0, are used to indicate the presence of vehicles and the space between them, respectively. Groups of memory cells are assigned and organized in such a way as to represent the roadway, and by suitable algebraic manipulations the binary digit "1's" are caused to shift positions to depict the flow of traffic. Vehicles can occupy only certain cells within the memory area assigned for the roadway, and individual vehicles have no identity. Because this method of representation is so complicated it is not satisfactory for a complex freeway system simulation.

The second technique (32, 91) may be called the memorandum notation. Here an entire computer word is used to represent a vehicle. Various parts of the word are reserved for individual characteristics such as location, lane, current speed and desired speed. In this way, the characteristics of each vehicle are identifiable throughout the simulation process. Distance in the system to be simulated is quantified using a unit block which is one lane wide and has a length equivalent to a fractional part of the length of an average vehicle. Thus, a vehicle can occupy only a limited number of discrete positions. A vehicle can be advanced through the system by changing the record indicating the position of the vehicle at the end of pre-set time intervals. This is accomplished by multiplying the vehicle's speed by the time increment and adding the product to its position at the beginning of the
time period.

A third method of representation has been called mathematical notation (31). This technique is similar to the memorandum notation with the exception that each vehicle is associated with its own position indicator. Unlike the previous procedure, a vehicle's position is essentially continuous, and speed and acceleration characteristics are no longer step functions.

A fourth technique developed by Lewis (60, 61), is a modification of the mathematical notation. In this method the entire roadway system is represented by a three-dimensional mathematical array. The length dimension corresponds to relative position along the roadway; the width dimension represents the several traffic lanes; and the vertical dimension contains all the characteristic information for each particular vehicle. A circular array concept is utilized to circumvent the problem of the limited storage capacity of the computer. The ends of the array are mathematically connected to describe a roadway of sufficient length so as to handle the entire traffic within the system. Two special registers are used for each traffic lane to store the index position of the lead vehicle and the number of vehicles in the lane. With the aid of these registers the characteristics for any vehicle can be extracted by stating its relative position with respect to the lead vehicle.

The fifth and final procedure, reported to date,
is one that was utilized by Buhr, et al. (7). It was developed by Sandefur (77) and is known as list processing, or chaining. In this technique, each vehicle is assigned a subscript number between 1 and 500 and the characteristics of each vehicle are stored in an array so that the characteristics of any particular vehicle can be obtained by addressing the appropriate array with the subscript number of the vehicle. Every vehicle is also assigned a value in each of two characteristic arrays which represent the subscript numbers of the vehicles ahead of and behind the particular vehicle in the same lane. This simplifies processing, and results in a savings in computer time.

The Adopted Procedure

The technique utilized for internal bookkeeping in the proposed simulation program is a combination of memorandum and mathematical notation. Apart from the usual vehicle characteristics, such as desired velocity, position, etc., several indices representing various modes of vehicle-decision were identified for each vehicle. This resulted in a total of fourteen characteristics to be stored in the computer for each vehicle at each interval of time. With an extensive system like freeway section, where a large number of vehicles may be expected in the system at any point in time, direct storage of all characteristics would require large amounts of storage space in the machine core. Therefore, a technique was
developed by means of which the fourteen characteristics for each vehicle could be packed into only four computer words. Any of these four words could again be unpacked to give the stored characteristics for a particular vehicle at an instant of time. Figure 4 illustrates the storage of the characteristics in computer words.

The entire system was represented by a two dimensional array—the first dimension is an index that represents the vehicles, and the second dimension represents the corresponding packed words. To create an image of the physical layout of the roadway system in the memory of the computer, a second two dimensional array was used. This array contains the first dimension of the first array. The entire length of the section to be studied, including the warm-up lengths, was divided into a number of unit blocks that were each seventeen feet in length and one lane in width. The first dimension of the second array represents the number of the block in which the vehicle is located, while the second dimension of the array represents the corresponding traffic lane. In other words, the second array provides the relative position of any vehicle in the system, corresponding to the second array. In the proposed model the general register comprising the first array is represented by

\[ \text{INDEX} (N, M) \]

where, \( N \) = vehicle index between 1 and 2000,

\( M \) = index for packed computer words between

1 and 4.
FIG. 4. ILLUSTRATION SHOWING STORAGE OF VEHICLE-DRIVER CHARACTERISTICS IN COMPUTER WORDS
The dimension $N$ again corresponds to the second array which is given by:

a. $IDW(J, I)$ for through lanes:
where, $J =$ number of unit blocks between 1 and 1000,
$I =$ number of lanes between 1 and 5.
b. $IDWR(JR, IR)$ for the on-ramps including acceleration lanes:
where, $JR =$ number of unit blocks between 1 and 100,
$IR =$ number of on-ramps between 1 and 4,
c. $IDWX(JX, IX)$ for off-ramps including deceleration lanes:
where, $JX =$ number of unit blocks between 1 and 100,
$IX =$ number of off-ramps between 1 and 6.

As vehicles are introduced into the system they are numbered sequentially and stored in the system in one of the three vehicle-index arrays depending on their location. During the simulation process, the movement of any particular vehicle is represented by shifting its index number within the same matrix or from one matrix to another. Its exact location in the system is recorded at every time interval in one of the packed words. As a vehicle goes out of the system its characteristics are
deleted from the general register and the index numbers of all the vehicles, that are equal to or greater than the index number of the outgoing vehicle, are updated by one. The general register is updated accordingly.

Selection of the Scan Interval

Due to the discrete nature of the digital computer, decisions associated with the movement of all vehicles through the system cannot be effected simultaneously. Since the computer can make only one logical choice at a time the decisions involved with all the entities in the system are scanned sequentially at prescribed intervals of time. The total real time that is simulated in the system is quantified in a number of equal scan intervals. The selection of this increment of time is an important aspect of any simulation model. If the time increment is too large, the simulator will lack realism because the occurrence of many events cannot be considered. If the scanning interval is too small, too much computer time is required. In most of the previous simulation models a one second time increment was found to be satisfactory. Considering the extent and the complexity of the present problem the scan interval for the proposed model was also established at one second.

Roadway Characteristics

A schematic diagram of a typical freeway section
is presented in Figure 5. The proposed model was developed for a freeway section with a maximum of five through lanes, four on-ramps and six off-ramps; the total length including the warm-up section was set at about three and one-half miles. Although no special feature, such as an operational lane, was considered in the general model, these situations can be included with minor modifications to the program logic.

The ramps were assumed to be direct on-ramps and off-ramps without consideration for the angle of convergence or divergence. No traffic control condition was assumed in the design of merging and diverging areas. The section considered was straight and level. However, with minor modifications to the program logic variations in the vertical geometry of the section could be introduced.

Vehicle-Driver Characteristics

Driver PIEV Time

The time lag for perception, intellect, and volition for a driver under emotional stress is grouped together as his reaction or response time to an external stimulus. Although the literature on this aspect of human behavior is extensive, no exact quantitative data are available. Forbes (25), Cumming (13, 14), Fenton (24) and several other investigators have studied the various factors involved with the reaction time of a driver. This time is variable from driver to driver, and even for the same driver from situation to situation.
FIG. 5. SCHEMATIC DIAGRAM OF A TYPICAL FREEWAY SECTION
The average values are given in a range between 0.29 to 1.5 seconds. It has also been reported that reaction time may be zero in some cases (60).

In the proposed model PIEV time requirements were not included as such. The existence of this driver characteristic is recognized, however, and was indirectly incorporated in appropriate applicable situations. The vehicles were allowed to react instantaneously to certain events, such as in the car-following situation. The inclusion of a response time lag in the car-following logic might have added realism, but it would not have had any significant effect on the performance of the overall simulation model. Moreover, Chandler, et al. (8), observed that a reaction time lag can cause instability. As a consequence of this, the speed changes of the following vehicle could be so amplified that a resonant condition might result.

Minimum Desired Spacing

The minimum desired spacing between a pair of vehicles is one of the most important features in any traffic simulation. It can be defined as the minimum safe spacing that a following driver should desire to keep behind a lead car. This spacing may be measured from front bumper to front bumper or, from the rear bumper of the lead car to the front bumper of the following car. In the later case, the spacing is the minimum clear
spacing between the two vehicles.

In the published literature, this element of safe distance between vehicles has been expressed in terms of both time headway in seconds, and distance headway in feet. However, under a given driving condition a distance headway between two vehicles can be approximately expressed in terms of time headway, by dividing the distance by the speed of the following vehicle.

According to Forbes (26) it is more useful to express the vehicle separation as a time headway. So far as the present means of traffic measurements are concerned it seems more reasonable to consider the spacings in terms of seconds rather than in feet, since the time headway can be directly obtained from field studies. However, in case of simulation of traffic problems where decisions for maneuvering are based on the separation of vehicles on the roadway, it is doubtful whether a driver can reasonably guess his time headway from the preceding car. In an actual situation a driver can see the distance spacing ahead and it is likely that he would estimate the distance more accurately than the time. Hence, in this study minimum desirable spacings were established in terms of distance in feet.

When vehicles are stopped in a queue the average minimum spacing measured from front bumper to front bumper has been observed to be approximately twenty-two feet (4, 40, 83). When vehicles are moving at the same speed,
the minimum desired spacing has been given in several references as a linear function of the speed (2, 11, 40). This linear equation can be written in the following general form:

\[ d_m = P + R \cdot V \]  

where, \( d_m \) = the desired minimum spacing in feet,

\( P \) = the jam concentration, or minimum spacing in a stopped condition in feet,

\( R \) = the brake reaction time in seconds,

\( V \) = speed of the stream in m.p.h.

This linear spacing equation can also be written in terms of the much quoted "California Driving Law":

\[ d_m = P + L \cdot V \]  

where, \( P \) = the jam concentration, or minimum, spacing in a stopped condition in feet,

\( L \) = one car length for each 10 m.p.h.,

\( V \) = velocity in m.p.h.

From the data reported in the 1950 Highway Capacity Manual it is evident that this relationship is not exactly linear. Several investigators have attempted to fit the observed data using quadratic equations (44), logarithmic transformations (48), and other non-linear forms. The spacing equation has also been expanded to include another term related to acceleration and/or deceleration (45). A recent work by Daou (15) gives the following equation for average minimum desired spacing.
between two cars in a platoon:

\[ d_m = L + C + R \cdot V \]  

\[ \text{eq. 4.1} \]

where, 

- \( L \) = length of lead vehicle in feet,
- \( C \) = constant independent of speed,
- \( R \) = reaction time in seconds,
- \( V \) = speed in feet per second.

By fitting several sets of data to Equation 4.3 Daou (15) obtained the following spacing equations:

\[ d_m = 31.9 + 1.37 \cdot V \]

\[ d_m = 35 + 1.49 \cdot V \]

In the proposed simulation model, the equation for minimum desired spacing was developed essentially as a linear relationship with the actual speed of a particular vehicle. It can be expected that the spacing desired by a following vehicle, that is travelling at a higher speed than the leading vehicle in the same lane, is greater than the spacing required when the following vehicle is at the same or lower speed than the lead vehicle. Therefore, a factor was introduced in the velocity term to compensate for the increased spacing required for a positive speed difference between the following and the leading vehicles. Moreover, it has been observed that under similar situations two drivers do not necessarily desire the same spacing. The minimum desired spacing varies even for the same driver under the same situation at different periods of time. Hence it can be assumed that the minimum desired spacing follows a statistical distribution. Since most
human behavioral elements are essentially normally distributed, a normally distributed parameter was introduced into the desired spacing equation. The generalised form of the minimum desired spacing may be expressed as

$$d_m = (C_1 + V_1 \cdot \text{CONST}) \cdot \text{PDF} \quad \text{eq. 4.4}$$

where,

- $d_m$ = minimum desired spacing between the rear bumper of the lead car and the front bumper of the following car, in feet,
- $C_1$ = length of the following car in feet,
- $V_1$ = actual speed of the following car at a time, $t$, in feet per second,
- CONST = variable parameter which depends upon the speed difference between the following and lead vehicles, at a time, $t$,
- PDF = following distance factor, normally distributed with mean 1.0 and standard deviation 0.1.

The parameter, CONST, is dependent on the speed difference between the two vehicles under consideration. When the following vehicle is travelling at a speed less than or equal to the speed of the lead car, the value of CONST is equal to 1.0. It varies linearly with a slope of 0.033; it has a maximum value of 2.5 when the speed difference is maximum. Therefore, it can be expressed as:

$$\text{CONST} = 1.0 + 0.033 \cdot (V_1 - V_2),$$

when $(V_1 - V_2) > 0$

$$\text{CONST} = 1.0, \quad \text{when } (V_1 - V_2) \leq 0 \quad \text{eq. 4.5}$$
where, $V_1$ = speed of the following car at a
time, $t$, in f.p.s.,
$V_2$ = speed of the lead car at a time,
t, in f.p.s.

Since on ramps vehicles follow much closer than
vehicles in through lanes, the values of minimum desired
spacings for ramp vehicles were assumed to be one-half of
the normal values.

Acceleration Characteristics

In most of the previous simulation studies both
acceleration and deceleration rates were assumed to have
constant values for all the drivers. These values were
provided as input information and were held constant
throughout the simulation process. It was recognized that
such generalization is somewhat unrealistic.

The average rate of acceleration for vehicles
whose movements are not constrained were determined on
the basis of a recent study by Dawson and Perrucio (19).
They developed an acceleration model as a function of
actual speed and desired speed of vehicles. This model
had the following form:

$$\text{acc} = f(V_a, V_d)$$  \hspace{1cm} \text{eq. 4.6}

where, acc = acceleration of vehicle of concern at time, $t$,
$V_a$ = actual speed of vehicle of concern at time, $t$,
$V_d$ = desired speed of vehicle of concern.
In application this model is integrated over increments of time, and throughout the entire period of integration the desired speed, $V_d$, remains constant. Since $V_a$ varies over time, acc is also forced to vary in accordance with the above equation. On the basis of the studies of Beakey (3) and Stonex (82) several acceleration models were developed and were compared with data presented in the 1965 *Traffic Engineering Handbook*. The proposed acceleration model was expressed as

$$\text{acc} = m + n (V_a)$$  \hspace{1cm} \text{eq. 4.7}

where, acc = acceleration of vehicle of concern at a time, $t$, in m.p.h. per second,

$m, n =$ two variable parameters dependent on the desired speed, $V_d$ of the vehicle of concern,

$V_a =$ actual current speed of the vehicle of concern at a time, $t$, in m.p.h.

The equations for the parameters, $m$ and $n$, were obtained by regression analyses and are given below:

$$m = 0.80847 + 0.15800747 (V_d) - 0.00089692 (V_d)^2$$  \hspace{1cm} \text{eq. 4.8}

$$n = -0.22501 + 0.00327593 (V_d) - 0.00001766 (V_d)^2$$  \hspace{1cm} \text{eq. 4.9}

where, $V_d =$ desired speed of the vehicle of concern, in m.p.h. Figures 6 and 7 present the variation of the parameters, $m$ and $n$, with respect to the desired speed.
Fig. 6. The relationship between the m parameter and the desired speed in the acceleration model.
FIG. 7. THE RELATIONSHIP BETWEEN THE n PARAMETER AND THE DESIRED SPEED IN THE ACCELERATION MODEL.
Deceleration Characteristics

The rate of deceleration for a vehicle is not a constant that is independent of the speed at which the vehicle is travelling; rather it is a function of the current speed and the desired speed of the vehicle. The general form can be given as following:

\[
\text{dec} = f (V_1, V_f) \quad \text{eq. 4.10}
\]

where, \( V_1 \) = actual current speed of the vehicle of concern at a time, \( t \),

\( V_f \) = actual final speed of the vehicle of concern at a time, \((t + T)\), \( T \) being any period of time after \( t \).

The deceleration rates and speeds of passenger vehicles approaching a stop sign from 20 to 60 m.p.h., as observed by Beakey (3), were presented in the 1965 Traffic Engineering Handbook. On the basis of this information deceleration rates were established for decelerating vehicles travelling at various speed levels. Figure 8 presents speed and deceleration rates reported in the 1965 Traffic Engineering Handbook. From this figure it is obvious that deceleration can also be expressed in a linear form just as acceleration was:

\[
\text{dec} = a + b (V) \quad \text{eq. 4.11}
\]

where, \( a \) = intercept of deceleration curve,

\[
= f (V_1', V_1'), V_1' \text{ and } V_1 \text{ being the actual veloc-}
\]
FIG. 8. OBSERVED SPEED AND FREE-FLOWING DECELERATION OF VEHICLES

(SOURCE: 1965 TRAFFIC ENGINEERING HANDBOOK pp. 26)
ties of the vehicle of concern at any point of
time, \((t - T')\) and the current point of time,
\(t\), respectively,

\[ T' = \text{any period of time lapsed between the time the} \]
\[ \text{vehicle started to decelerate and the current} \]
\[ \text{point of time, } t, \]

\[ b = \text{negative slope of deceleration curve dependent} \]
\[ \text{upon } V_{1}\]

\[ V = \text{velocity vector}. \]

The parameter, \(a\), is computed at every increment of time
on the basis of the action of the driver during the pre-
ceding time interval. It is zero at the point of time,
\(t - T'\), when deceleration starts. If the deceleration
process continues over several consecutive time intervals,
the respective values of the parameter, \(a\), are obtained as
discussed below.

It may be noted from Figure 8 that the rate of
change of deceleration remains essentially the same for
all the deceleration curves. Pending further research
the slope, \(b\), of Equation 4.11 has been assumed to be
\(-0.2\). This value approximately represents all the decel-
eration curves.

In actual application in the simulation program
vehicles are successively processed at every increment of
time and their characteristics are updated at the end
of the time period. In a situation where a vehicle is
decelerating it may do so over several consecutive time
periods. If a vehicle decelerates at a normal rate over several time increments, the deceleration can be expressed in the form of the following differential equation:

\[ \frac{dv}{dt} = a + bV \]  

\[ \text{eq. 4.12} \]

or,

\[ \frac{dv}{a + bV} = dt \]  

\[ \text{eq. 4.13} \]

The velocity vector, \( V \), can be obtained by integrating Equation 4.13 over time boundaries representing one increment of time, \( t \) and \( t + \Delta t \). The resulting vector describes the velocity at time, \( t + \Delta t \). If the actual velocity at time, \( t \), is \( V_i \) and the resulting velocity at time, \( t + \Delta t \), is \( V_f \),

\[ \int_{V_i}^{V_f} \frac{dv}{a + bV} = \int_{t}^{t + \Delta t} dt \]

\[ \int_{V_i}^{V_f} \frac{b \, dv}{a + bV} = \int_{t}^{t + \Delta t} dt \]

\[ \log \left( \frac{a + bV_f}{a + bV_i} \right) = b \Delta t \]

\[ \frac{a + bV_f}{a + bV_i} = e^{b \Delta t} \]  

\[ \text{eq. 4.14} \]
\[ a + bV_f = (a + bV_i) e^{b\Delta t} \]
\[ bV_f = (a + bV_i) e^{b\Delta t} - a \]
\[ V_f = \frac{(a + bV_i)}{b} e^{b\Delta t} - \frac{a}{b} \quad \text{eq. 4.15} \]

Equation 4.15 is a general model that describes the velocity of a decelerating vehicle at the end of a time increment, \( \Delta t \). A graphical example, depicted in Figure 9 and Figure 10, presents a typical speed-deceleration curve for a free-flowing vehicle. The vehicle begins to decelerate normally at time, \( t_1 \), with a velocity of \( V_i \). Since the intercept, \( a_0 \), is equal to zero at this point, the resulting velocity, \( V_{t_1 + \Delta t} \), at the end of a time increment, \( \Delta t \), or at time, \( t_1 + \Delta t \), is given by:

\[ V_{t_1 + \Delta t} = V_{t_1} e^{b\Delta t} \quad \text{eq. 4.16} \]

If the vehicle continues to decelerate normally for another time increment, \( \Delta t \), the resulting velocity, \( V_{t_1 + 2\Delta t} \), at the time, \( t_1 + 2\Delta t \), can be obtained from the following equation:

\[ V_{t_1 + 2\Delta t} = \frac{1}{b} \left( s_1 + b \left( V_{t_1 + \Delta t} \right) \right) e^{b\Delta t} - \frac{a_1}{b} \quad \text{eq. 4.17} \]

\( V_{t_1 + \Delta t} \) is known from Equation 4.16, and the values of \( b \) and \( \Delta t \) are constant. The value of the parameter, \( s_1 \), is obtained from Equation 4.18.
FIG. 9. SCHEMATIC DIAGRAM SHOWING DECELERATION PROCESS OF A VEHICLE.

FIG. 10. TYPICAL SPEED-DECELERATION CURVE FOR FREE-FLOWING DECELERATION OF A VEHICLE.
\[ a_1 = a_0 + \left( V_{t_1} - V_{t_1} + \Delta t \right) b \]

Equation 4.18

\( V_{t_1 - 2 \Delta t} \) can be computed by substituting the values of \( a_1 \), \( V_{t_1 + \Delta t} \), \( b \) and \( \Delta t \) in Equation 4.17. If the deceleration continues over successive time increments, the resulting velocities can be obtained in the same manner, until the mode of vehicle behavior changes.

Car-Following Model

A car-following model is another essential feature of a traffic simulation system; it is required for describing driver-vehicle behavior in those situations where the movement of the following vehicle is influenced by that of the lead vehicle. Several attempts have been made to develop models to describe this phenomenon. Analytical or deterministic theories based on experimental and theoretical investigation have been suggested \((8, 29, 46, 47, 57, 74)\). Continuum and/or hydrodynamic concepts have also been utilized by investigators to describe the resulting driver-vehicle characteristics of a platoon where the vehicles are following each other \((39, 68)\). Car-following equations describe the acceleration or deceleration of the of the following vehicle as a function of the relative spacing and the relative velocity between the pair of vehicles, and as a function of the reaction time of the following vehicle. However, most car-following studies have been concerned with the bottleneck or near capacity.
situations where vehicles tend to follow each other as closely as possible.

For the purposes of this freeway simulation study a more general car-following model, to describe a wide range of traffic volumes, was required. A model was developed from the acceleration and deceleration equations presented earlier in this chapter. The basic premise for the derivation of the proposed car-following model is that the vehicles do not come in physical contact.

One of the two cases may arise in any car-following situation:

1. the following vehicle is travelling at a velocity less than or equal to that of the lead vehicle, or
2. the following vehicle is travelling faster than the lead vehicle.

In the first case, the following vehicle will attempt to accelerate according to Equation 4.7. The following vehicle will accelerate only if it can maintain the minimum desired spacing, as described by Equation 4.4. The most critical case in a car-following condition, however, is the situation in which the following car is travelling faster than the lead car. Figure 11 presents the factors involved in the development of a car-following model for such a situation. In Figure 12 a time-space diagram depicts a following car travelling at a velocity, \( V_1 \), and a lead car travelling at a velocity, \( V_2 \), at a time, \( t_1 \).
FIG. II. FACTORS INVOLVED IN A TYPICAL CAR FOLLOWING SITUATION

FIG. I2. TIME-SPACE DIAGRAM OF A SITUATION WHEN THE FOLLOWING VEHICLE IS TRAVELLING FASTER THAN THE LEADING VEHICLE
After a time increment, $\Delta t$, the lead car is travelling at a velocity $V_2'$ and $V_1$ is faster than $V_2'$. If $V_2'$ remains constant, the following car travelling at a constant velocity, $V_1$, will eventually collide with the lead car. In order to avoid collision the following car must adjust its trajectory in such a way that after a period of time, $t_{eq}$, a safe spacing, $d_m$, will exist between the lead and the following vehicles. The decision to slow down will obviously be dependent upon the available spacing between the two vehicles at any instant of time. The spacing, $d_{cr}$, is the critical spacing at which the following vehicle must start to adjust its trajectory in order to achieve the same velocity as that of the lead vehicle at time $t_1 + \Delta t$ and to effect a safe spacing, $d_m$, between itself and the lead vehicle, over a time period, $t_{eq}$. In Figure 12:

- $X_1$ = the distance travelled by the lead vehicle during the time period, $t_{eq}$,
- $X_2$ = the distance travelled by the following vehicle during the time period, $t_{eq}$,
- $d_m$ = minimum safe spacing,
- $t_{eq}$ = time of equilibrium, i.e., the time required by the following vehicle to achieve the same velocity as the lead vehicle.

If the following vehicle decelerates at a normal rate, Equation 4.13 can be solved over boundaries, $V_1$ and $V_2'$, to compute the time of equilibrium, $t_{eq}$. 
\[ \frac{V_2'}{V_1} = \frac{t_{1+eq}}{t_1} \]  

or, \[ t_{eq} = \frac{1}{b} \log \left( \frac{a + bV_2'}{a + bV_1} \right) \]  

eq. 4.19

After a time period \( t_{eq} \), the velocity of the following vehicle, \( V_{eq} \), becomes equal to that of the lead vehicle, \( V_2' \), which remains constant during the time period between \( t_1 + \Delta t \) and \( t_1 + t_{eq} \). From Equation 4.15 the final velocity of the following vehicle can be written as,

\[ v_{eq} = \frac{(a + bV_1)}{b} e^{bt} - \frac{a}{b} \]  

eq. 4.20

or, \[ \frac{dx}{dt} = \frac{(a + bV_1)}{b} e^{bt} - \frac{a}{b} \]

The distance travelled by the following vehicle, \( x_2 \), during the time period, \( t_{eq} \), can be obtained from the model integrated below:

\[ \int_{0}^{t_{eq}} dx = \int_{0}^{t_{eq}} \left[ \frac{(a + bV_1)}{b} e^{bt} - \frac{a}{b} \right] dt \]

or, \[ x_2 = \frac{(a + bV_1)}{b^2} \left( e^{bt_{eq}} - 1 \right) - \frac{a}{b} t_{eq} \]
or, \[ x_2 = \frac{a}{b} \left( e^{b \cdot t_{eq}} - 1 \right) + \frac{V_2}{b} \left( e^{b \cdot t_{eq}} - 1 \right) - \frac{a}{b} \cdot t_{eq} \]

\[ \text{eq. 4.21} \]

Since the lead vehicle changes its velocity from \( V_2 \) to \( V_2' \) at the end of the time increment, \( \Delta t \), and then it maintains the same velocity for the rest of the time period, \( t_{eq} \), the distance that it travels during \( t_{eq} \) is approximately:

\[ x_1 = 0.5 \left( V_2 + V_2' \right) \Delta t + V_2' \left( t_{eq} - \Delta t \right) \]

Since, at time, \( t + t_{eq} \), \( V_{t_{eq}} = V_2' \), the minimum safe spacing, \( d_m \), according to Equations 4.4 and 4.5 is described as:

\[ d_m = (C_1 + V_2') \text{PDF} \]

where, \( C_1 \) = length of the following vehicle,
\( \text{PDF} \) = following distance factor of the following vehicle.

From Figure 12 the critical spacing can be obtained as below:

\[ d_{cr} = x_2 + d_m - x_1 \]
\[ \text{eq. 4.22} \]

where, \( d_{cr} \) = distance spacing between the successive vehicles, at which the following vehicle must adjust its trajectory.

At any point in time, the available spacing between the lead vehicle and the following vehicle can be computed, but there are three distinct conditions that might exist:
1. The available spacing is equal to the critical spacing,
2. The available spacing is greater than the critical spacing,
3. The available spacing is less than the critical spacing.

Under the first condition, the vehicle will decelerate at its normal rate, and the resulting velocity and distance travelled can be computed from Equations 4.23 and 4.24:

$$v_1' = \frac{(a + b v_1)}{b} e^{b \Delta t} - \frac{a}{b} \text{ eq. 4.23}$$

$$\Delta x = \frac{a}{b^2} \left( e^{b \Delta t} - 1 \right) + \frac{v_1}{b} \left( e^{b \Delta t} - 1 \right) - \frac{a}{b} \Delta t \text{ eq. 4.24}$$

where, $v_1'$ = actual velocity of the vehicle of concern at the end of time increment, $\Delta t$,
$\Delta x$ = distance travelled during the time increment, $\Delta t$,
$a, b$ = parameters of deceleration equation,
$v_1$ = actual velocity of the vehicle of concern at the beginning of time increment, $\Delta t$.

Under the second condition, the available spacing, $d_1'$, as shown on Figure 12, is greater than $d_{cr}$. The following vehicle must either maintain a constant velocity over the current time increment, or accelerate according to Equation 4.7. However, the vehicle must maintain the
minimum desired spacing to the lead vehicle described by Equation 4.5.

The third condition arises when the initial position of the following vehicle is within the critical region, and the available distance, $d_{a2}$, is less than the critical distance, as shown on Figure 12. In such a case, the time available for reaching the equilibrium is less than the time, $t_{eq}$, computed on the basis of either the normal rate, or its current rate of deceleration if it is already in the process of deceleration. It is obvious, therefore, that the following vehicle has to decelerate faster so as to reach the point D with minimum safe spacing. In Figure 12 point C is the position of the following vehicle, $t_x$ is the elapsed time, and $t_{eqx}$ is the time available to adjust its trajectory so as to reach the point D. The elapsed time, $t_x$, can be approximately computed as follows:

$$x_3 = d_{cr} + x_4 - d_{a2}$$

$$V_1 t_x = d_{cr} + 0.5 (V_2 + V_2') t_x - d_{a2}$$

$$t_x (V_1 - 0.5 (V_2 + V_2')) = d_{cr} - d_{a2}$$

$$t_x = \frac{d_{cr} - d_{a2}}{V_1 - 0.5 (V_2 + V_2')}$$

$$t_{eqx} = t_{eq} - t_x \quad \text{eq. 4.25}$$

If $t_{eqx}$ is known, the new value for the slope of deceleration...
tion curve, $b_n$, as shown on Figure 13, can be obtained from Equation 4.26:

$$\frac{a + b_n v_1}{a + b_n} = e^{b_n x} = 0$$

This equation can be solved for $b_n$ by a method of successive approximation. The technique developed for the solution of Equation 4.26 is presented in Appendix A.

Substituting the new value for the slope of the deceleration curve, $b_n$, into Equations 4.23 and 4.24, the resulting velocity, $v_1$, and the distance travelled, $\Delta x$, at the end of time increment, $\Delta t$, can be computed, respectively.

In the next time increment, the critical spacing can be computed on the basis of this updated rate of deceleration, and if it is still necessary for the vehicle to decelerate the necessary computations can be repeated. This process continues until the vehicle ceases to decelerate.

During the actual simulation, vehicles are processed in an order moving from the right to the left end of the roadway system. As any particular following vehicle is being processed at an instant in time, the vehicle ahead of it has already been processed and its characteristics have already been updated. In this way, the maneuvers of a lead vehicle affect the maneuvers of the following vehicle which, in turn, acts as a lead vehicle to subsequent vehicles. Due to this chain process, at every incre-
FIG. 13. TYPICAL SPEED-DECELERATION CURVE FOR A CAR-FOLLOWING SITUATION.
ment of time, a continuity is provided in the car-following procedure to render a more realistic simulation model.

The car-following model developed in the present study was found to be practical in the sense that it does not cause rapid fluctuation in the resulting velocities, as was observed in the models developed on the basis of the available car-following equations. This is due to the fact that in the proposed model the decision at any point of time is not independent of the decisions encountered in the previous time increment, and the deceleration of any vehicle is smoothly continuous between that point in time at which the deceleration process was initiated and the instant at which its mode of behavior changes.

Gap Acceptance

When a vehicle changes lanes on the through roadway lanes or when it merges from an on-ramp into the shoulder-lane stream, an interaction takes place within the stream of traffic. This interaction involves driver decisions in maneuvering the vehicles within the stream. The gap-acceptance phenomenon is a critical aspect of this traffic interaction.

Several researchers have investigated the driver characteristics that are involved in merging process. These investigations have resulted in the development of gap-acceptance distributions based on experimental studies (58, 72, 73). Although the gap-acceptance phenomenon is
very complex, several researchers have attempted mathema-
tical treatment of the merging maneuver (21, 89). In
their initial simulation work, the Midwest Research
Institute group used gap-acceptance distributions developed
on the basis of field data. In their subsequent work (56),
they used empirical, normal distributions to describe both
the merging process from on-ramp to shoulder lane, and
the lane changing maneuver between adjacent lanes in a
freeway section. Buhr, et al., (7), did not consider any
probabilistic variation in the lane-changing process.
In the ramp merging process, however, they utilized a
gap-acceptance distribution developed from data collected
in a nationwide study of merging behavior.

Several theoretical probability functions have
been suggested to describe the gap acceptance phenomena
—including the shifted negative exponential, Erlang and
log-normal functions. The log-normal function perhaps
provides the best description (22). The technique of
probit analysis, which was used by Solberg and Oppenlander
(60), was utilized by Drew, et al. (23), to transform
the non-linear, log-normal function into the simple linear
form:

\[ Y = a + b \log x + 5 \]

where, \( x = \log t \), where \( t \) is the time gap or lag, and
\( Y \) = the probit of \( P \), where \( P \) is the probability of
accepting a gap or lag of \( t \).

In the proposed simulation model a two-variable
probit gap acceptance model that had been developed by Drew, et al. (23) was used. By analyzing the gap-acceptance data from the nationwide freeway merging study, Drew, et al., showed that there is a three space function that relates the probit of gap-acceptance to the log of the gap or lag length and to the relative speed of the ramp and freeway vehicles. This model can be written mathematically as:

\[ Y = a + b_1 x + b_2 z + 5 \]  

\text{eq. 4.27}

where, \( Y \) = probit of \( P \) where \( P \) is the probability of accepting a gap or lag, \( t \),

\( x = \log t \) where \( t \) is the gap or lag in seconds,

\( z = \) relative speed of merging ramp vehicle to shoulder lane vehicle in m.p.h., and

\( a, b_1, b_2 \) = parameters dependent on the ramp configurations.

Probit equations for several on-ramps with different geometric configurations, from all across the country were reported (23). For the purpose of this study a typical ramp was selected and the necessary parameters were calculated to describe the gap-acceptance model.

A similar gap-acceptance model, as given in Equation 4.27, was selected to describe the lane changing maneuver between adjacent through lanes. The parameters for the model were established from research data reported for a parallel on-ramp with a long, level acceleration lane.
The final forms for the gap-acceptance models selected for use in the proposed simulation system are given below:

a. For ramp merging process:

\[ P = -2.372 + 4.483z_1 \quad \text{eq. A.28} \]
\[ P = 0.6135 + 2.2349x_2 + 0.0095z_1 \quad \text{eq. 4.29} \]

b. For lane changing between adjacent lanes:

\[ P = -1.495 + 2.948x_1 \quad \text{eq. 4.30} \]
\[ P = 0.6242 + 2.5667x_2 - 0.1027z_2 \quad \text{eq. 4.31} \]

where, \( P \) = probability of accepting gap or lag of \( t \),
\( x_1 \) = log \( t \) (\( t \) is the time gap in seconds),
\( x_2 \) = log \( t \) (\( t \) is the time lag in seconds),
\( z_1 \) = relative speed between the merging ramp vehicle and the shoulder-lane vehicle, in m.p.h.,
\( z_2 \) = relative speed between the through lane weaving vehicle and the trailing vehicle in adjacent lane, in m.p.h.

Vehicle Type and Length

All of the vehicles in the system were assumed to have the geometric and operating characteristics typical of either passenger cars or commercial vehicles. The overall length for the passenger vehicles was set at seventeen feet, and that for the commercial vehicles was established at thirty-four feet, although these lengths do not necessarily correspond to the standards established
Vehicle Performance

Vehicle performance was described by limits for acceleration and deceleration rates. Although the average rates of acceleration and deceleration depend primarily on the driver characteristics, the maximum values are generally controlled by vehicle performance. In all of the previous freeway simulation models the maximum rates of acceleration and deceleration, along with the normal rates, were established at constant levels. In this study, the maximum acceleration capabilities of vehicles were based upon Equation 4.7. The maximum vehicular speed was established at 100 m.p.h. and the values for the parameters, m and n, were computed from Equations 4.8 and 4.9. The resulting equation provided a linear relationship between the maximum acceleration of a vehicle and its actual speed; this equation is given below:

\[
\text{acc}_{\text{max}} = 7.64 - 0.0724 (V_a)
\]

where, \(\text{acc}_{\text{max}}\) = maximum acceleration of a vehicle of concern in m.p.h. per second,

\(V_a\) = actual speed of a vehicle of concern, in m.p.h.

A limiting value for maximum deceleration was established from data reported in the 1965 Traffic Engineering Handbook. This data indicated that
about 96 percent of the passenger vehicles are capable of decelerating at a rate equal to or greater than 20 feet per second², whereas 90 percent of the passenger vehicles are capable of decelerating at a rate equal to or greater than 27 feet per second². It is also suggested in this source that the maximum rate of deceleration will exceed 20 feet per second² only in emergencies. According to Herman, et al. (47), the maximum deceleration rate is only about 16 feet per second². In the proposed model, the maximum rate of deceleration was established at 20 feet per second².

Traffic and Environmental Characteristics

Because they are closely related, traffic and environmental characteristics are combined. It is obvious that the changes in environmental conditions such as weather, lighting, roadside development, etc., have considerable effect on traffic characteristics, but the necessary information that would enable one to incorporate such effects in a simulation model is not available. Therefore, the environmental conditions were assumed to be ideal, so far as their effect on the traffic characteristics were concerned.

Lateral Distribution of Traffic Volume

The level of traffic demand, or the traffic volumes, is a necessary input to a traffic simulator. This
information is provided by specifying volumes by lanes. The total traffic volume in one direction of freeway flow is specified as an input parameter, and the lateral distribution of traffic volume between lanes is computed from a set of equations. Most of the studies (11, 55, 72) related to this freeway traffic characteristic have reported traffic distributions between lanes as a function of total volume only. An extensive study conducted by the U. S. Bureau of Public Roads (10) reported traffic volume distributions as a function of several variables such as number of freeway lanes, total freeway volume, distances from on-ramps and off-ramps, etc.

In this study the volume distribution models, presented in the 1965 Highway Capacity Manual were utilized. These models were developed from data obtained in a comprehensive, nationwide study. These lane distributions are presented in Figure 14 as a function of the number of freeway lanes and of the total one-directional freeway traffic volume. Because there was no information available to describe lane distributions on ten-lane freeways, the assumption was made that traffic volumes on lanes four and five were identical. Thus it was possible to synthesize the ten-lane volume distribution curve presented in Figure 14, from the eight lane freeway curve.
FIG. 14. DISTRIBUTION OF TRAFFIC VOLUME BETWEEN LANES IN ONE DIRECTION AT APPROACH TO RAMP (PART 1)
FIG. 14. DISTRIBUTION OF TRAFFIC VOLUME BETWEEN LANKES IN ONE DIRECTION AT APPROACH TO RAMP (PART 2)
Generation of Vehicles

Generation of vehicles into the system on the through lanes, as well as on the on-ramps, is accomplished by utilizing a cumulative probability distribution of vehicle-headways. Several investigations have attempted to develop a probabilistic headway descriptor. The more common headway models referred to in the literature are the negative exponential distribution (33, 41, 55), the shifted exponential distribution (9), the hyper-exponential distribution (51, 78), the modified binomial distribution (59, 60), and the Erlang distribution (42, 71). A recent study (17) suggested the hyper-Erlang distribution of vehicle-headways. For the purposes of this research study experiments were conducted using several of the available headway distributions in order to select the best possible headway descriptor for freeway lanes. After comparing the resulting cumulative headway distributions with the data as presented in the 1965 Highway Capacity Manual, the shifted exponential model was selected as a good descriptor of the intervehicular spacings on multilane highways. There was no data available to test the effectiveness of any model for ramp vehicle generation. However, the hyper-Erlang distribution as developed by Dawson and Chimini (17) was found to be an efficient descriptor of headways in one-lane streams on two-lane, two-way highways. Though the characteristics of on-ramp traffic are governed by its geometric configuration, an on-ramp traffic situation can
be expected to closely follow the situation on one-lane of a two-lane, two-way highway with restricted passing. Thus the hyper-Erlang function was selected for the generation of on-ramp traffic.

The shifted exponential model is described by the following mathematical model:

\[ P(h \geq t) = e^{-(t - d)} \quad , \quad t > d \]  

(eq. 4.23)

where, \( P(h \geq t) \) = probability that a headway, \( h \), in seconds, is equal to or greater than \( t \),
\( t \) = any time duration, in seconds,
\( d \) = minimum allowable headway in the stream, in seconds,
\( \bar{h} \) = average headway in stream, in seconds.

In the literature the minimum allowable headway, \( d \), is reported to be between 0.5 and 1.5. Smaller values have also been reported. Dawson's (16) empirical relation between minimum headway and shoulder-lane volume tends to give smaller values for \( d \). However, in this simulation study, only one vehicle is allowed to enter the system through each lane per scan period. Since the scan interval is one second, the minimum allowable headway was established at a level such that it would not generate arrivals of more than one vehicle in any time period. The value for \( d \) was set at 0.75 seconds which is the average of the reported range of minimum allowable headways.
A plot of the resulting headway distributions is presented in Figure 15.

The hyper-Erlang headway model employed for the purpose of ramp vehicle generation is based on the assumption that a traffic stream is composed of two components—free vehicles and constrained vehicles—each with its own headway distribution. The complete model, obtained by forming a linear combination of the free and constrained components, is given below:

\[
P(h \geq t) = \alpha e^{-\frac{(t - d_1)}{(t_1 - d_1)}} - \frac{k(t - d_2)}{(t_2 - d_2)} \sum_{x=0}^{K-1} \frac{k(t - d_2)}{(t_2 - d_2)} x!
\]

\[t > d_1, d_2\]

\text{eq. 4.34}

where, \(P(h \geq t)\) is the probability that a headway, \(h\), in seconds, is greater than or equal to \(t\),

\(t\) = any time duration, in seconds,

\(d_1\) = the minimum headway in the free headway distribution, in seconds,

\(d_2\) = the minimum headway in the constrained headway distribution, in seconds,

\(a\) = the proportion of free vehicles in the traffic stream,

\((1 - a)\) = the proportion of constrained vehicles
in the stream,

\[ t_1 = \text{the average headway in the free headway distribution, in seconds,} \]

\[ t_2 = \text{the average headway in the constrained headway distribution, in seconds,} \]

\[ k = \text{an index that indicates the degree of non-randomness in the constrained headway distribution.} \]

Dawson and Chimini (17) observed that the best fit for the two-lane two-way highways data, presented in the 1965 Highway Capacity Manual, is obtained with a value of \( k = 2 \). The values of minimum headways, \( d_1 \) and \( d_2 \), were set at 0.75 seconds in both cases, and the rest of the parameters were evaluated by the technique proposed by Dawson and Chimini (17). Table 1 presents the estimates of parameters for traffic volumes between 150 v.p.h., and 1050 v.p.h., and the resulting headway distributions are shown in Figure 16.

Speed Models

Speed is one of the most basic characteristics of any vehicular traffic stream. In a freeway simulation model, there are three speeds that should be considered: the desired speed, the assigned speed, and the actual speed. The significance of the desired speed, which remains constant throughout the simulation period, is apparent. The assigned speed can be defined as the speed
<table>
<thead>
<tr>
<th>Volume in v.p.h.</th>
<th>a</th>
<th>$t_1$</th>
<th>$t_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0.64177579</td>
<td>32.63238525</td>
<td>2.17100716</td>
</tr>
<tr>
<td>200</td>
<td>0.59738338</td>
<td>27.94625654</td>
<td>2.11585617</td>
</tr>
<tr>
<td>250</td>
<td>0.54767692</td>
<td>24.62222290</td>
<td>2.12278938</td>
</tr>
<tr>
<td>300</td>
<td>0.51379591</td>
<td>21.59776306</td>
<td>2.11677265</td>
</tr>
<tr>
<td>350</td>
<td>0.48069739</td>
<td>19.47511292</td>
<td>2.11892128</td>
</tr>
<tr>
<td>400</td>
<td>0.45825976</td>
<td>17.72589111</td>
<td>2.12109566</td>
</tr>
<tr>
<td>450</td>
<td>0.43702978</td>
<td>15.70682812</td>
<td>2.13021137</td>
</tr>
<tr>
<td>500</td>
<td>0.41967368</td>
<td>14.67396069</td>
<td>2.13313580</td>
</tr>
<tr>
<td>550</td>
<td>0.39445335</td>
<td>13.84506226</td>
<td>2.16940784</td>
</tr>
<tr>
<td>600</td>
<td>0.39460331</td>
<td>12.41594219</td>
<td>2.14740181</td>
</tr>
<tr>
<td>650</td>
<td>0.38362604</td>
<td>11.42671490</td>
<td>2.14806938</td>
</tr>
<tr>
<td>700</td>
<td>0.37321579</td>
<td>10.75085449</td>
<td>2.15555382</td>
</tr>
<tr>
<td>750</td>
<td>0.36866891</td>
<td>9.56088448</td>
<td>2.14855671</td>
</tr>
<tr>
<td>800</td>
<td>0.36592650</td>
<td>8.82242775</td>
<td>2.14004898</td>
</tr>
<tr>
<td>850</td>
<td>0.34936744</td>
<td>8.40607166</td>
<td>2.14523597</td>
</tr>
<tr>
<td>900</td>
<td>0.33652645</td>
<td>7.81767559</td>
<td>2.15123272</td>
</tr>
<tr>
<td>950</td>
<td>0.33213121</td>
<td>7.08277035</td>
<td>2.13866615</td>
</tr>
<tr>
<td>1000</td>
<td>0.31640965</td>
<td>6.80178070</td>
<td>2.14789295</td>
</tr>
<tr>
<td>1050</td>
<td>0.29717964</td>
<td>6.38515949</td>
<td>2.15721321</td>
</tr>
</tbody>
</table>

$k = 2, \quad d_1 = d_2 = 0.75$
that a vehicle attempts to maintain in the simulation, and it is nothing but the desired speed adjusted for the effect of grade. The actual speed is the speed that a vehicle has at any point in the simulation process and is subject to variation throughout the simulation period.

In the present study only the desired speed and the actual speed were taken into consideration, since the simulated section was assumed to have negligible vertical grade. As any instant in time, the difference between the desired speed and the actual speed reflects the amount of congestion or interference to free movement on the highway.

Desired Speed — It can be assumed that a driver attempts to maintain some desired speed whenever he has the opportunity to do so. In this study, this speed has been called the desired speed, and it is defined as that speed at which a particular driver would operate if his movement were unimpeded.

An analysis of the data reported by Perchonok and Levy (58, 73) in their simulation study indicated that speed can be approximated by a normal distribution. The frequency distribution of passenger car speeds under ideal, uninterrupted flow conditions on freeways and expressways as reported in the 1965 High Capacity Manual also supports this assumption.

The entire table for desired speed distribution can be stored in the computer, or the mean and the stan-
card deviations can be specified in the input information. Several attempts have been made in previous studies to assume reasonable values for means and standard deviations of desired speeds of vehicles. Richard, Baker, and Sheldon (75) assumed that the distribution of observed speeds for medium traffic volumes, as reported by Perchonok and Levy (58, 73), best reflected the desired speeds. In their study, the standard deviation of the desired speeds, \( S_d \), was taken to be equal to 0.2 \( \overline{V_d} \), where \( \overline{V_d} \) is the average desired speed. The average desired speed was obtained in terms of the posted speed on the highway, and it was assumed to correspond to the 85th percentile speed. Buhr, Meserole, and Drew (7) used the following relations for normal distribution of desired speeds:

\[
\overline{V_d} = 0.85 \times \text{Maximum Freeway Speed}
\]

\[
S_d = 0.07 \times \overline{V_d} + 1.375
\]

In the real world situation the desired speed of a driver is generally governed by the speed limit posted on the highway. It is perhaps reasonable to assume that the desired speed follows a normal distribution with a mean close to the speed limit. It can also be expected that the dispersion of the desired speeds will not be wide and the individual speeds will be closely clustered to the mean value. In the present study it was assumed that the 99th percentile corresponds to a level about equal to the mean plus 0.15 \times Mean.

Therefore, \( 3 S_d = 0.15 \times \text{Mean Desired Speed} \)
or, \[ S_d = 0.05 \times \text{Mean Desired Speed} \]

It is an established fact that on an open section of a freeway, speeds in inner lanes are higher than on the outer lanes. Therefore, it can be postulated that the desired speeds of vehicles located in inner lanes are higher than the desired speeds of vehicles in the outer lanes. Although the overall mean of desired speeds in the system was assumed to be equal to the speed limit, the means of the desired speed distributions for the individual lanes were assumed to be functions of the speed limit, with the inner lanes having higher means than the outer lanes.

It is a common practice to establish the speed limit at approximately the 85\% percentile speed observed on the highway. From the speed curves presented in the 1965 *Highway Capacity Manual*, it may be noted that the 85\% percentile speed for any speed curve corresponds to 85 percent of the maximum freeway speed. For a five-lane one-directional freeway the mean desired speeds were assumed to be 0.80, 0.80, 0.85, 0.90 and 0.90 of the Maximum Freeway Speeds, for lanes 1, 2, 3, 4, and 5, respectively. However, it should be mentioned that in the above discussion multilane highway without any left hand on or off-ramps were considered. Any other situations should be dealt with differently and the coefficients for mean desired speeds must be established at different levels. The example problems discussed in Chapter Six of this
text will show how the input speed parameters were selected according to the prevailing conditions of the problem concerned.

Desired speeds were generated as normally distributed random variables subject to the following conditions:

\[ \bar{V}_d = C_d \text{ (Maximum Freeway Speed)}, \quad \text{and} \]
\[ S_d = 0.05 \bar{V}_d \]

where: \[ \bar{V}_d = \text{Mean Desired Speed in m.p.h.}, \]
\[ S_d = \text{standard deviation in m.p.h.}, \]
\[ C_d = \text{coefficient dependent upon the lane and its location.} \]

In general, it has been observed that trucks have slower speeds on a highway. Thus, the mean desired speed for trucks was established at 90 percent of that for passenger cars, while the standard deviation was assumed to be equal.

In the proposed simulation model each vehicle was assigned a desired speed along with other characteristics during the preloading of the system. As new vehicles were generated into the system, they were given desired speeds in the similar manner. If during the random generation of desired speeds, a speed was higher than the Maximum Freeway Speed, it was set equal to the latter.

The desired speed of a particular driver was assumed to remain constant throughout the entire simula-
tion process. But in the real world situation a driver cannot really keep his desired speed at an absolute level. It is natural to assume that there is a speed range in which the driver tries to maintain his speed. This is due to the fact that a driver cannot judge or control his speed adequately. Some of the observations of various researchers, as reported by Fox and Lehman (27), support this assumption. Hakinen (43) found that, in general, a driver underestimates his own speed. Cosgriff, et al. (12), observed that low speeds are generally underestimated and higher speeds are overestimated. Denuton (20) found that underestimation of speeds takes place during deceleration while overestimation takes place during acceleration. On the basis of the findings of Kidd and Laugner (54), the desired speed of a driver can have a range from 92 percent to 115 percent of the assigned desired speed. However, Fox and Lehman (27) found that the exact values of the parameters for the lower and the higher values of desired speed did not have a critical effect on traffic performance in their simulation research. According to them, the assigned desired speed is the important parameter.

It was felt by this author, that though the incorporation of certain limiting values for a range of desired speeds would perhaps be desirable for certain situations, it would not have any significant influence on the results from an overall simulation model of a freeway traffic system. Hence, no attempt was made to include
these parameters in the proposed model.

Actual Speed — As opposed to the desired speed, the actual speed of a car is that speed at which a driver can operate, at a particular instant in time, under the prevailing traffic and roadway conditions. While the desired speed remains constant throughout the simulation period, the actual speed is subject to variation at every time increment. During the simulation, a driver's actual speed is determined on the basis of traffic conditions at the particular time interval. The actual speed of any vehicle was restricted to values less than or equal to the desired speed. The lower limit for the actual speed distribution was established at the minimum speed for the freeway. The value for this limit was specified as 30 m.p.h. to be compatible with speed for freeways presented in the 1965 Highway Capacity Manual.

Ramp Operating Speed — Operating speeds for vehicles on entrance ramps were also generated according to normal distribution of random numbers. Since there is little variation between the speeds for passenger cars and for trucks on ramps, the mean and the standard deviation for both types were considered to be the same. This assumption is justified because the ramp geometry is generally more restrictive than prevailing traffic conditions on the ramp. The parameters for the ramp speed distribu-
tion follow:

Mean Ramp Operating Speed = 28.0 m.p.h.

Standard deviation = 1.0 m.p.h.

In the process of generating random ramp speeds, if any speed was generated at a level higher than the assigned maximum speed on a ramp, this speed was set equal to the latter. The maximum speed for any ramp vehicle was assumed to be 35 m.p.h.
CHAPTER FIVE

PROGRAMMING OF THE PROPOSED MODEL

Following the development of the mathematical models for the component parts of the proposed simulator, these mathematical models were integrated into an operational system. The integrated system was then coded in the FORTRAN IV and IBM 360 Assembler Language codes for dynamic processing on an IBM 360/65 high-speed computer. The overall logic for the programming of the proposed freeway simulator is presented herein.

The Simulation Languages

Although most traffic simulator programs have been written in the problem-oriented, FORTRAN language, there are several special simulation languages. GPSS (General Purpose System Simulator) and SIMSCRIPT are two of these languages. In GPSS, models are constructed using a schematic block diagram to describe the system; activities within the system are represented by the blocks, and changes in the state of the system are represented by transactions along the block diagram. Although SIMSCRIPT is a more complex language, it has more extensive capabil-
ity than GPSS does. Both of these simulation languages have been widely used in the simulation of industrial and business problems, and they have been employed to a limited extent in traffic engineering studies. The use of GPSS for the simulation of an interchange area was discussed by Blum (5).

Shumate and Dirksen (79) developed a general purpose traffic simulation language, SIMCAR, which has been validated for two-lane rural highways.

These simulation languages have not been used extensively in traffic engineering problems; therefore, no definite conclusion can be drawn about their usefulness. However, they do lack the flexibility of FORTRAN. Perhaps the most serious deficiency is the fact that it is difficult to obtain information about any individual entity, such as a vehicle or a driver, from the output data of these special purpose languages. On the other hand, the FORTRAN language is widely used and readily understood; and it affords the programmer complete control over the operation of the system.

Outline of the Simulation Logic

The overall logic of the proposed simulator is presented schematically in the flow diagram in Figure 17. The computer coding included both open and closed subroutines under the control of a monitor or master program. In this way it was possible to structure the model so
Starting point of logic

1. Initialize arrays and other parameters
2. Initialize Random Number Generators
3. Read input information
4. Preload the system
5. Increment time by one unit
6. Update off-ramp vehicles
7. Find the vehicle to be processed on freeway section

Is it on acc. lane?
Yes
Acc lane logic
No
Is it on dec. lane?
Yes
Dec. lane logic
No
Is it going out of the system?
Yes
Remove it and update the system
No

FIG. 17. FLOW DIAGRAM OF GENERAL SIMULATION LOGIC (PART 1)
FIG. 17. FLOW DIAGRAM OF GENERAL SIMULATION LOGIC
(PART 2)
FIG. 17. FLOW DIAGRAM OF GENERAL SIMULATION LOGIC

(PART 3)
that component parts could be programmed independently of each other, and tested and debugged without affecting the entire simulator.

Subroutines were programmed to set up the matrices that depicted the freeway and ramp roadways, and to initialize the values in these matrices. Similarly subroutines were prepared to initialize index parameters and seed values for the several independent, open subroutine, random number generators.

A subsequent subroutine contained the necessary logic to preload the simulated roadways with vehicles and to assign distinctive characteristics to each of the vehicles.

A routine was structured to simulate a real-time clock to be advanced at the start of each scan interval. This was followed by the logic for detecting off-ramp vehicles that would be processed out of the system during the scan currently under execution. Upon detecting exiting off-ramp vehicles, this subroutine removes them from the system by deleting the appropriate descriptive characteristics from the storage files. Subsequent off-ramp vehicles are then moved a distance down the ramp that is commensurate with a scan interval. Then, the freeway portion is scanned from the shoulder lane toward the median lane to locate the vehicle nearest to the downstream end of the simulated section. If the vehicle encountered is located on either an accelerating lane or
on a deceleration lane the program control is passed to a subroutine that contains the acceleration lane logic or the deceleration lane logic, respectively, for moving vehicles. If the vehicle encountered is on one of the through lanes, the vehicle characteristics are processed to determine if the vehicle will leave the system during the current scan period. Those vehicles that will pass the bounds of the simulation section in the current scan period are processed out of the system. Other vehicles are processed in accordance with logic compatible with lane position and desired system exit. The distance from the vehicle of concern to the appropriate exit is computed for vehicles in the shoulder lane that are exiting from the system via an off-ramp, and if the vehicle is in the proximity of the deceleration lane, control is passed to a subroutine containing the logic to diverge the vehicle into the deceleration lane. If an exiting vehicle, located on an inner lane, has already passed an exit decision station, control is passed to logic to effect the lane change process. In the event that a vehicle is not exiting from the system it is processed to ascertain if it can be moved forward without encountering the vehicle ahead. If the vehicle cannot proceed freely, logic for a normal lane change between adjacent through lanes is called. If lane changing is not possible, the vehicle is maintained in the same lane, and it is moved ahead in accordance with car-following logic. When all the vehicles
on the freeway portion of the system have been processed for the current time interval, the on-ramp vehicles are moved forward for one time increment. Subsequently, new vehicles are introduced into the system according to the vehicle generation logic.

As each vehicle is processed during a simulation interval, a check is made to determine whether it will pass any of the pre-established control points. If it will, several descriptive operational characteristics are computed and stored on disk outside the core area of the computer. When the total time for simulation is over, the stored characteristics are statistically analyzed and output to provide a description of traffic operations along the simulated section of the freeway.

**General Rules of Operation**

From the summary of the simulation logic discussed above, it is apparent that this freeway simulation system can be divided into five constituent parts to regulate vehicle movement. Separate components were prepared for the following freeway sections:

1. Through lanes,
2. Off-ramps,
3. Deceleration lanes,
4. On-ramps, and
5. Acceleration lanes.

Vehicles can accelerate, decelerate or they can
remain at the same speed. Vehicles on through lanes are allowed to move left, right or straight ahead. Vehicles on ramps are allowed to move forward, only. While vehicles on acceleration lanes can change into adjacent through lanes, those on deceleration lanes can only move ahead. When possible, all through lane vehicles attempt to maintain their desired speeds, and ramp vehicles try to operate at maximum allowable ramp speed. With the exception of on-ramp vehicles that are not able to merge and are thereby forced to stop on an acceleration lane, vehicles are not allowed to stop anywhere in the system. A basic constraint on vehicular movement is that the vehicles must not come into physical contact; they must maintain a safe spacing behind a preceding vehicle.

Discussion of Simulation Logic

The detailed logic associated with the component parts of the model is described in the following paragraphs. For the purposes of these descriptions $V_1$ and $V_2$ are defined, respectively, as the velocity of the vehicle under investigation and the velocity of the preceding vehicle at the start of the current scan interval. $V'_1$ and $V'_2$ are the velocities of these respective vehicles at the end of the current scan interval.

Vehicles on Through Lane

Vehicles on through lanes can be categorized in-
to two groups—exiting vehicles and non-exiting vehicles.

Exiting vehicles are those that will exit via one of the exit-ramps. Those vehicles which are assigned to an off-ramp exit that have not yet passed the appropriate exit decision station are processed in the same way as the non-exiting vehicles.

**Non-Exiting Through-Lane Vehicles** — The logic associated with the processing of non-exiting through-lane vehicles is presented schematically in Figure 18.

When any vehicle is considered, the preceding vehicle has already been processed. Thus $V_1$, $V_2$, and $V_2'$ are already known. If $V_1$ exceeds $V_2'$, and the actual spacing, $d_a$, is less than the critical spacing, $d_{cr}$, at the beginning of the scan interval, the vehicle of concern is decelerated at a rate higher than the current value. If $d_a$ is exactly equal to $d_{cr}$, deceleration is maintained at the present rate, if it is already in the midst of a deceleration process; otherwise it is decelerated at its normal rate. If the vehicle is not in the critical region, a tentative velocity, $V_{tn}$, is computed on the basis of a free-flowing acceleration model. Computations are then made to determine if the safe spacing will be maintained throughout the current time increment. These computations follow:

$$f_d = P_2 - P_1 - C_2 \quad \text{eq. 5.1}$$

$$r_d = 0.5 (V_1 + V_{tn}) \cdot \Delta t + d_m \quad \text{eq. 5.2}$$

$$d_m = (C_1 + V_{tn} \cdot \text{CONST}) \text{FDB} \quad \text{eq. 5.3}$$
FIG. 18. FLOW DIAGRAM OF THROUGH LANE NORMAL LOGIC
(PART 1)
FIG. 18. FLOW DIAGRAM OF THROUGH LANE NORMAL LOGIC
(PART 2)
where, 
\[ f_d = \text{actual spacing between the updated lead vehicle and the vehicle of concern}, \]
\[ r_d = \text{required spacing between them}, \]
\[ d_m = \text{desired safe spacing after the current time increment}, \]
\[ P_2 = \text{updated position of the lead vehicle}, \]
\[ P_1 = \text{current position of the vehicle of concern}, \]
\[ C_1 = \text{length of the vehicle of concern}, \]
\[ C_2 = \text{length of the lead vehicle}, \]
\[ \Delta t = \text{time increment}, \]
\[ \text{CONST} = \text{parameter based on speed difference between the lead vehicle and the vehicle of concern}, \]
\[ \text{FDF} = \text{following distance factor of the vehicle of concern}. \]

If \( f_d \) is greater than, or equal to, \( r_d \), the updated velocity of the vehicle is set at \( V_{tn} \). Otherwise, the possibility of lane changing to improve status is evaluated.

In the event that it is not possible to make a lane change, a test is made to determine if it is possible to accelerate and still maintain a safe spacing. If it is not possible, the vehicle is updated at its current speed.

On the other hand, if the current speed of the vehicle of concern is less than, or equal to, the speed of the lead vehicle, it is checked to determine if a safe spacing can be maintained at this speed. If it cannot be, a lane change is attempted. If this attempt is unsuccessful, the vehicle is decelerated in accordance with a de-
celeration model and updated. If the vehicle can maintain its speed during the current time increment, it does so unless it can accelerate to achieve a speed nearer to its desired speed.

**Normal Lane Changing Between Adjacent Through Lanes**

If a vehicle on a through lane can not proceed normally, it attempts a lane change maneuver to improve its movement. When the need to change lanes is imminent, a maneuver is attempted first to the adjacent left lane, and then to the right lane. However, vehicles in the shoulder lane can change only to the left, and vehicles in the median lane can change only to the right.

In a lane-change analysis, the relative position of the merging vehicle with respect to leading and following vehicles in the adjacent lane, is evaluated to determine if the vehicle under consideration would be too close to either of these two vehicles after the maneuver. A lane-change maneuver is diagrammed in Figure 19. A flow diagram of the associated logic is presented in Figure 20. The available physical distance between the leader in the adjacent lane and the merging vehicle is compared with the distance required ahead for merging. These distances are computed using the following equations:

\[ f_{df} = P_3 - P_1 - C_3 \]  

\[ f_{d} < f_{df}, \quad f_{df} = f_{d} \]  

\[ f_{df} = \text{eq. 5.4} \]
CURRENT POSITION OF A VEHICLE

UPDATED POSITION OF A VEHICLE

FIG. 19. SCHEMATIC DIAGRAM OF A LANE CHANGE MANEUVER
FIG. 20. FLOW DIAGRAM OF LANE CHANGING LOGIC
\[ r_{df} = 0.5 \left( V_l + V_c \right) \Delta t + d_{m1} \quad \text{eq. 5.5} \]

\[ d_{m1} = (C_l + V_c \cdot \text{CONST}) \cdot \text{PDF} \quad \text{eq. 5.6} \]

where,
- \( f_{df} \) = available spacing between the lead vehicle on adjacent lane and the vehicle of concern,
- \( f_d \) = available spacing between the updated lead vehicle in the same lane and the vehicle of concern, computed by Equation 5.1,
- \( r_{df} \) = total distance required ahead for changing lanes,
- \( d_{m1} \) = desired safe spacing ahead, after changing lanes,
- \( P_1 \) = position of the vehicle changing lanes,
- \( C_1 \) = length of the vehicle changing lanes,
- \( P_3 \) = position of the leading vehicle in the adjacent lane,
- \( C_3 \) = length of the lead vehicle in the adjacent lane,
- \( V_1 \) = actual current velocity of the vehicle of concern,
- \( V_c \) = lane changing speed of the vehicle of concern,
- \( \text{CONST} \) = the parameter computed from Equation 4.5 on the basis of the speed difference between a pair of vehicles,
- \( \text{PDF} \) = following distance factor for the vehicle of concern.
The required distance, \( r_{df} \), is computed using a tentative lane-change speed based on maximum acceleration for the merging vehicle. If \( f_{df} \) is less than \( r_{df} \), the test is repeated using another tentative lane-change speed based on normal acceleration of the vehicle. If this speed is also unsatisfactory a test is made to determine if the vehicle can maintain its current speed in its current lane. If it can, the lane-change attempt is abandoned. If it cannot, a check is made to determine the feasibility of a lane-change maneuver at current speed. If not possible, the vehicle will remain in its current lane, and its movement will be controlled by car-following logic.

After the distance requirement between the merging vehicle and the new leader is found satisfactory, the relative position between the merging vehicle and the following vehicle in the adjacent lane is evaluated according to the following models:

\[
\begin{align*}
 f_{dt} &= p_1 - p_4 - c_1 + 0.5 (v_1 + v_c) \Delta t \quad \text{eq. 5.7} \\
 r_{dt} &= v_4 \cdot \Delta t + d_{m2} \quad \text{eq. 5.8} \\
 d_{m2} &= (c_4 + v_4 \cdot \text{CONST}) PFD \quad \text{eq. 5.9}
\end{align*}
\]

where, \( f_{dt} \) = available distance between the vehicle of concern and the following vehicle in the adjacent lane,
\[ r_{dt} = \text{total distance required behind for changing lanes,} \]
\[ d_{m2} = \text{desired safe spacing behind, after changing lanes,} \]
\[ P_4 = \text{position of the following vehicle at the beginning of the current time increment,} \]
\[ C_4 = \text{length of the following vehicle,} \]
\[ V_4 = \text{actual velocity of the following vehicle at the beginning of the current time increment,} \]
\[ t = \text{length of the time increment.} \]

The required distance, \( r_{dt} \), is computed on the assumption that the following vehicle will maintain the same speed. Since the decision to change lanes is made by the car under investigation, the computation of safe spacing is based on its following distance factor.

After the physical constraints are checked, a test is made to determine if the lane-changing vehicle will accept the available time gap. This decision is effected by a random process, described by Equations 4.30 and 4.31. If the outcome of the test is positive the vehicle is moved to the adjacent lane and updated. Otherwise, it is maintained in the same lane and its movement is governed by the normal logic described earlier.

**Processing of Exiting Vehicles on Inner Lanes**

Vehicles marked to exit, and located on inner lanes, at-
tempt to weave to the right until they reached the shoulder lane. The logic for this sequential lane-change maneuver is similar to that for a normal lane-change process with the following exceptions:

1. an exiting vehicle only attempts lane-changes to the right,
2. an exiting vehicle might not increase its velocity while changing lanes, and
3. in order to satisfy the physical constraints on lane-changing, an exiting vehicle will decelerate normally or even at its maximum rate, if required.

Lane changing by exiting vehicles is not optional as it is in the case of the normal lane-change maneuver. Thus shorter inter-vehicle spacings can be anticipated. The desirable safe spacing for exiting vehicles was set at 75 percent of the normal value. If the lane-changing attempt is unsuccessful, an exiting vehicle is moved ahead at its current speed, provided it is safe to do so. Otherwise, it is decelerated at normal rate. If the resulting velocity is less than the minimum speed on the freeway it is set equal to the latter and the vehicle is updated.

Processing of Exiting Vehicles on the Shoulder Lane -- An exiting vehicle located on the shoulder lane attempts to diverge into the appropriate deceleration lane. The logic for this diverging process is presented
in a flow diagram in Figure 21. This logic is separated in two parts—(a) for vehicles adjacent to the deceleration lane, and (b) for those vehicles just approaching the deceleration lane, in the current time increment.

The diverging maneuver for the former situation is depicted schematically in Figure 22. In this maneuver, if the current velocity is less than the maximum allowable ramp speed, \( V_{max} \), the exiting vehicle is accelerated toward the maximum ramp speed. If the resulting velocity is higher than the maximum ramp speed a tentative weaving velocity, \( V_{tw} \), is set equal to the latter. The spacing to the leading vehicle on the deceleration lane is then evaluated in the same manner as discussed in the general lane-change maneuver. If this spacing is adequate, the clearance to the immediately following vehicle on the deceleration lane is evaluated. Otherwise, subsequent tests are made with the same speed, normally decelerated speed, and a speed based on maximum deceleration. In no case is the weaving speed allowed to be less than the minimum allowable ramp speed, \( V_{min} \). If the physical constraints are satisfied the vehicle is moved to the deceleration lane and updated.

The diverging maneuver for exiting vehicles that have not yet reached the deceleration lane is depicted schematically in Figure 23. It was assumed that an exiting vehicle, approaching the deceleration lane, is only concerned with its relative position to the first ve-
FIG. 21. FLOW DIAGRAM OF LOGIC FOR DIVERGING TO A DECELERATION LANE (PART 1)
FIG. 21. FLOW DIAGRAM OF LOGIC FOR DIVERGING TO A DECELERATION LANE  (PART 2)
FIG. 21. FLOW DIAGRAM OF LOGIC FOR DIVERGING TO A
DECELERATION LANE (PART 3)
FIG. 22. SCHEMATIC DIAGRAM OF A DIVERGING MANEUVER AS A VEHICLE EXITS TO A DECELERATION LANE.
CURRENT POSITION OF A VEHICLE

UPDATED POSITION OF A VEHICLE

\[ d_x \]

\[ f_d \]

\[ f_{df} \]

\[ d_{m,1} \]

FIG. 23. SCHEMATIC DIAGRAM OF A DIVERGING MANEUVER AS AN EXITING VEHICLE APPROACHES A DECELERATION LANE
vehicle located from the left end of the deceleration lane. If after necessary maneuvers the vehicle can maintain a safe spacing to the leading vehicle on the deceleration lane, and on doing so can reach the deceleration lane, weaving is possible and the vehicle is updated accordingly. The safe spacing between vehicles on deceleration lanes was assumed to be 50 percent of normal value.

Vehicles on Off-Ramp

All vehicles on off-ramps are processed at the beginning of the scan interval, starting from the ramp terminal and moving upstream to the nose of the ramp. The logic associated with processing vehicles on off-ramps is presented as a flow diagram in Figure 24. If any vehicles go out of the system during the scan interval, the entire system is updated, and the scanning continues until all of the off-ramp vehicles have been processed. The logic for moving off-ramp vehicles was divided into two parts to distinguish between free-flowing, off-ramp vehicles and off-ramp vehicles under the influence of a lead vehicle. If there is no vehicle ahead, and the vehicle of concern is travelling at the maximum allowable ramp speed, it is updated at this same speed. Otherwise, the vehicle of concern is accelerated, or decelerated normally, as necessary. In no case is a vehicle allowed to travel at a speed higher than the maximum allowable ramp speed, $v_{mxr}$.

If there is a vehicle ahead, the movement of the
FIG. 24. FLOW DIAGRAM OF OFF-RAMP LOGIC
(PART I)
FIG. 24. FLOW DIAGRAM OF OFF-RAMP LOGIC
(PART 2)
FIG. 24. FLOW DIAGRAM OF OFF-RAMP LOGIC
(PART 3)
vehicle under consideration is influenced by the requirement for safe spacing to the lead vehicle, as well as by the maximum ramp speed. In a case where the vehicle of concern is travelling slower than the updated speed of the lead vehicle, $V_2'$, and its speed is less than the maximum ramp speed, a tentative speed, $V_{tn}'$, is computed on the basis of normal acceleration. If a safe spacing can be maintained with this speed, the vehicle is updated at $V_{tn}$. Otherwise, the updated speed of the vehicle is set equal to $V_2'$. If a vehicle is travelling faster than $V_2'$ and it does not have sufficient clearance ahead, it is decelerated. If the resulting speed, $V_{tn}'$, is still faster than $V_2'$, the updated speed of the vehicle under investigation, $V_1'$, is set equal to $V_2'$.

**Vehicles on Deceleration Lane**

Vehicles on a deceleration lane are processed separately from the vehicles on off-ramps. Although these vehicles are allowed just to move forward, and the logic governing their movement is essentially the same as for off-ramp vehicles, they are scanned along with the through lane vehicles and updated accordingly at every time increment. As soon as the scanning index reaches the nose of an off-ramp, the order of lane searching is modified to begin with the deceleration lane, instead of the shoulder lane. In this way the diverging maneuvers from the shoulder lane to the deceleration lane can be simulated.
in a more realistic manner.

Vehicles on On-Ramp

Vehicles on on-ramps are processed from the ramp nose upstream to the local terminal of the ramp, after all of the vehicles on the through section have been scanned. The logic governing the movement of on-ramp vehicles is essentially the same as that for off-ramp vehicles. After all of the on-ramp vehicles have been processed and updated, a test is made to determine if there are any new vehicles to be introduced into the system via the local terminals of the on-ramps. If there are any, these vehicles are placed in the appropriate position in the on-ramp matrix and updated. The logic governing the introduction of new vehicles in the system is discussed later in this chapter.

Vehicles on Acceleration Lane

The movement of vehicles along an acceleration lane is depicted schematically in Figure 25. As opposed to vehicles on a deceleration lane, the vehicles on an acceleration lane do not necessarily stay in the same lane. In the proposed model, as soon as a vehicle reaches the on-ramp nose, it attempts to merge into the adjacent through lane. It will stay on the acceleration lane only if it cannot merge. The logic governing the processing of vehicles on an acceleration lane is depicted
FIG. 25. SCHEMATIC DIAGRAM OF A TYPICAL MERGING MANEUVER FROM AN ACCELERATION LANE TO AN ADJACENT THROUGH LANE
in the flow diagram presented in Figure 26. In a manner
similar to that for vehicles on a deceleration lane, ve-
hicles on acceleration lanes are scanned along with the
through lane vehicles.

After the vehicle to be processed has been lo-
cated, the adjacent through lane is scanned to determine
the locations of the leading and following vehicles in
that lane. The relative positions of the merging vehicle
with respect to these prospective leading and following
vehicles are evaluated in the same manner as described for
the lane-changing maneuver presented earlier. However, the
minimum desired safe spacings in front of and behind the
merging car, as it merges into the shoulder lane were set
at 30 percent of normal values. The speeds assigned ten-
tatively to the vehicle of concern, during the merging
process, are listed below in the order that they were con-
sidered during the process of selecting a merging speed, $V_c$:

1. $V_{c1}$, a speed based on the maximum accel-
eration of the vehicle of concern,
2. $V_{c2}$, a speed based on normal acceleration
   of the vehicle of concern,
3. $V_c$, the current speed of the vehicle of
   concern,
4. $V_{c3}$, a speed based on normal rate of
deceleration,
5. $V_{c4}$, a speed based on maximum rate of
deceleration.
Starting point of logic

Is it a left hand ramp?

No: Set IS = 1

Yes: Set IS = NL

Find gap on adjacent through lane

Set $V_0 = V_{o1}$

Is $V_0 \leq V_d$?

Yes: Set $V_0 = V_d$

No: $\Delta t < \Delta t_f$?

Yes: Find $V_{o2}$

No: $V_{o2} \geq V_0$?

Yes: $\Delta t < \Delta t_f$?

No: $\Delta t < \Delta t_f$?

Yes: 18

No: 17

FIG. 26. FLOW DIAGRAM OF ACCELERATION LANE LOGIC (PART 1)
FIG. 26. FLOW DIAGRAM OF ACCELERATION LANE LOGIC
(PART 2)
FIG. 26. FLOW DIAGRAM OF ACCELERATION LANE LOGIC
(PART 3)
The desired safe spacing in front of a merging vehicle was assumed to be one half of the normal value if the leading vehicle merged during the same time increment. When the physical constraints for merging were satisfied, a test was made to determine if the merging vehicle would accept the available time gap in the adjacent lane. The test involves a random decision process based on Equations 4.28 and 4.29. As a ramp vehicle merges into the through lane it is shifted from the on-ramp matrix to the appropriate location in the through-lane matrix.

If the merging attempt is unsuccessful the vehicle is maintained on the acceleration lane until it can merge into the through-lane stream. If the vehicle under consideration is the first vehicle in line it can move as far as the end of the acceleration lane, but it must stop there to await an acceptable through-lane gap. Subsequent vehicles stop with an eight feet clear spacing from front bumper to the rear bumper of the leading car. The processing of unsuccessful merging vehicles is divided into two parts. In the first part vehicles that are already at a stop are processed. These vehicles are moved ahead only if there is available space after the lead car has merged. In the second part of the logic, moving vehicles that were slowed down as they approached the end of the acceleration lane or the tail end of a queue waiting to merge, are processed. The available clear space ahead of
the vehicle, \( d_{\text{ea}} \), is compared with the critical spacing, \( d_{\text{ca}} \). The clear space, \( d_{\text{ea}} \), is measured to the end of the acceleration lane from first-in-line vehicles and to the car ahead from subsequent queued vehicles. The critical spacing, \( d_{\text{ca}} \), on an acceleration lane, is computed from the car-following equations presented in the previous chapter. A vehicle is allowed to move at the same speed until the available spacing becomes less than or equal to the critical spacing, at which time it must be decelerated.

**Introduction of Vehicles into the System**

A flow diagram of the simulator logic for introducing new vehicles into the system is presented in Figure 27. Separate time clocks for each of the through lanes and for each on-ramp are maintained to keep account of the arrivals of vehicles. During each time period the individual time clocks are checked to see if there is a vehicle waiting to enter the system during the current time period. If there is, the portion of the time increment, \( t_{\text{xc}} \), that remains after the introduction of the vehicle into the system is computed and the vehicle is assigned necessary characteristics. The updated actual speed of the vehicle at the end of the current time increment is tentatively set equal to desired speed. If the available spacing ahead is adequate for the vehicle to travel during the time period, \( t_{\text{xc}} \), as well as to maintain safe spacing at the end of the current time incre-
FIG. 27. FLOW DIAGRAM OF LOGIC FOR THE INTRODUCTION OF A VEHICLE INTO THE SYSTEM
ment, the updated actual speed is held at a value equal to the desired speed. Otherwise, a new safe speed is computed.

**Master Program**

The Master Program serves as a monitor for the overall simulation system. In addition, it contains the logic to initialize the computer at the start of each simulation run and to prepare statistical summaries of the output information from each run. The basic functions of the master or main program can be categorized as follows:

1. initialize all arrays including the general register and the vehicle index arrays,
2. provide starting seed values for random number generators,
3. read in all input information for a simulation run,
4. increment the simulation time clock,
5. control the scanning process and select the proper subroutine as each vehicle is processed,
6. sample vehicular traffic data at each lane and at each control station,
7. process and analyze the collected data,
8. provide output information describing speed, headway and volume distributions at each
9. prepare and provide other output information as required during the simulation.

Subprograms

Several subprograms were developed to effect the various processes during simulation. These subprograms are listed and described below:

1. PRLoad preloads the system with vehicles, and assigns characteristics to each of them. Initially, a vehicle is placed at the downstream end of each through lane and at the nose of each on-ramp. Subsequent vehicles in each traffic stream are spaced on the basis of a shifted exponential distribution, and characteristics are assigned to each vehicle according to input information and established distributions. The preloading process removes the bias that would be introduced by operating initially with an empty system, and it minimizes warm-up time.

2. SPCWG is a subroutine to PRLoad, and is used to compute the successive spacings between vehicles in the system.

3. RPLD assigns driver-vehicle characteristics to each new on-ramp vehicle as it is generated.

4. VOLDIS -- the traffic volumes in each of the lanes may be specified as input information, or they may be computed from the total volume on the freeway in VOLDIS.
5. XTRAMP scans all off-ramps at the beginning of each scan interval, to determine if any vehicle will leave the system during the current interval. It also affects the processing of subsequent vehicles on the off-ramps.

6. RAMP processes the vehicles on the acceleration lanes.

7. XRMLOG processes the vehicles on the deceleration lanes.

8. DECWL1 processes exiting vehicles in the shoulder lane that are located upstream of the appropriate deceleration lane if they will reach the deceleration lane during the current time period. It effects the maneuvers associated with the diverging process.

9. DECWL2 processes exiting vehicles in the shoulder lane that are already adjacent to the deceleration lane.

10. FRLNCG processes through-lane, constrained vehicles during lane-change maneuvers between through-lanes.

11. XTLNCG processes exiting vehicles located on inner lanes as they move to the outer lanes to reach the appropriate exit ramp.

12. CNG1 computes the safe distances required from a weaving vehicle to both the leading and following vehicles in the adjacent lane.

13. SCGAP searches out gaps in the adjacent
lanes.

14. FUN computes the values for a normal probability density function.

15. FRNORM integrates the area under a normal probability density curve and stores the areas in a table.

16. PROBIT computes the probit value of a threespace gap acceptance function that is expressed in terms of gap length and relative speed.

17. ACCEPT contains the logic for making the decision to accept or reject a gap or lag.

18. NUCHAR computes the resulting velocity and the distance travelled by a decelerating vehicle during a time period.

19. CRSPC computes the critical distance at which a following vehicle, travelling faster than the lead vehicle, must start to decelerate.

20. DSLOPE successively approximates the slope of a deceleration curve.

21. CRSACL computes the critical distance at which a vehicle on an acceleration lane must start to decelerate.

22. PARAACL computes the slope and intercept of an acceleration curve for a free flowing vehicle as a function of actual speed and desired speed.

23. UPDATE is part of the internal bookkeeping system in the simulator. As a vehicle goes out of the system this routine updates the entire general register,
as well as the vehicle index arrays.

24. RAMLOG moves the on-ramp vehicles along the ramp. It also generates new on-ramp vehicles into the system.

25. RAMVEN generates time headways between successive entering on-ramp vehicles in accordance with a hyper-Erlang distribution.

26. INTEX introduces new through-lane vehicles into the system.

27. VEHGEN generates time headways between entering through-lane vehicles, in accordance with a shifted-exponential distribution.

28. CHAR3 computes the location of each vehicle in the system at the end of every time increment. The location is described in terms of blocks and position within block.

29. PACK stores or packs the descriptive characteristics for each vehicle into four computer words. It uses either one-half or one-quarter of a word for each characteristic to be stored.

30. UNPACK extracts the descriptive characteristics of each vehicle from the four computer words in which they are stored.

31. STC is an IBM 360 Assembler Language routine that places descriptive characteristic values into a computer word.

32. GETCAR is an IBM 360 Assembler Language
routine that extracts the descriptive characteristic values from a packed computer word.

33. RANDU generates uniformly distributed random numbers.

34. GAUSS generates normally distributed random numbers.

35. ASORT sorts the sampled data that is collected at each control point into an ascending order.

Input Information

The input data that is required in the proposed general model can be categorized as below:

1. Roadway characteristics
   a. number of through lanes, between 1 and 5,
   b. number of on-ramps, between 1 and 4,
   c. number of off-ramps, between 1 and 6,
   d. number of left hand on-ramps,
   e. length of the freeway section given in numbers of unit blocks,
   f. length of each of the on-ramps and off-ramps, given in numbers of unit blocks,
   g. length of each of the acceleration and deceleration lanes, given in numbers of unit blocks,
   h. location of the end of the accelera-
tion lanes and the beginning of the
deceleration lanes,

2. Traffic characteristics
   a. total one directional traffic volume
      in through section, in vehicles per
      hour,
   b. volume of traffic on each of the on-
      ramps, in vehicles per hour,
   c. percentage of commercial vehicles in
      each through lane and on each on-
      ramp,
   d. the percentage of vehicles that exit
      through each of the off-ramps,
   e. for each on-ramp, the percentage of
      vehicles that exit through each of
      the off-ramps,
   f. the values of the parameters re-
      quired to generate on-ramp vehicle
      headways,
   g. maximum allowable freeway speed,
   h. minimum allowable freeway speed,
   i. maximum allowable ramp speed,
   j. minimum allowable ramp speed.

3. Driver-vehicle characteristics
   a. the values of the coefficients to
      compute the mean desired speeds for
      each on-coming traffic stream,
b. the values of the gap acceptance parameters,
c. the location of exit decision stations,

4. Program control
   a. the scan interval time,
   b. the warm-up time,
   c. the period of simulation,
   d. the location of control points.

The input geometry for a typical simulation run is presented in Figure 28.

Output Information

The proposed model was developed as a general purpose tool for analyzing freeway traffic operating characteristics. The computer output from a simulation run provides general information about the freeway traffic system as a whole. This output includes:

1. distribution of headways in each lane at each control point,
2. distribution of speeds in each lane at each control point,
3. distribution of traffic volumes in each lane at each control point,
4. distribution of exiting, entering and through vehicles at each control point,
5. distribution of exiting, entering and
NB  NUMBER OF BLOCKS IN TOTAL SECTION
NL  NUMBER OF THROUGH LANES
LONRM NUMBER OF BLOCKS IN AN ON-RAMP
LXTRM NUMBER OF BLOCKS IN AN OFF-RAMP
JACLN BLOCK NUMBER INDICATING END OF ACCELERATION LANE
JRNSE BLOCK NUMBER INDICATING LOCATION OF ON-RAMP NOSE
JDCLN BLOCK NUMBER INDICATING BEGINNING OF DECELERATION LANE
JXNSE BLOCK NUMBER INDICATING LOCATION OF OFF-RAMP NOSE
DECST LOCATION OF EXIT DECISION STATIONS, MEASURED FROM BEGINNING OF SECTION
CP  LOCATION OF CONTROL POINTS, MEASURED FROM BEGINNING OF SECTION

FIG. 28. INPUT SIMULATION GEOMETRY FOR A TYPICAL FREEWAY SECTION
through vehicle speeds in each lane and at each control point.
CHAPTER SIX

VALIDATION OF THE PROPOSED MODEL

Since the purpose of building a digital simulator is to duplicate the real world situation, it is essential to verify the performance of a simulation model. This verification, or validation, can be accomplished by comparing the traffic characteristics generated by the proposed model with those measured in the field. Although a complete duplication of micro details cannot be expected, a reasonable compliance of the simulation results with the real world situation is required if the model is to be used as a tool for design purposes.

Criteria for Validation

The criteria for validation of a simulator should be based on the operational criteria that are used for design purposes. However, the design criteria for one particular aspect of a freeway system may be different from the criteria for other aspects. Thus there is no universally applicable performance criteria for the validation of a general simulator.

In earlier simulation studies the researchers relied upon some or all of the following criteria to
evaluate model performance:

1. traverse time through the system,
2. delay in the system,
3. number and direction of lane changes,
4. average volume and speed in each traffic stream,
5. number of vehicles stopping on the acceleration lane, and
6. length of queue on the acceleration lane.

However, little of this information is currently available from field observations.

In this study, the validation of the simulation model was performed at both "microscopic" and "macroscopic" levels. As the model was being developed simulation runs were made for short periods of time and the operating characteristics for each vehicle in the system were output at the end of each simulation time increment. The movements of each vehicle, and the decisions involved in these movements, were analyzed and compared to data available in the literature. These microscopic examinations were performed in two steps. The performance of the various components of the model was reviewed separately, and then the operation of the entire model was examined as a whole. These microscopic examinations helped to modify the logic associated with different parts of the model. After the microscopic evaluation was completed, the program was ready for macroscopic verification. The
following criteria were established as a basis for the macro evaluations:

1. Overall merging and weaving behavior on a section of a freeway,
2. Distribution of headways upstream of on-ramps on a section of a freeway,
3. Distributions of velocities, headways and volumes at specified control points located on an open section of a freeway,
4. Traffic characteristics on a section of freeway with an operational lane connecting an on-ramp to an off-ramp.

Because it was not feasible to collect large volumes of field data, the necessary validation data were obtained from studies that had been reported in traffic research literature. Several simulation runs were devised for this purpose.

Weaving Behavior on a Freeway Section

The output from two simulation runs, A and B, was compared with experimental data collected on a section of a Long Island parkway with relatively heavy weaving movements (56). The geometric configuration of this study area included four through lanes, two right-hand off-ramps and one right-hand on-ramp. Traffic consisted of only passenger cars. The available experimental data contained information regarding the weaving behavior of traffic at
both low and high volumes.

The overall geometric layout of the study section is presented in Figure 29, and the digital description that was prepared for input to the simulator is tabulated in Tables 2 and 3. Input volumes in the through lanes were specified on the basis of the information reported by Kobett and Levy (55). Input speeds were established hypothetically.

The experimental data included traffic volumes for six minute periods in each through lane immediately upstream of off-ramp 2 and immediately downstream of off-ramp 1. It also included the entering volume from the on-ramp, and the concurrent volumes on each of the off-ramps. The results obtained from simulation runs and the experimental observations are compared for low and high levels of traffic flow in Figures 30 and 31, respectively.

At the low-volume level, the simulation results are in general agreement with the field data. The through volumes upstream of off-ramp 2 and the exiting volumes on the off-ramps compare very closely. However, the through volumes downstream of off-ramp 2 deviate from the observed volumes. This discrepancy is due, in part, to the fact that the simulated on-ramp volume was 150 v.p.h., whereas the observed on-ramp volume was 50 v.p.h. Simulator input parameters are not currently available for on-ramp volumes below 150 v.p.h. As a consequence a greater number of ramp vehicles merged into the shoulder lane and
FIG. 29. INPUT GEOMETRY FOR MERGING-WEAVING SIMULATION RUNS

NOTE—NUMBERS INDICATE THE BLOCK NUMBERS
TABLE 2
INPUT DATA FOR LOW VOLUME MERGING-NEAVING SIMULATION RUN

<table>
<thead>
<tr>
<th>Volumes in v.p.h.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp</td>
<td>150</td>
</tr>
<tr>
<td>Lane 1</td>
<td>1000</td>
</tr>
<tr>
<td>Lane 2</td>
<td>600</td>
</tr>
<tr>
<td>Lane 3</td>
<td>450</td>
</tr>
<tr>
<td>Lane 4</td>
<td>850</td>
</tr>
</tbody>
</table>

Proportion of Exiting Vehicles for Off-Ramp 1

<table>
<thead>
<tr>
<th>Lane</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Proportion of Exiting Vehicles for Off-Ramp 2

<table>
<thead>
<tr>
<th>Lane</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Factors of Mean Desired Speed

<table>
<thead>
<tr>
<th>Location</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp</td>
<td>0.75</td>
</tr>
<tr>
<td>Lane 1</td>
<td>0.8</td>
</tr>
<tr>
<td>Lane 2</td>
<td>0.8</td>
</tr>
<tr>
<td>Lane 3</td>
<td>0.85</td>
</tr>
<tr>
<td>Lane 4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Maximum Freeway Speed -- 50 m.p.h.
Warm-Up Time -- 100 seconds
Sampling Period -- 6 minutes
### TABLE 3

**INPUT DATA FOR HIGH VOLUME MERGING-WEAVING SIMULATION RUN**

**Volumes in v.p.h.**

- On-ramp: 150
- Lane 1: 2040
- Lane 2: 2220
- Lane 3: 400
- Lane 4: 1430

**Proportion of Exiting Vehicles for Off-Ramp 1**

- Lane 1: 0.115
- Lane 2: 0.0556
- Lane 3: 0.175
- Lane 4: 0.035

**Proportion of Exiting Vehicles for Off-Ramp 2**

- Lane 1: 0.181
- Lane 2: 0.019

**Factors of Mean Desired Speed**

- On-ramp: 0.75
- Lane 1: 0.75
- Lane 2: 0.75
- Lane 3: 0.85
- Lane 4: 0.90

- **Maximum Freeway Speed:** 50 m.p.h.
- **Warm-Up Time:** 100 seconds
- **Sampling Period:** 6 minutes
FIG. 30  RESULTS OF THE LOW VOLUME MERGING-WEAVING SIMULATION

(NUMBERS SHOWN REPRESENT SIX-MINUTE VOLUMES)
forced an excessive volume into lane 1.

The simulation results for the high-volume situation do not agree well with the experimental observations. The input volume in lane 1 was above capacity and that in lane 2 was near-capacity. Many of the exiting vehicles from the inner lanes were not able to weave through the dense traffic in the outer lanes to get to the off-ramps. Consequently the off-ramp volumes were too low. In addition, because of the excessive on-ramp volumes called for in the simulation run a large number of vehicles were unable to merge into the shoulder-lane stream.

**Distribution of Headways Upstream of the On-Ramps**

Field data on time headways in lanes adjacent to right and left-hand on-ramps was available for a portion of the westbound half of the Eisenhower Expressway in Chicago (64). This section of highway contained three through lanes and two on-ramps. Headways were measured 650 feet upstream of a left-hand on-ramp from Harlem Avenue and 700 feet upstream of a right-hand on-ramp from Des Plaines Avenue. The on-ramp from Harlem Avenue was followed by a 1000 foot long acceleration lane, whereas the ramp from Des Plaines Avenue was followed by an 800 foot long acceleration lane. The data included headways for both low and high-volume conditions.

Two simulation runs, C and D, were devised to obtain headway data for comparison with the field data.
The input geometry for these simulation runs is presented in Figure 32. Two control points were set up; headway data for lane 1 was collected at control point 1, and data for lane 3 was collected at control point 2. Other input information required for the runs is given in Tables 4 and 5. The simulator was run for 200 seconds in order to bring the system to a stable condition and the sampling was conducted for a period of five minutes.

The headway frequency distributions obtained from simulation runs C and D are plotted in Figures 33 to 36. Experimental headways are superimposed on the same plots for purposes of comparison. The results from the simulation runs are in reasonable overall agreement with the experimental observations, especially in the range above three seconds. This range of larger headways represents the time-spacings between successive platoons of vehicles, that are formed as a consequence of complex vehicular interactions. It is interesting to note that Kobett and Levy (56) also obtained the best agreement in this region.

Contrary to experimental observations, headways smaller than 0.75 seconds did not appear in the simulation results. In addition, the simulated distributions present higher peaks than the observed distributions between 1.5 and 2.5 seconds. These discrepancies can be attributed to the empirical models used to regulate the minimum desired distance spacing. The empirical models forced
FIG. 32. INPUT GEOMETRY FOR SIMULATION RUNS TO OBTAIN DISTRIBUTIONS OF HEADWAYS UPSTREAM OF ON-RAMPS

NOTE—NUMBERS INDICATE BLOCK NUMBERS
TABLE 4
INPUT DATA FOR SIMULATION RUN TO OBTAIN
HEADWAY DISTRIBUTION UPSTREAM OF ON-RAMPS
AT LOW VOLUME

<table>
<thead>
<tr>
<th>Volumes in v.p.h.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp 1</td>
<td>200</td>
</tr>
<tr>
<td>On-ramp 2</td>
<td>200</td>
</tr>
<tr>
<td>Lane 1</td>
<td>600</td>
</tr>
<tr>
<td>Lane 2</td>
<td>1080</td>
</tr>
<tr>
<td>Lane 3</td>
<td>720</td>
</tr>
</tbody>
</table>

Proportion of Commercial Vehicles

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp 1</td>
<td>.03</td>
</tr>
<tr>
<td>On-ramp 2</td>
<td>.03</td>
</tr>
<tr>
<td>Lane 1</td>
<td>.06</td>
</tr>
<tr>
<td>Lane 2</td>
<td>.03</td>
</tr>
<tr>
<td>Lane 3</td>
<td>.01</td>
</tr>
</tbody>
</table>

Factors of Mean Desired Speed

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp 1</td>
<td>0.75</td>
</tr>
<tr>
<td>On-ramp 2</td>
<td>0.75</td>
</tr>
<tr>
<td>Lane 1</td>
<td>0.85</td>
</tr>
<tr>
<td>Lane 2</td>
<td>0.9</td>
</tr>
<tr>
<td>Lane 3</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Maximum Freeway Speed -- 60 m.p.h.
Warm-Up Time -- 200 seconds
Sampling Period -- 5 minutes
### Table 5

**Input Data for Simulation Run to Obtain Headway Distributions Upstream of On-Ramps at High Volume**

<table>
<thead>
<tr>
<th>Volumes in v.p.h.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp 1 -</td>
<td>400</td>
</tr>
<tr>
<td>On-ramp 2 -</td>
<td>400</td>
</tr>
<tr>
<td>Lane 1 -</td>
<td>1200</td>
</tr>
<tr>
<td>Lane 2 -</td>
<td>1/20</td>
</tr>
<tr>
<td>Lane 3 -</td>
<td>1380</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proportion of Commercial Vehicles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp 1 -</td>
<td>0.03</td>
</tr>
<tr>
<td>On-ramp 2 -</td>
<td>0.01</td>
</tr>
<tr>
<td>Lane 1 -</td>
<td>0.06</td>
</tr>
<tr>
<td>Lane 2 -</td>
<td>0.03</td>
</tr>
<tr>
<td>Lane 3 -</td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors of Mean Desired Speed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramps -</td>
<td>0.7</td>
</tr>
<tr>
<td>Through Lanes -</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Maximum Freeway Speed** -- 60 m.p.h.

**Warm-Up Time** -- 200 seconds

**Sampling Period** -- 5 minutes
FIG. 33. FREQUENCY DISTRIBUTION OF HEADWAYS IN ADJACENT LANE UPSTREAM OF RIGHT HAND ON-RAMP AT LOW VOLUME
FIG. 34. FREQUENCY DISTRIBUTION OF HEADWAYS IN ADJACENT LANE UPSTREAM OF RIGHT HAND ON-RAMP AT HIGH VOLUME
FIG. 35. FREQUENCY DISTRIBUTION OF HEADWAYS IN ADJACENT LANE UPSTREAM OF LEFT HAND ON-RAMP AT LOW VOLUME
FIG. 36. FREQUENCY DISTRIBUTION OF HEADWAYS IN ADJACENT LANE UPSTREAM OF LEFT HAND ON-RAMP AT HIGH VOLUME
long minimum distance spacings that in turn generated long
time spacings between vehicles in platoons.

Traffic Characteristics on an Open Section of Freeway

Three simulation runs were made to investigate
traffic characteristics on an open section of freeway,
without on and off-ramps. A freeway section with five
through lanes, two on-ramps and two off-ramps was selec-
ted. The geometric configuration of the study area is
presented in Figure 37. Three runs, E, F, and G, were made
with low, medium, and high volume levels, respectively.
For each of the runs all of the input information except
the total volume in the through lanes, was held constant.
The list of input data for these runs is presented in
Table 6.

The distributions of volumes, headways and
speeds at each lane were obtained by sampling for a period
of ten minutes during each simulation run. A control
point was located in the middle of a 3000 feet long open
section that was essentially free of any influence from
on and off-ramps.

The distribution of volumes between lanes is
presented in Figure 38. The cumulative headway distri-
butions for low, medium and high volumes are plotted in
Figures 39 to 41. The cumulative speed distributions for
the same volumes are plotted in Figures 42 to 44.

The results obtained from these simulation runs
Fig. 37. Input geometry for the simulation of traffic flow on a 10-lane freeway section.
### Table 6

**Input Data for Simulation Runs to Obtain Traffic Characteristics on an Open Freeway Section**

<table>
<thead>
<tr>
<th>Total Freeway Volume in v.p.h.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Run E</td>
<td>2500</td>
</tr>
<tr>
<td>Simulation Run F</td>
<td>5000</td>
</tr>
<tr>
<td>Simulation Run G</td>
<td>7000</td>
</tr>
</tbody>
</table>

**On-Ramps Volume in v.p.h.**  
500

**Proportion of Commercial Vehicles**

| On-ramps | 0.05 |
| Lanes 1, 2, and 3 | 0.05 |

**Proportion of Exiting Vehicles for Off-Ramp 1**

| On-ramp 1  | 0.05 |
| On-ramp 2  | 0.10 |
| Lane 1     | 0.15 |
| Lane 2     | 0.10 |
| Lane 3     | 0.08 |
| Lane 4     | 0.05 |
| Lane 5     | 0.00 |

**Proportion of Exiting Vehicles for Off-Ramp 2**

| On-ramp 1  | 0.00 |
| On-ramp 2  | 0.05 |
| Lane 1     | 0.15 |
| Lane 2     | 0.10 |
| Lane 3     | 0.08 |
| Lane 4     | 0.05 |
| Lane 5     | 0.00 |
TABLE 6, contd.

INPUT DATA FOR SIMULATION RUNS TO OBTAIN TRAFFIC CHARACTERISTICS ON AN OPEN FREEWAY SECTION

<table>
<thead>
<tr>
<th>Factors of Mean Desired Speed</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramps</td>
<td>0.75</td>
</tr>
<tr>
<td>Lane 1 and 2</td>
<td>0.80</td>
</tr>
<tr>
<td>Lane 3</td>
<td>0.85</td>
</tr>
<tr>
<td>Lane 4 and 5</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Maximum Freeway Speed — 60 m.p.h.

Location of Exit Decision Stations

<table>
<thead>
<tr>
<th>Lane</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>592 feet</td>
</tr>
<tr>
<td>3</td>
<td>1060 feet</td>
</tr>
<tr>
<td>4</td>
<td>1800 feet</td>
</tr>
<tr>
<td>5</td>
<td>2450 feet</td>
</tr>
</tbody>
</table>

Location of Control Point — 5729 feet

Warm-Up Time — 100 seconds

Sampling Period — 10 minutes
FIG. 38. VOLUME DISTRIBUTION BETWEEN LANES ON AN OPEN SECTION OF A 10-LANE FREEWAY
FIG. 39. - CUMULATIVE HEADWAY DISTRIBUTIONS ON AN OPEN SECTION OF A 10-LANE FREeway AT LOW VOLUME
FIG. 43. CUMULATIVE SPEED DISTRIBUTIONS ON AN OPEN SECTION OF A 10-LANE FREEWAY AT MEDIUM VOLUME
FIG. 44. CUMULATIVE SPEED DISTRIBUTIONS ON AN OPEN SECTION OF A 10-LANE FREEWAY AT HIGH VOLUME.
were consistent and reasonable. But, since there was no available field data for five-lane freeways, these results could not be verified with observed phenomena. However, some general observations can be made on the basis of the simulation findings. The percentage of vehicles in the shoulder lane is lowest and it increases in successive lanes. The average highway speed is also lowest in shoulder lane and increases successively in inner lanes. Thus, lanes 4 and 5 were observed to be the most heavily travelled as well as the fastest lanes on the open section of a five lane freeway. These observations are generally consistent with flow phenomena that have been observed on freeways with less than five lanes.

Effects of an Operational Lane

The proposed model did not contain any special design features for simulating flow on freeway sections with unusual geometric configurations such as exist on highways with auxiliary or operational lanes. However, with minor modifications in the program logic this feature was readily simulated. As an example problem the study area presented in Figure 45 was considered. It consisted of two through lanes and a 629 feet long operational lane between an on-ramp and an off-ramp. Traffic flow on this section was simulated under the following constraints:

1. Vehicles on the on-ramp must only move forward until they reach the ramp nose. On-ramp vehicles
FIG. 45. INPUT GEOMETRY FOR SIMULATING A FREEWAY SECTION WITH AN OPERATIONAL LANE
on the operational lane, that are not marked to exit through the adjoining off-ramp, must merge into the shoulder lane stream or exit from the system via the off-ramp.

2. Vehicles on the shoulder lane, that are marked to exit, must attempt to weave to the operational lane for eventual exiting through the off-ramp, as soon as they reach the left hand of the operational lane. The shoulder-lane vehicles, that are not marked to exit, must remain in the through section.

3. Vehicles on the median lane, that are marked to exit, must attempt to change to the shoulder lane as soon as they pass the exit decision station. Other vehicles must stay in the through section.

4. Vehicles on the operational lane that are marked to exit must move ahead to the off-ramp.

5. Vehicles on the off-ramp must proceed forward until they go out of the system.

The program logic for the through section of the proposed general model was utilized with the following modifications:

1. The operational lane including both the on-ramp and the off-ramp were labelled as lane 1. The shoulder lane and the median lane were labelled as lane 2 and lane 3, respectively. Thus it was possible to place all of the vehicles in the entire system in one vehicle-index matrix.

2. Vehicles on lane 1 were processed by
one of three routines, depending on their location in the lane (i.e., on the on-ramp, on the operational lane, or on the off-ramp). Normal lane changing was prohibited for vehicles on lane 1.

3. In the proposed general model the logic for the on-ramp merging operation was essentially the same as that for the lane-changing maneuver of exiting vehicles on inner lanes. Therefore, the same routine was utilized for both operations with the exceptions that, (a) the factor for safe following distance in case of on-ramp merging vehicles was set at 25 percent of the normal value, and (b) the required following distance to a lead vehicle on the shoulder lane from an on-ramp merging vehicle was set at one-half of the normal value.

4. Vehicles on lane 2 could not move to the right in order to improve their status.

5. Vehicles on lane 3 could not move to the left in order to improve their status.

Three simulation runs, \( H, I, \) and \( J \), were conducted to obtain distributions of vehicle-volumes, headways, and speeds at each lane and at each control point. Separate speed and volume distributions were obtained for through, exiting and entering vehicles. In addition, the number of vehicles that were not able to merge onto shoulder lane, or to weave to the operational lane was obtained. The warm-up time for all the runs was 60 seconds and the sampling was conducted for a period of
TABLE 7
INPUT DATA FOR SIMULATING A FREEWAY SECTION
WITH AN OPERATIONAL LANE

<table>
<thead>
<tr>
<th>Volume in v.p.h.</th>
<th>Run G: On-ramp</th>
<th>Lane 2</th>
<th>Lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>700</td>
<td>1075</td>
<td>925</td>
</tr>
<tr>
<td>Run H: On-ramp</td>
<td>700</td>
<td>1310</td>
<td>1190</td>
</tr>
<tr>
<td>Run I: On-ramp</td>
<td>1400</td>
<td>1140</td>
<td>860</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proportion of Commercial Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp</td>
</tr>
<tr>
<td>Through Lanes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proportion of Exiting Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp</td>
</tr>
<tr>
<td>Lane 2</td>
</tr>
<tr>
<td>Lane 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors of Mean Desired Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-ramp</td>
</tr>
<tr>
<td>Lane 2</td>
</tr>
<tr>
<td>Lane 3</td>
</tr>
</tbody>
</table>

Location of Exit Decision Station -- 592
Warm-Up Time -- 1 minute
Sampling Period -- 15 minutes
<table>
<thead>
<tr>
<th></th>
<th>Control Points</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Through Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 2</td>
<td>171</td>
<td>184</td>
<td>200</td>
</tr>
<tr>
<td>Lane 3</td>
<td>258</td>
<td>241</td>
<td>225</td>
</tr>
<tr>
<td><strong>Entering Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>13</td>
<td>28</td>
<td>138</td>
</tr>
<tr>
<td>Lane 2</td>
<td>106</td>
<td>104</td>
<td>0</td>
</tr>
<tr>
<td>Lane 3</td>
<td>17</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td><strong>Exiting Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>90</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>Lane 2</td>
<td>7</td>
<td>12</td>
<td>64</td>
</tr>
<tr>
<td>Lane 3</td>
<td>3</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>103</td>
<td>113</td>
<td>168</td>
</tr>
<tr>
<td>Lane 2</td>
<td>284</td>
<td>300</td>
<td>264</td>
</tr>
<tr>
<td>Lane 3</td>
<td>278</td>
<td>252</td>
<td>232</td>
</tr>
</tbody>
</table>

Number of Vehicles That Cannot Merge -- 13
Number of Vehicles That Cannot Weave -- 10
Volumes Represent Vehicles per 15 minutes
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Through Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 2</td>
<td>156</td>
<td>176</td>
<td>215</td>
</tr>
<tr>
<td>Lane 3</td>
<td>281</td>
<td>258</td>
<td>216</td>
</tr>
<tr>
<td><strong>Entering Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>24</td>
<td>47</td>
<td>267</td>
</tr>
<tr>
<td>Lane 2</td>
<td>207</td>
<td>198</td>
<td>0</td>
</tr>
<tr>
<td>Lane 3</td>
<td>39</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td><strong>Exiting Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>163</td>
<td>98</td>
<td>58</td>
</tr>
<tr>
<td>Lane 2</td>
<td>19</td>
<td>25</td>
<td>65</td>
</tr>
<tr>
<td>Lane 3</td>
<td>6</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>127</td>
<td>145</td>
<td>325</td>
</tr>
<tr>
<td>Lane 2</td>
<td>382</td>
<td>399</td>
<td>280</td>
</tr>
<tr>
<td>Lane 3</td>
<td>326</td>
<td>291</td>
<td>227</td>
</tr>
</tbody>
</table>

Number of Vehicles That Cannot Merge — 24
Number of Vehicles That Cannot Weave — 25
Volumes Represent Vehicles per 15 minutes
<table>
<thead>
<tr>
<th>CONTROL POINTS</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 2</td>
<td>218</td>
<td>231</td>
<td>256</td>
</tr>
<tr>
<td>Lane 3</td>
<td>310</td>
<td>296</td>
<td>271</td>
</tr>
<tr>
<td>Entering Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>11</td>
<td>27</td>
<td>133</td>
</tr>
<tr>
<td>Lane 2</td>
<td>112</td>
<td>98</td>
<td>0</td>
</tr>
<tr>
<td>Lane 3</td>
<td>12</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Exiting Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>107</td>
<td>103</td>
<td>33</td>
</tr>
<tr>
<td>Lane 2</td>
<td>6</td>
<td>10</td>
<td>71</td>
</tr>
<tr>
<td>Lane 3</td>
<td>7</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Total Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>118</td>
<td>130</td>
<td>166</td>
</tr>
<tr>
<td>Lane 2</td>
<td>336</td>
<td>339</td>
<td>327</td>
</tr>
<tr>
<td>Lane 3</td>
<td>329</td>
<td>314</td>
<td>288</td>
</tr>
</tbody>
</table>

Number of Vehicles That Cannot Merge -- 11
Number of Vehicles That Cannot Weave -- 13
Volumes Represent Vehicles per 15 minutes
FIG. 48. CUMULATIVE HEADWAY DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, H, AT CONTROL POINT 3
FIG. 50  CUMULATIVE HEADWAY DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, I, AT CONTROL POINT 2
FIG. 51  CUMULATIVE HEADWAY DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, I, AT CONTROL POINT 3
FIG. 63  CUMULATIVE HEADWAY DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, J, AT CONTROL POINT 2

Lane 3
Lane 2
Lane 1

TIME IN SECONDS
HEADWAYS EQUAL TO OR SMALLER THAN TIME SHOWN (S)
FIG. 54 CUMULATIVE HEADWAY DISTRIBUTIONS OBTAINED FROM SIMULATION RUN J, AT CONTROL POINT 3
FIG. 55  CUMULATIVE SPEED DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, H, AT CONTROL POINT 1
FIG. 56  CUMULATIVE SPEED DISTRIBUTIONS OBTAINED FROM SIMULATION RUN, H, AT CONTROL POINT 2
FIG. 57  CUMULATIVE SPEED DISTRIBUTIONS OBTAINED FROM SIMULATION RUN H, AT CONTROL POINT 3
FIG. 58 CUMULATIVE SPEED DISTRIBUTIONS OBTAINED FROM SIMULATION RUN 1, AT CONTROL POINT 1
FIG. 59 CUMULATIVE SPEED DISTRIBUTION OBTAINED FROM SIMULATION RUN 1, AT CONTROL POINT 2

VEHICLES TRAVELLING AT OR LESS THAN SPEED SHOWN (%)
FIG. 60  CUMULATIVE SPEED DISTRIBUTION OBTAINED FROM SIMULATION RUN 1, AT CONTROL POINT 3
FIG. 61 CUMULATIVE DISTRIBUTIONS OF SPEEDS OBTAINED FROM SIMULATION RUN, J, AT CONTROL POINT 1
VEHICLES TRAVELLING AT OR LESS THAN SPEED SHOWN (%)  

SPEED IN M.P.H.  

0 10 20 30 40 50 60 70 80  

0 20 40 60 80 100  

FIG. 62 CUMULATIVE DISTRIBUTIONS OF SPEEDS OBTAINED FROM SIMULATION RUN, J, AT CONTROL POINT 2
FIG. 63 CUMULATIVE DISTRIBUTIONS OF SPEEDS OBTAINED FROM SIMULATION RUN J, AT CONTROL POINT 3
are presented in Figures 64 to 72. Although no compari-
sions can be made with field observations due to the lack
of such data, it can be noted that the simulated speed
and headway distributions are both rational and consis-
tent.
FIG. 64 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN, H, AT LANE 1 AND CONTROL POINT 2
FIG. 65 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN, H, AT LANE 2 AND CONTROL POINT 2
FIG. 66 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN H, AT LANE 3 AND CONTROL POINT 2
FIG. 67 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN 1, AT LANE 1 AND CONTROL POINT 2
FIG. 68 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN, I, AT LANE 2 AND CONTROL POINT 2

VEHICLES TRAVELLING AT OR LESS THAN SPEED SHOWN (%)

SPEED IN M.P.H.

°C Entering
 cá Exiting
  Through
FIG. 69 DISTRIBUTION OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN 1, AT LANE 3 AND CONTROL POINT 2
FIG. 70 DISTRIBUTIONS OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN, J, AT LANE 1 AND CONTROL POINT 2
FIG. 71 DISTRIBUTIONS OF ENTERING, EXITING AND THROUGH VEHICLE SPEEDS OBTAINED FROM SIMULATION RUN J, AT LANE 2 AND CONTROL POINT 2
CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. An objective review was made of the technique of digital simulation of vehicular traffic flow, its historical development and its application in the analysis of the problems associated with freeway traffic system.

2. A general simulator was developed for a freeway section with five through lanes, four on-ramps and six off-ramps. It was designed to simulate flow on a section with a maximum length of three and one-half miles, with both on-ramps and off-ramps.

3. The development of the proposed model was realized in two steps. First, the mathematical models were constructed to describe the various micro-aspects of the system—including the roadway, the vehicle, the driver, and the traffic and environmental conditions. Then, a computer program was written to sequentially process the interrelated components, thereby effecting a dynamic solution of the abstracted system.

4. The micro-models were formulated on the basis of the present understanding of traffic flow theory. In some cases, empirical expressions were utilized in the
The required computer time varied widely from problem to problem; and even for a particular run the ratio of computer time to real time was discovered to decrease considerably as the period of simulation was increased. Moreover, third-generation high-speed computers have made this time aspect relatively unimportant. However, the ratios of computer time to real time, as observed by the author, ranged from 1/2 to 1/10, for several different problems.

Recommendations for Further Research

Additional research in the development of freeway traffic simulator is recommended in the following general areas:

1. More extensive studies should be conducted to obtain information on the traffic characteristics of multilane highways.

2. Specific micro-aspects that should be described more adequately are:
   a. desired speeds,
   b. acceleration-deceleration characteristics,
   c. minimum desired spacings,
   d. ramp headway distributions,
   e. gap acceptance relationships in lane changing maneuvers.

3. Additional laboratory studies should be
conducted to evaluate and improve the program logic of the proposed simulator.
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APPENDIX
APPENDIX A

The Successive Approximation Technique to Obtain a New Value for the Slope of a Speed-Deceleration Curve
APPENDIX A

In the solution of Equation 4.26, it was necessary to obtain a new value for slope, b, in order to find the deceleration rate for a trailing vehicle when the actual spacing to a leading vehicle was less than the critical spacing. This was accomplished by a method of successive approximation. The author gratefully acknowledges the help rendered by Professor George N. Raney of the Department of Mathematics in the development of this method.

Equation 4.26 is expressed as

\[
\frac{a + b V_2'}{a + b V_1} e^{n t_{eqX}} = 0
\]

The above equation can be viewed as a combination of two functions of \( b \)—hyperbolic and exponential. Let the hyperbolic function be \( h(b) \) and the exponential function be \( E(b) \).

Then, \( h(b) = \frac{a + b V_2'}{a + b V_1} \)

and, \( E(b) = e^{t_{eqX}} \)

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The composite function can be written as:

\[ F(b) = h(b) - E(b) \quad , \quad b < 0 \]

Since the slope of the deceleration curve must be less than zero, the significant portion of the composite function lies in the fourth quadrant as shown in Figure A-1. From this figure it can be noted that the point A represents the intersection of \( h(b) \) and \( E(b) \) corresponding to the required value of the slope, \( b \). A method of successive approximation can be employed to reach the point, A. This is performed by computing the value of \( h(b) \) for an approximate value of \( b \) and then proceeding along XY intersecting \( E(b) \) at Y to obtain a new value of \( b \). The value of \( h(b) \) is again computed corresponding to the new value of \( b \), and the process is repeated until the convergence occurs. The value of \( b \) at the convergence is the required value, \( b_n^* \). Let \( b_{n-2} \) be an approximation of the required value of \( b \). Then, the next approximate value of \( b \), \( b_{n-1} \), is obtained as below:

\[ E(b_{n-1}) = h(b_{n-2}) \]

\[ e^{(b_{n-1})t_{eqX}} = h(b_{n-2}) \]

\[ (b_{n-1})t_{eqX} = \log h(b_{n-2}) \]
FIG. A-1. GRAPHICAL REPRESENTATION OF EQUATION NUMBER 4.26

FIG. A-2. SUCCESSIVE APPROXIMATION FOR A NEW VALUE OF THE SLOPE OF A SPEED-DECELERATION CURVE
therefore, \( b_{n-1} = \frac{1}{t_{eq}} \log \left( \frac{a + b_n - 2 \cdot V_2'}{a + b_n - 2 \cdot V_1} \right) \)

Figure A-1 depicts the process of successive approximation as discussed above. In the actual application the first approximate value of \( b \) was assumed to be -1.0, and successive approximations were made according to the above equation. Convergence was assumed with

\[
| h(b_{n-1}) - h(b_{n-2}) | \leq .0001
\]
APPENDIX B.1

Definitions of FORTRAN Variables
DIGITAL SIMULATION OF FREEWAY TRAFFIC SYSTEM

DEFINITIONS OF FORTRAN VARIABLES USED IN THE PROGRAM

AA  - INTERCEPT PARAMETER OF ACCELERATION MODEL
ACCL - NORMAL ACCELERATION OF THE VEHICLE
ACPTNO - INDEX OF ACCEPTANCE OF AN AVAILABLE GAP
ADLC - CURRENT VALUE OF THE INTERCEPT OF SPEED-DECELERATION MODEL
ACMAX - MAXIMUM ACCELERATION OF THE VEHICLE
ACMIN - MAXIMUM DECELERATION OF THE VEHICLE
ACMAXR - MAXIMUM ACCELERATION ON RAMP
ACMINR - MINIMUM ACCELERATION ON RAMP
ALPHA1 - AN ARRAY CONTAINING THE PARAMETERS USED IN HYPERLANG
                      HEADWAY DISTRIBUTION
AM  - MEAN OF ANY POPULATION
AMF - MEAN FOLLOWING DISTANCE FACTOR
ARR1 - AN ARRAY USED TO CONTAIN THE HEADWAYS DURING THE ANALYSIS
ARR2 - AN ARRAY USED TO CONTAIN THE SPEEDS DURING ANALYSIS
ARR3 - AN ARRAY USED TO CONTAIN THE SPEEDS OF ENTERING VEHICLES
                        DURING THE ANALYSIS OF SIMULATED DATA
ARR4 - AN ARRAY USED TO CONTAIN THE SPEEDS OF THE EXITING
                VEHICLES DURING THE ANALYSIS OF SIMULATED DATA
ARR5 - AN ARRAY USED TO CONTAIN THE SPEEDS OF THROUGH VEHICLES
                        DURING ANALYSIS OF SIMULATED DATA
ASPD - ACTUAL SPEED OF THE VEHICLE OF CONCERN
ASPD1 - ACTUAL CURRENT SPEED OF THE FOLLOWING VEHICLE ON ADJACENT LANE
ASPD2 - UPDATED SPEED OF THE LEADING VEHICLE ON THE ADJACENT LANE
ASPDNU - UPDATED SPEED OF THE VEHICLE OF CONCERN
ASPDL - ACTUAL SPEED OF THE LEAD VEHICLE AHEAD AT THE END OF THE
                        CURRENT TIME INCREMENT
ASPDLR - UPDATED ACTUAL SPEED OF THE LEADING CAR ON A RAMP
ASPDV - CURRENT ACTUAL SPEED OF THE RAMP VEHICLE
ASPEED - ACTUAL SPEED OF A CAR IN THE CURRENT TIME INCREMENT
AVLSC - AVAILABLE SPACING BETWEEN A PAIR OF VEHICLES AT THE START
AVSPC - AVERAGE SPACING IN FEET
AVSPD - MEAN SPEED IN MPH
AVT1 - MEAN HEADWAY FOR FREE VEHICLES FOR RAMP VEHICLE GENERATION
AVT2 - MEAN HEADWAY FOR CONSTRAINED VEHICLES FOR RAMP VEHICLE GENERATION
BA - SLOPE PARAMETER OF ACCELERATION MODEL
BDF - REQUIRED VALUE OF THE SLOPE PARAMETER OF DECELERATION MODEL
BDLC - THE CURRENT VALUE OF THE SLOPE OF SPEED-DECELERATION MODEL
BDD - FIRST APPROXIMATION OF NEW VALUE OF SLOPE PARAMETER IN DECELERATION MODEL
CARLN1 - LENGTH OF THE FOLLOWING CAR ON ADJACENT LANE
CARLN2 - LENGTH OF THE LEADING CAR ON ADJACENT LANE
CHSPD - TENTATIVE LANE CHANGING SPEED
CL - LENGTH OF THE VEHICLE OF CONCERN
COF - COEFFICIENT OF MAXIMUM FREEWAY SPEED TO OBTAIN MEAN DESIRED SPEED
CONST - CONSTANT DEPENDING ON THE SPEED DIFFERENCE BETWEEN A PAIR OF VEHICLES ON THE SAME LANE
CP - CONTROL POINT AT WHICH TRAFFIC DATA IS SAMPLED
CPD - LOCATION OF THE CONTROL POINT
CRDIS - DISTANCE AT WHICH AN ON-RAMP VEHICLE MUST START TO DECELERATE ON AN ACCELERATION LANE IF IT CANNOT MERGE INTO FREEWAY
CRSP - CRITICAL SPACING AT WHICH A FOLLOWING CAR MUST START TO DECELERATE
DEC - DISTANCE OF THE DECELERATION LANE
DEGST - AN ARRAY TO REPRESENT THE EXIT DECISION STATIONS
DELSP - MINIMUM DISTANCE SPACING
DELX - DISTANCE TRAVELLED DURING THE CURRENT TIME INCREMENT
DIS1 - DISTANCE A VEHICLE TRAVELS AT ITS CURRENT SPEED
DIS2 - DISTANCE REMAINING TO CROSS THE END OF THE SYSTEM
DIS4 - DISTANCE OF THE VEHICLE FROM THE END OF DECELERATION LANE
DSPED - DESIRED SPEED OF A CAR
DX - DISTANCE BETWEEN THE FRONT BUMPER OF A SHOULDER LANE VEHICLE AND THE BEGINNING OF THE DECELERATION LANE
DUIT - DISTANCE OF THE DESIRED EXIT
FACT - MULTIPLYING FACTOR USED TO COMPUTE REQUIRED FOLLOWING
CHSPD - FINAL LANE CHANGING SPEED
INDEX  - AN ARRAY USED AS A GENERAL REGISTER OF THE SYSTEM
INPT  - ENTRY POINT OF A VEHICLE
IX    - INDEX OF LANE FOR OFF-RAMP MATRIX
IX1   - STARTING RANDOM NUMBER FOR OFF-RAMP MATRIX
IXAR  - STARTING RANDOM NUMBER FOR RAMP SPEED GENERATOR
IDX   - STARTING RANDOM NUMBER FOR DESIRED SPEED GENERATOR
IXEX  - STARTING RANDOM NUMBER TO ASSIGN RANDOMLY ASSIGN AN EXIT
IXF   - STARTING RANDOM NUMBER FOR ASSIGNING FOLLOWING DISTANCE FACTOR
IXFR  - STARTING RANDOM NUMBER FOR THROUGH LANE VEHICLE GENERATOR
IXFLC - STARTING RANDOM NUMBER FOR GAP ACCEPTANCE COMPUTATION IN NORMAL LANE CHANGE LOGIC
IXIT  - THE EXIT NUMBER
IXMRC - STARTING RANDOM NUMBER FOR GAP ACCEPTANCE COMPUTATIONS IN RAMP VEHICLE MERGING LOGIC
IXSP  - STARTING VALUE OF A RANDOM NUMBER GENERATOR USED TO RANDOMLY SPACE THE VEHICLES
IXV   - STARTING RANDOM NUMBER FOR RANDOM ASSIGNMENT OF COMMERCIAL VEHICLES
J1    - BLOCK NUMBER IMMEDIATELY AHEAD
JACLN - BLOCK NUMBER TO INDICATE THE END OF THE ACCELERATION BLOCK NUMBER OF EACH ON-RAMP
JBG   - BLOCK NUMBER OF THE MERGING VEHICLE AT THE END OF THE TIME INCREMENT ON THE SHOULDER LANE
JDCLN - BLOCK NUMBER TO INDICATE BEGINNING OF DECELERATION LANE
JK    - INDEX OF BLOCK FOR ON-RAMP MATRIX
JNOS  - BLOCK NUMBER TO INDICATE THE LOCATION OF ON-RAMP NOSE CHANGING VEHICLE IN THE SAME LANE AT THE END OF THE CURRENT TIME INCREMENT
JX    - INDEX OF BLOCK FOR OFF-RAMP MATRIX
JXNOSE-BLOCK NUMBER TO INDICATE THE LOCATION OF OFF-RAMP NOSE
K1K2K3K4 - PACKED COMPUTER WORDS
LACLN - LENGTH OF ACCELERATION LANE EXPRESSED IN NUMBER OF BLOCKS
LDCLN - LENGTH OF DECELERATION LANE EXPRESSED IN NUMBER OF BLOCKS
LDIPL - LANE NUMBER OF THE LEAD CAR DURING THE LAST TIME INCREMENT
LONRM - LENGTH OF ON RAMP EXPRESSED IN NUMBER OF BLOCKS
LXRNM - LENGTH OF OFF-RAMP EXPRESSED IN NUMBER OF BLOCKS
NB - NUMBER OF BLOCKS
NCP - NUMBER OF CONTROL POINTS SPECIFIED
NL - NUMBER OF LANES
NLNC - NUMBER OF LANE CHANGES
NOR - NUMBER OF ON RAMPS IN THE SYSTEM
NOUT - NUMBER OF VEHICLE GOING OUT OF THE SYSTEM
NUBL - BLOCK NUMBER AT WHICH THE VEHICLE IS UPDATED AT THE END
NVEH - NUMBER OF VEHICLES ENTERING THE SYSTEM
NVMEG - NUMBER OF VEHICLE MERGING AT THE CURRENT TIME INCREMENT
NXR - NUMBER OF OFF-RAMPS IN THE SYSTEM
P - CLEAR SPACE BETWEEN THE REAR OF THE LEAD VEHICLE AND THE
FRONT BUMPER OF THE FOLLOWING VEHICLE
P1 - POSITION OF THE FOLLOWING VEHICLE ON ADJACENT LANE
P2 - POSITION OF THE VEHICLE OF CONCERN
P3 - POSITION OF THE LEADING VEHICLE ON ADJACENT LANE
P2LC - AN ARRAY TO REPRESENT THE POSITION OF A VEHICLE AT
PREVIOUS TIME INCREMENT
P2LR - POSITION OF THE LEADING CAR ON A RAMP
P2R - POSITION OF THE RAMP VEHICLE
PCL - LENGTH OF THE LEAD CAR AHEAD
PLC - LENGTH OF THE LEADING CAR ON A RAMP
PL - POSITION OF THE LEAD CAR AT THE END OF THE CURRENT
TIME INCREMENT
POST - EXACT POSITION OF THE FRONT BUMPER OF A CAR IN A BLOCK
PSDF - POSITION OF THE FOLLOWING CAR ON SHOULDER LANE USED IN RAMP
MERGING LOGIC
PSDL - POSITION OF THE LEADING CAR ON SHOULDER LANE USED IN RAMP
MERGING LOGIC
PSPDL - ACTUAL SPEED OF THE LEAD VEHICLE AT THE START OF THE
CURRENT TIME INCREMENT
PSPDLR - ACTUAL SPEED OF THE LEADING CAR ON A RAMP AT THE BEGINNING OF
THE PREVIOUS TIME INCREMENT
PSPEED - ACTUAL SPEED OF A CAR IN THE PREVIOUS TIME INCREMENT
R - GENERATED HEADWAY IN ON RAMP
RAMVOL - AN ARRAY CONTAINING THE VOLUME OF TRAFFIC IN EACH ON-RAMP
RCLOCK - AN ARRAY TO REPRESENT ON-RAMP TIME CLOCKS
RDIST - REQUIRED DISTANCE BEHIND OF A LANE CHANGING VEHICLE ON ADJ LANE
RDIST - REQUIRED DISTANCE BEHIND OF A LANE CHANGING VEHICLE ON ADJACENT LANE
RELSP - RELATIVE SPEED BETWEEN A PAIR OF VEHICLES
RPEX - AN ARRAY CONTAINING THE PERCENTAGE OF VEHICLES EXITING THROUGH EACH OFF-RAMP FROM EACH ON-RAMP
S - STANDARD DEVIATION OF ANY POPULATION
SDEV - STANDARD DEVIATION OF FOLLOWING DISTANCE FACTORS
SDT - SPECIFIED TIME FOR SAMPLING DATA FROM SIMULATION RUN
SPACE - DISTANCE TRAVELED BY AN ENTERING VEHICLE
SPDiff - SPEED DIFFERENCE BETWEEN A PAIR OF VEHICLES
SPDF - ACTUAL SPEED OF THE FOLLOWING CAR ON THE SHOULDER LANE USED IN RAMP MERGING LOGIC
SPDL - ACTUAL SPEED OF THE LEADING CAR ON SHOULDER LANE USED IN RAMP MERGING LOGIC
SPMIN - MINIMUM DESIRED SPACING USED IN SUBROUTINE CRSPC
T - GENERATED HEADWAY IN THROUGH LANES
TCLOCK - TIME CLOCK FOR THROUGH LANES TO KEEP LOG OF ARRIVALS
TENSPD - TENTATIVE SPEED ASSIGNED TO AN ENTERING VEHICLE
TEQ - TIME OF EQUILIBRIUM FOR A FOLLOWING CAR TO REACH THE SAME SPEED AS THAT OF THE LEADING CAR
TEQX - AVAILABLE TIME TO REACH EQUILIBRIUM
TGAP - DISTANCE AVAILABLE AHEAD OF AN ENTERING VEHICLE
TIME - REAL TIME CLOCK
TIMEIN - TIME THE CAR ENTERS IN THE SYSTEM
TIMEC - TIME A CAR PASSES THE LAST CONTROL POINT
TIMMAX - TIME AT THE START OF NEXT SCAN INTERVAL
TMIN - MINIMUM TIME SPACING USED IN VEHICLE GENERATION LOGIC
TOCP - TIME THE VEHICLE GOES OUT OF THE SYSTEM
TP2 = POSITION OF THE VEHICLE AT THE END OF CURRENT TIME INCREMENT
TSPD = SPEED BASED ON NORMAL ACCELERATION OF THE VEHICLE
TSPD1 = TENTATIVE SPEED TO MAINTAIN A SAFE SPACING
TSPD2 = TENTATIVE SPEED DUE TO NORMAL DECELERATION
TX = ELAPSED TIME SINCE THE VEHICLE PASSED THE CRITICAL POINT
VOL = VOLUME IN A THROUGH LANE
VOLTOT = TOTAL VOLUME IN THE THROUGH LANES
VMAX = MAXIMUM FREEWAY SPEED
VMAXR = MAXIMUM ALLOWABLE RAMP SPEED
VMINR = MINIMUM ALLOWABLE RAMP SPEED
VVMAX = MAXIMUM SPEED CAPABILITY OF VEHICLES
WTIME = WARM UP TIME
X1 = DISTANCE TRAVELLED BY THE LEADING CAR DURING TEO
X2 = DISTANCE TRAVELLED BY THE FOLLOWING CAR DURING TEO
X CLOCK = TIME LEFT IN THE SCAN INTERVAL SINCE THE VEHICLE ENTERED
APPENDIX E.2

Code Listing of Main Routine
EXTERNAL FUNCTION
INTEGER II14

C EQUIVALENCE (II1,II1)

C INITIALIZE THE ARRAYS
DO 1 I=1,5
1 DEGST(I)=0.0
DO 500 J=1,700
DO 500 J=1,5
500 IDW(J)=-1.0
DO 600 L=1,1500
DO 600 M=1,4
600 INDEX(L,M)=0
DO 700 N=1,5
700 TCLOCK(N)=0.0
DO 701 K=1,5
701 P2LC(K)=0.0
DO 4000 IR=1,4
KCLOCK(IR)=0,3
IVOF(IR)=0

C CONTINUE
DO 801 JX=1,86
DO 801 IR=1,4
IDWR(JR+IR)=0
801 CONTINUE
DO 802 JX=1,86
DO 802 IX=1,6
802 IDWX(JX+IX)=0
DO 804 IX=1,6
804 VXTR(I)=0
DO 805 IC=1,4
DO 805 IL=1,5
805 VIEW(IL)=0

C INITIALIZE THE RANDOM NUMBER GENERATORS
C BY PROVIDING SEED VALUES
C
C IVX=563
C IXD=257
C IXP=241
C REWIND THE DISK IN ITS INITIAL POSITION
REWIND 1
C READ THE INPUT INFORMATION
READ5*100 VOLTOT,NL,NB,NOR,NXR,NCP,IRTON
100 FORMAT(F10.2,6I0)
DO 94 N=1,NL
94 READ(5,704) (FPEXT(N,I),I=1,NXR)
704 FORMAT(2F10.4)
READ5*97 FOG,FOL,FGL,FOL,FIL,FGL,F2L
97 FORMAT(3F10.3,1X,2F10.4)
98 FORMAT(4I6)
READ5*98 (JRNONE(IRAMP),IRAMP=1,NOR*)
DO 16 I=1,19
16 READ5*15 ALPHA(I),AVT(I),AVT2(I)
15 FORMAT(1X,2F12.8)
READ5*99 (CP(I),I=1,NCP*)
99 FORMAT(6F10.1)
DO 90 IRAMP=1,NOR
90 READ5*91 (RPEXIT(IRAMP,IP),IP=1,NXR*)
91 FORMAT(6F8.4)
READ5*92 (JBRG(IRAMP),IRAMP=1,NOR*)
READ5*92 (RAMVOL(IRAMP),IRAMP=1,NOR*)
92 FORMAT(4F8.2)
93 FORMAT(6I5)
94 FORMAT(1X,2F10.2)

CALL PRNG01, PROB, FUN
WRITE(*,940) VOLT, NL, NB, NVEH
940 FORMAT(2A0,TOTAL VOLUME=8F8.0, NUMBER OF LANCS=5, NO OF BLOCKS=5, */  

C PRELOAD THE SYSTEM
CALL PRLOAD(IDW, IDVR, INDEX, IXX, IXXL, IXXE, IXXA, IXXAR, NVEH, FPEXT,  
IRAMVOL, RPEXT, VOLT, NL, NB, NHR, NXR, DACLMN, LONRM, COF, VMAX, FPCV, RPCV)

C INCREMENT THE SIMULATOR CLOCK
TOTM=TIME+SIHIM
ITOTM=ITOTM
DO 800 ITIME=1, ITOTM
800 TIME=TIME+1.
DO 702 LK=1, 300
702 JSTORE(LK)=0
JSTORE(LK)=0
NLNC=0
IMR=0
ION=0
NVMSG=0

C CHECK IF ANY CAR LEAVES THE SYSTEM THRU EXIT RAMP
C AND MOVE THE EXIT RAMP VEHICLES

C
CALL XTRAMP(INDEX,IDW,IDX,IDWR,NVEH,TIME,NXR,LXTRM,LDCLN,NL,NS, 1)
INOR,LONRM* 118
DO 192 J=1,NS 119
C CHECK IF THE VEHICLE IS ON ACCELERATION LANE 120
DO 392 TRAMP=1,NOR 121
J=JACLN(1RAMP)+1 122
IF(J.GE.JC*AND.J.LE.JRNOSIRAMP&&) GO TO 393 123
GO TO 392 124
393 JRAMPS=LACLNM1RAMP--JERNOSIRAMP--J* 125
IF(IDWR=0RAMP,TRAMP=,LE*) GO TO 392 126
IF(JRAMPS=,GT1=) GO TO 8999 127
8999 CALL RAMP()IXRMP=1RAMP=1RAMP=INDEX,IDW,IDX,BOG,B1G,B2G,BOL, 1
B1L,B2L,PROB,JGR,IMR,ION,NS,LONRM,ITRON,NL,NVRG= 128
392 CONTINUE 129
C CHECK IF VEHICLE IS ON DECELERATION LANE 130
DO 396 IXRMP=1,NXR 131
JN=JXNOSE(IXRMP)+1 132
IF(J.GE.JN*AND.J.LE.JDCLN(IXRMP)) GO TO 394 133
GO TO 396 134
394 JXRMP=LXTRM()IXRMP=1JDCLN()IXRMP=1J* 135
IF(IDWX(JXRMP),IXRMP,LE*) GO TO 396 136
CALL XRMLOG(JXRMP,IXRMP)INDEX,IDWX,LXTRM* 137
396 CONTINUE 138
C CHECK IF THE VEHICLE IS ON THROUGH LANES 139
DO 192 I=1,NL 140
ACCL=0.0 141
CRSP=0.0 142
TEG=0.0 143
AVLSPC=0.0 144
IDCHV=0 145
IF(IDWJ=1*LE*) GO TO 192 146
IF(IDWJ=1*E&=NVRG*) GO TO 192 147
192 DO 200 M=1,K 148
200 IF(I=INDEX(IDWJ=1*M)) CALL UNPACK(IPK) 149
POS=POST 150

ASPD=ASPEED
DSPD=DSPEED
PSPD=PSPEED
CL=IVEH
FIDF=IDF
FDP=FIDF/100.
AD=ADLC
BD=BLOC
TMN=TIMEIN
TLC=TIMELC
IXT=IXIT
INDX=IND
INT=ENPT
ACMAXX=17.64*0.074*ASPD**1.47
BNM=J
BNB=NB
P2=BNB-BNM*17**POS
C CHECK IF THE CAR IS GOING PAST THE END OF THE SYSTEM DURING THE
C CURRENT TIME PERIOD
DIS1=1.47*ASPD
C DIS1 IS THE DISTANCE REMAINING TO CROSS THE END OF SYSTEM
DIS2=BNB*17-=P2
C IF (DIS1-LT DIS2) GO TO 101
C VEHICLE GOES OUT OF THE SYSTEM
NOUT=IDW(J+1)
C CALL UPDATE(IINDEX, IDW, IDWX, NVEH, NOUT, NL, NB, NOR, LONRM, NXR
1LXTRM=
C REGISTER THE TIME THE VEHICLE GOES OUT OF THE SYSTEM
STIME=DIS2/(ASPD**1.47)
C TOCP IS THE TIME THE VEHICLE LEAVES THE SYSTEM
TOCP=TIME+STIME
C GO TO 1157
C CHECK IF THE CAR APPROACHES THE DESIRED EXIT OR NOT
C CHECK IF THE CAR IS IN SHOULDER LANE
101 IF (IXT.LE.0) GO TO 219
XNOSE=J[XNOSE*IXT]
10 CONTINUE
110 FSPC=0.0
AVLSPC=0.0
PSPDOL=0.0
ASPDOL=0.0
PL2=NB=17.
PCL=0.0
P=PL2–PZ=PCL
IF(IDCWH+E2=0) GO TO 11
GO TO 25
11 IF(INDXT+N=1) GO TO 404
IF1:GO=1* GO TO 513
C
CAR ATTEMPTS TO CHANGE TO RIGHT TO REACH ITS EXIT
CALL XTLNCG(APSDP+PSPD+MAX+CMN+J+CL+P2+FDF+AD+BD+PCL+
1PL2+IXFLEC+F0G+FEG+F2G+PROB1D+INDEX1+INDL+INDEX2+SPEED+NULANG+NB+1
ASPEED=SPEED
IF1(INDL+INDEX2)=0 GO TO 132
GO TO 913
2 DO 803 M=1,4
803 I1M=INDEX1DwJ2,J1,*M*
CALL UNPACK1IPKED*
POSL1=P0ST
ASPDOL=ASPEED
PSPDOL=PSPEED
PCL=IVEH
LDIPL=PL
BJ2=J2
PL2=TVNB-BJ2*17**POSL1
FSPC=1PL2–P2*
P=PL2+PZ=PCL
IF(IDCWH+E2=1) GO TO 17
C
SHOULDER LANE CAR ATTEMPTS TO DECELERATE TO DECELERATION LANE
25 IF(IDCWH+E2=0) GO TO 12
CALL DECW1(ASPD+AD+BD+P2+CL+IXF+INDEX1+INDL+SPEED+
0+IP+POST+NUBL+INDL+INDEX2+SPEED+1
LDCL+INDEX2+SPEED+1
LDCL+INDEX2+SPEED+1
LDCL+INDEX2+SPEED+1
GO TO 14
12  JXRMP=186-(JDCMN(IXT)-J1)
    CALL DECW2(JXRMP,IXT,INDEX,IDX,P2,POS,P,ASPD,CL,FDF,
    INUBL,INDL,TPOST,SPEED,AD,BD,JDCN,DSPD,IXFLC,PROG,FOG,F1G,F2G
    ZNZLXTRM,LDCMN)
14  IF(INDL.EQ.1) GO TO 20
    IF(ASPD.GT.VMAXR) GO TO 26
    ASPEED=ASPD
    GO TO 512
26  CALL NUCHAR(AD,BD,ASPD,ASPDNU,DELX)
    ASPEED=ASPDNU/I*47
    GO TO 521
20  IDWX(NUBLOC,IXT)=IDW(J,J1)
    IDNWBI=IDWX(NUBLOC,IXT)
    JBSHL=JDCN(IXT++)*LXTRM*I=NUBLOC*
    IDW(JBSHL,I1)=IDW(J,J1)
    NLNC=NLNC+1
    JSTORE(NLNC)=JBSHL
    ISTORE(NLNC)=I
    IPL=I
    POST=TPOST
    ASPEED=SPEED
    ADLC=0.0
    BDLC=0.2
    GO TO 154
27  IF(INDX.NE.1) GO TO 498
    IF(I.EQ.1) GO TO 115
    CALL XTLNCG(ASPD,DSPD,ACMAX,ACMIN,J,C,PL2,IXFLC,FOG,F1G,F2G,PROG,IDX,INDEX,INDL,SPEED,NULAN,NB
    ASPEED=SPEED
    IF(INDL.EQ.1) GO TO 152
    IF(ASPD.GT.ASPDL) GO TO 301
C THE EXITING CAR CANNOT CHANGE LANE AND REMAINS IN THE SAME LANE
    CONST=1
    GO TO 302
301  CONST=1.0+0.033*(ASPD-ASPD)*1.47
302 FDIST=D1S1+PCL+CL+ASPD*1.47*CONST)*DF
IF(FDIST<LEFSPC)GO TO 513
C FIND NEW SPEED DECELERATE
IF(ASPD<LEASPD)GO TO 304
TSPD1=ASPD
GO TO 306
306 TSPD1=(FSPC-0.735*ASPD-PCL-CL*DF)/(10*735+1*47*DF)
308 CALL NUCHAR(AD+BD+ASPD+ASPDNU+DELX)
TSPD2=ASPDNU+1.47
IF(TSPD2>TSPD2)GO TO 308
ASPEED=TSPD1
GO TO 310
309 ASPEED=TSPD2
310 IF(ASPEED<LT.30.0).ASPEED=30.0
GO TO 512
312 IF(LDIPL=EQ.1)GO TO 499
C THE LEAD CAR HAS CHANGED LANE IN THIS INTERVAL
IF(ASPD<LEASPD)GO TO 403
DELX=LT.4*ASPD
CONST=1.0+0.03*(ASPD-ASPD)*1.47
FSPD=DELX+PCL+CL+ASPD*CONST*1.47)*DF
IF(FDIST<LEFSPC)GO TO 513
C FIND NEW SPEED
CALL NUSPD(ASPD,LEFSPC,ASPD,CL,DF,TSPD1)
IF(TSPD1<LT.1.47)TSPD1=ASPD
CALL NUCHAR(AD+BD+ASPD+ASPDNU+DELX)
TSPD2=ASPDNU+1.47
IF(TSPD2>LT.1.47)GO TO 315
ASPEED=TSPD1
GO TO 316
315 ASPEED=TSPD2
316 IF(ASPEED<LT.30.0).ASPEED=30.0
GO TO 512
499 AVLSPC=('PLC1')-92
IF(ASPD<LEASPD)GO TO 401
C THE FOLLOWING CAR IS TRAVELLING FASTER THAN LEAD CAR
C FIND THE CRITICAL SPACING
CALL CRSPCIA+BD•PSPDL•ASPD•PCL•CL•FDF•CRSP•TEQ•ASPDL)
IF (AVLSPC.GE.CRSPE GO TO 112
IF (TEQ.GT.110) GO TO 502
ASPEED=ASPDL
DELY=0.51ASPDL•ASPDL•+1.47
CALL CHAR31DELX•J•POS•POST•NUBLOC
ADLC=0
BDL>=0.2
IPL=I
GO TO 150
C FIND THE ELAPSED TIME
502 TX=(CRSPC-AVLSPC)/(1.47•(ASPD-ASPDL))
TEQ=TEQ-TX
IF (TEQ.GT.110) GO TO 503
ASPEED=ASPDL
DELY=0.51ASPDL•ASPDL•+1.47
CALL CHAR31DELX•J•POS•POST•NUBLOC
ADLC=0
BDL>=0.2
IPL=I
GO TO 150
C FIND THE NEW SLOPE OF THE DECELERATION CURVE
503 CALL DSOPE1AD•BD•ASPDL•ASPD•TEQ•BDF
CALL NUCHAR1AD•BD•ASP•ASPNU•DELX
CALL CHAR31DELX•J•POS•POST•NUBLC
ASPEED=ASPNU/1.47
ADLC=BD=ASPDE=ASPEED•1147•AD
BDLC=BD
IPL=I
GO TO 150
112 IF (AVLSPC.GT.CRSPE GO TO 111
C IF THE CAR CANNOT PROCEED NORMALLY, IT ATTEMPTS TO CHANGE LANE
CHSPD=ASPDL
FCHSPD=ASPDL
CALL FRANCASPD•CL•FDF•PL2•PCL•IXFLC•CHSPD•FCHSPD•P2•I•IDW
INDEX.INDLCE SPEED+ULANE*FOG+FIG+F2G+PROB+J+NB+NL*
ASPEED=SPEED
IF(INDLCE=EQ.1) GO TO 152
CALL NHCHAR(AD+BD+ASPD+ASPDNU+DELX*)
CALL CHAR3jDELX+J+PS5+GOST+NU5LOC*
ASPEED=ASPDNU/1.47
ADLC=BD+ASPD-ASPEED*1.47*AD
BDLC=-0.02
IPL=1
GO TO 150
DELX=ASPD*1.47
FDIST=DELX*PCL+CL+ASPD*1.47**PFD
IF(FDIST+LE+F5PC= GO TO 404
CHSPD=(ASPD*1.47+4CMAXX1/3)+47
IF(CHSPD+GT+DSPD) CHSPD=DSPD
IF(CHSPD+GT+DSPD) CHSPD=DSPD
FCHSPD=ASPD
CALL PRLNCGO+ASPD+CL+PFD+PL2+PCL+IXFCL+CHSPD+FCHSPD+P2+1+IDW*
INDEX+INDLCE* SPEED+ULANE*FOG+FIG+F2G+PROB+J+NB+NL*
ASPEED=SPEED
IF(INDLCE=EQ.1) GO TO 152
C FIND NEW SPEED. DECELERATE NORMALLY IF NO LANE CHANGE
TSPD1=(F5PC=0.75*ASPD-PLC-CL-PFD)/(0.75+1.47*PFD)
CALL NHCHAR(AD+BD+ASPD+ASPDNU+DELX*)
TSPD2=ASPDNU/1.47
IF(TSPD2+LT+TSPD1) GO TO 402
ASPEED=TSPD1
GO TO 402
ASPEED=TSPD2
IF(ASPEED+LT+30.0) ASPEED=30.0
GO TO 512
C CAR ATTEMPTS TO ACHIEVE ITS DESIRED SPEED
IF(ASPD+LT+DSPD) GO TO 405
ASPEED=ASPD
GO TO 512
C CAR ACCELERATE
C IF(INLDC=ED+1) GO TO 152
   439
FIND NEW SPEED IF NO LANE CHANGE POSSIBLE
   440
TSPD = (FSPC=0.755*ASPD-PCL=CL*DFD)/(0*755+1.47*DFD)
   441
IF(TSPD>GT=ASPD)* TSPD = ASPDL
   442
IF(TSPD=L=E=ASPD) TSPD = ASPD
   443
   444
410 ASPED= TSPD
   445
GO TO 512
   446
111 IF(ASPD=LT=DSPD) GO TO 505
   447
ASPEED = ASPD
   448
GO TO 512
   449
505 CALL PARA(1)DSPD= AA=BA=
   450
ACCL=(AA-DATA=ASPD)*1.47
   451
TSPD=(ASPD=1.47+ACCL)/1.47
   452
IF(TSPD=GT=DSPD) TSPD = DSPD
   453
DELX=ASPD*TSPD=0.5*1.47
   454
CONST=1.0+*033*(TSPD=ASPD)*1.47
   455
FDIST=DELX=PCL=(CL+TSPD)*1.47*CONST)*PDF
   456
IF(FDIST=LE=FXPC) GO TO 509
   457
CHSPD=(ASPD=1.47+ACMX)/1.47
   458
IF((CHSPD=GT=DSPD)) CHSPD=DSPD
   459
FCHSPD=TSPD
   460
CALL PPLNCNGIASPD=CL*DFD*PL2*PCL*IXFLC*CHSPD=FCHSPD=P2=I*IDW
   461
INDEX=INDLC* SPEED=NULANE*FOG*FIG*F2G*PROBJ*NB*NL=
   462
ASPEED=SPEED
   463
IF(INLDC=ED+1) GO TO 152
   464
C FIND NEW SPEED
   465
CALL NUSPD(ASPD,FSPC=ASPD,PCL=CL*DFD+TSPD)
   470
IF(TSPD=LE=ASPD) GO TO 512
   471
509 ASPEED = TSPD
   472
GO TO 512
   473
513 ASPED = ASPD
   474
512 DELX=Q=1.47*(ASPD+ASPEED)
   475
521 CALL CHAR3JDELX=J*POS*POST*NUBLDC=
   476
ADLC=O=9
   477
BDLC=O=2
   478
TPL=1
DLC=ASPDLC+11=CTIME*0.5+ACLD1*1=CTIME***2
PL2C=PL2-DLC
SEC=PL2C=CPD
ASPD=ASPD1+AT1*ACCL1*CTIME)/1+47
ISPD=ASPD*0.5
ASPD1=ISPD
GAPTC=SEC//1=47*ASPD1#
IF(TIME=LE.WTIME) GO TO 370
IVAL(ICP++)=IVAL(ICP++)+1
WRITE1# ICP++,GAPTC+ASPD
GO TO 370
156 TIME=+TLC
370 CALL PACK(IPKD)
DO 201 M=1,4
201 INDEX(I)WDNBL,M=11)M#
1157 IDW,J++,=0
P2LC1#=#P2
192 CONTINUE
DO 293 KJ=1,300
JS=JSTORE(KJ)
IS=ISTORE(KJ)#
IF(JS+GT+AND+IS+GT+0) GO TO 294
GO TO 293
294 IDW,JS=IS#0
293 CONTINUE
C MOVE THE ON-RAMP CARS
CALL RAHLOG(IDX,IXY,IXZ,IXF,IXR,INDEX,IDW,DTIME,VMAX, 11X1,ALPHA1,AVT1,AVT2,CKLOCK,NVHE1,RAHVOL,PEXT,ROLS,LOHNM,LACLN,NXR, 2IVON,WTIME,RPVC)
C CHECK IF ANY CAR ENTERS THE SYSTEM
CALL ENTER(TIME,IDX,INDEX,IXY,IXF,IXZ,IXR,INDEX,IDW,DTIME,VMAX, 1NVHE1,TLOCK,NL,NXR,ND,VLT0T,COF,VMAX,RPVC)
800 CONTINUE
APPENDIX B.3

Code Listing of Subprograms
SUBROUTINE DECSSA(NL,VOLMED,DECSS)
C THIS ROUTINE COMPUTES THE EXIT DECISION STATIONS IF NO INFORMATION
C IS SPECIFIED
DIMENSION DECSS(5)
NL=5
IWK=3371
IXT=8007
VOLMED=5000
ASPD2=40
DECSS(1)=6*ASPD2
DQ 103 KW=2*N
IWK=K=1
50 CALL VOLDIS(VOLMED,IKW,VOL)
51 EN=VOL/3600
AMT=30
SST=0.5
CALL GAUSS(IXT,SST,AMT,T)
10
c AVLEF IS THE AVERAGE BLOCK LENGTH IN FT
C
2 AVLEB=(1/EN)*(EXP(EN*T)-1)
21 AVLEF=0.5*AVLEB*ASPD2*1.47
23 VF=ASPD2*10
24 VS=ASPD2-10
25 F=VF*(VF+VS)
26 CALL RANDU(IWK,IY,RNWV)
27 IYV=IY
28 IF(RNWV>GT,F) GO TO 54
29 ASPD1=VS
30 GO TO 20
31 54 ASPD1=VF
32 20 SPDFF=ABS(ASPD1-ASPD2)*1.47
C
C DISLNG IS THE DISTANCE TO CHANGE LANE
34 DISLNG=AVLEBF/SPDFF
C WADIS IS THE DISTANCE TO WEAVE FROM ONE LANE TO OTHER
35 WADIS=(AVLEBF/SPDFF)*ASPD1*1.47
36 DECSS(KW)=DECSS(IKW)-WADIS
103 WRITE(6,70) KW,IWK,DECSS(KW),DECSS(IKW),WADIS,VOL,ASPD1,ASPD2
70 FORMAT(2X,216*7(2X,F9.2))
STOP
END
SUBROUTINE PRLOAD(IDW,IDWR,INDEX,IXV,IXD,IXF,IXE,IXA,IXAR,NVEH,
1PEXT,RAMVOL,RPEXT,VLTOT,NL,NB,NOR,MAX,LACL,LON,RM,COF,VMAX,
2FPCV,RPCV)

C THIS IS A ROUTINE TO PRE LOAD THE SYSTEM

COMMON /P/ TIMEIN,TIMEL,ADLC,BDLC,POST,DSPEED,PSPEED,ASPEED
1
COMMON /VE/ K1,K2,K3,K4

INTEGER*2 IPKD(2)

EQUIVALENCE (IPKD(1)*K1)

DIMENSION INDEX(1500,4)*IDW(700,5)

DIMENSION TPV(5),CL(5),PCL(5),SPD(5)

DIMENSION IDWR(86+6)

DIMENSION FPEXT(506)

DIMENSION RAMVOL(4)

DIMENSION PPEXT(4,6)

DIMENSION CLARLIN(4),LONRM(4)

DIMENSION COF(5)

DIMENSION FPCV(15)

DIMENSION RPCV(4)

INTEGER I114*

EQUIVALENCE (I111(1)*K1)

C PRELOAD THE FREeway LANEs

IXP=61287

IND=0

INPT=0

ADLC=-0

BDLC=-0.2

FNML=N

AVL=VOLTOT/FNEL

DO 1 IV=1,NL

J=1

NVEH=1

IDW,JV,IV=NVEH

POST=17.0

IPL=IV

TIMEIN=0.0
C ASSIGN A DESIRED SPEED
257 AM=COF1*V**VMAX
   IF VEH=EQ.34 AM=0.9*AM
   S=0.05*AM
   CALL GAUSSIAR(S,AM,V)
   IF V+GT+VMAX GO TO 260
   DSPEED=V
   GO TO 261
260 DSPEED=VMAX
C ASSIGN AN ACTUAL SPEED
261 AVSPD=AM
2541 ASPEED=DSPEED
2542 IF AVSPD+GT+SPD1*IV** GO TO 300
   CONST=1.0
   GO TO 301
300 SPD1FF=1.47*(ASPEED+SPD1*IV)
   CONST=1.0+0.039*SPD1FF
301 CLAR=1/VEH
C ASSIGN A FOLLOWING DISTANCE FACTOR
   AMF=1.0
   SDF=0.1
   CALL GAUSSIARXF,SDF,AMF,FDF
   FDF=(FDF+0.001)*100.
   IDF=FDF
255 FACT=1.0
   CALL SPCHIST(PL,SPD,AVSPD,ASPEED,FU,F,IXSP,TRV,POST,JOHN,
   IF P1+DELSP+IV+CONST*FACT)
   IF JOHN+GT+N= GO TO 2
   IP1=IV
C ASSIGN AN EXIT
DO 270 J=1,NXR
   IF (JX+NXR+1=1) CALL RANDU(IKEX,JY,RXT)
   IXEX+1Y
   IF (IXEX+1E,FPEXT(IV+JX)) GO TO 271
270 CONTINUE
IXIT=0
GO TO 272
272 IXIT=1JX
TIMEIN=0.0
TIMELC=0.0
PSPEED=ASPEED
NVEH=NVEH+1
IDW1JJIN+IV=NVEH
CALL PACK(IPKD)
DO 9 M=1+4
INDEX(IDW1JJIN+IV),M=II(M)
9 CONTINUE
PCLI(IV)=CL1(IV)
SPI(IV)=ASPEED
2 CONTINUE
C
PRELOAD THE ON RAMP SPEED 28+0
DO 970 IR=1+NOR
JR=LACLN1IR=
POST=0.0
TIMEIN=0.0
TIMELC=0.0
IPL=0
PSPEED=ASPEED
NVEH=NVEH+1
IDWR1JR1=IR=NVEH
CALL RPLD(IDX1IXV1IXEX1IXF1RPEXT1IR1ASPEED1DSPEED1IXIT1IWEH1
1DF1IXAR1NXR1VMAX1RPCV)
FDT=0.0
DELP=0.0
CALL PACK(IPKD)
DO 971 M=1+4
INDEX(IDWR1JR1IR1),M=II(M)
971 CONTINUE
ACL=LACLN1IR=
TPV1IR=ACL17+1
PCL(IR)=IVEH
SPD(IR)=ASPEED
970 CONTINUE
DO 972 IR=1,NBR
  NBR=LRNRM)IR=
  DO 972 IR=1,NBR
  CALL SRLDI(IDO,IXV,IXEX,IXF,RFEXT,IR,ASPEED,DSPEED*IIXT,IVEH*
  1DF,IXAR,NXR,VMAX,RPCV)
  CL(IR)=IVEH
  IFD=FDF
  DF=FDF/100.
  IF(ASPEED*GT,SPD(IR)) GO TO 20
  CONST=1.0
  GO TO 15
  20 SPDIF=F+47*(ASPEED-SPD(IR))
  CONST=1.0*0.033*SPDIF
  15 FACT=0.3
  VOL=RAVVOL(IR)
  CALL SPCNG(CL,SPD,AVSPD,ASPEED,FDF,IXSP,VOL,TPV,POST,JJNR*
  1PDL,DELSP,IR,CONST,FACT)
  IFJJNR=STRING(NBR= GO TO 972
  TIMEIN=0.0
  TIMEIC=0.0
  IPL=0
  PSPEED=ASPEED
  NVEH=NVEH+1
  IDWR(JJNR(IR)=NVEH
  CALL PACK(IPKD)
  DO 973 M=1,4
  INDEX(IDWR(JJNR(IR),M)=I(M)
  973 CONTINUE
  PCL(IR)=CL(IR)
  SPD(IR)=ASPEED
  972 CONTINUE
  RETURN
  END
SUBROUTINE RPLD(IXD,IXV,IXEX,IXF,RPEXT,IR,ASPEED,DSPEED,IXIT)
  IVEH,IFX,IXAR,IXXR,VMAX,RPCV)
DIMENSION RPEXT(4,6)
DIMENSION RPCV(4,6)
C ASSIGN THE TYPE OF VEHICLE
CALL RANDU(IXV,IXY,IFL)
IXV=1Y
IF(IXFL.LT.RPCV(IR)) GO TO 950
IVEH=17
GO TO 951
950 IVEH=34
C ASSIGN DESIRED SPEED
951 AM=0.75*VMAX
IF(IVEH.EQ.34) AM=0.9*AM
SM=0.09*AM
CALL GAUSS(IXD,S,AM,V)
IF(V.GT.VMAX) GO TO 940
DSPEED=V
GO TO 949
940 DSPEED=VMAX
949 AM=28.0
C ASSIGN ACTUAL SPEED
S=2.0
CALL GAUSS(IXAR,S,AM,V)
IF(V.GT.35.0) GO TO 9510
ASPEED=V
GO TO 9511
9510 ASPEED=35.0
C ASSIGN THE EXIT
9511 DO 956 IJ=1,IXXR
  IJ=1,IXXR,1
  CALL RANDU(IXEX,IXY,RXT)
  IXEX=IXY
  IF(RXT.LE.RPEXT(IR,IXJ)) GO TO 957
956 CONTINUE
IXIT=0
GO TO 958
957 IXIT=1+JX
C ASSIGN A FOLLOWING DISTANCE FACTOR
958 AMF=1+0
SDF=0+1
CALL GAUSS*IXF,SDF,AMF,FDF*
FDF=(FDF+0+001)*100*
IDF=FDF
961 RETURN
END
SUBROUTINE FRLNCG(ASPD,CL,DFP,PL1,PL2,PCL,IXF,LC,CHSPD,FCHSPD,PZ,IL)
1IDW,INDEX,INDLC, SPEED,NULANE,FGD,F1G,F2G,Prob,INB,NL*
COMMON /I/ TIMEC,TIME,ADLC,FLDC,POST,DGRAPH,SPEED,ASPEED,
1 L=1
COMMON /U/ K1,K2,K3,K4
INTEGER*4 (IPKD)
EQUIVALENCE (IPKD(11),K1)
DIMENSION INDEX(1500,4*,IDW)700,5*
DIMENSION PROB(701*)
EXTERNAL FUN
INTEGER III4*
EQUIVALENCE (III(1),K1)
ACPTND=0+0
IL=1+1
IF(1+1*GT.NL) GO TO 51
1 CALL SOGAPIL1+IDW,INDEX,J,ASPD1,ASPD3,P1,P3,GAPT1,CARNL1,CARNL3*
1NL=1+1
IF(ASPD3+LE+0+0.0) GO TO 40
2 IF(CHSPD+LE+ASPD3)GO TO 3
CONST1+1+0+0.03*(CHSPD-ASPD3)*1.47
GO TO 5
3 CONST1=1+0
5 FDISSL=(CL-CHSPD)/1.47*CONST1*FDF+0.5+1.47*(CHSPD+ASPD)
23
FDISSL=P2=CARLN3
24
IF(FDISSL+LE+0.0)GO TO 50
IF(FDISSL+GT.1+1PL2=PCL)FDISSL=(P2=PCL)
IF(FDISL.GE.RDISL) GO TO 40
IF(CHSPD.LE.CHSPD)GO TO 50
CHSPD=CHSPD
GO TO 2
C
CHECK THE TRAILING AND WEAVING CARS
40 IF(AASPD1.LE.0.0)GO TO 60
IF(AASPD1.LE.CHSPD)GO TO 7
CONST=1.0+33*(AASPD1-CHSPD)*1.47
GO TO 9
7
CONST=1.0
9
RDIST=(CARLN1+AASPD1*1.47*CONST)*DFD+1.47*AASPD1
FDIST=P2-P1+CL+5.1*1.47*(AASPD1-CHSPD)
IF(FDIST.LT.RDIST)GO TO 50
C
LANE CHANGE MAY TAKE PLACE
20
C
CHECK THE PROBABILITY OF GAP ACCEPTANCE
RELSP=(AASPD1-ASPD)
CALL PROBT(IAPTI+RELSP+FOG+F1G+F2G+ZDEV)
CALL RANDU(IXFLC+1+ARDNO)
IXFLC=IY
CALL ACEPT(I2DEV+PROB+ARDNO+ACPTNO)
IF(ACPTNO)60=60,50
60 NULANE=IL
SPEED=CHSPD
INDLC=1
GO TO 70
50 IF(I1.LE.(I-1)) GO TO 55
51 IL=I+1
IF(I1.LE.0)GO TO 55
GO TO 1
55 INDLC=0
SPEED=0.0
NULANE=0
70 RETURN
END
SUBROUTINE CRSPC)AD,BD,PSDLP,ASPD,PCL,CL,DFD,CRSP,TEO,AASPD1)
TEQ=1.0+RO3+1.0+AD*BD*ASPD1*1.47**1/AD+BD*ASPD1*1.47**
X2=AD*BD*ASPD*1.47#/18D*2#49*EXP#BD*TEQ*1#4*)AD/BD*TEQ
SPM1= PCL*(CL+ASPD)*1.47#/FD
IF(TEQ<>LE*1.0) GO TO 20
X1=(PSPD*ASPD1)/0.5*1.47+ASPD*1.47#/TEQ=1#0) GO TO 21
20 X1=(PSPD+ASPD1)*0.5*1.47#TEO
21 CRSP=X2+SPMIN=X1
RETURN
END
SUBROUTINE XTNLCG(ASPD, D SPD, ACMAx, ACMIN, J, CL, P2, FDF, AD, BD, PCL,
1PL2, TFLC, FG, F2G, PROG, INDW, INDEX, INDCL, SPEED, NULANE)
COMMON /P/ TIME, TIMELC, ADLC, BDLC, POST, DSPEED, PSPEED, ASPEED,
1 IND1VEH, IPL, IXIT, INPT, IDF
 COMMON /U/ K1, K2, K3, K4
INTEGER*2 IPKD(2)
EQUIVALENCE (IPKD(I), K1)
DIMENSION [INDEX] 1500, 4*/IDW1700*5*
DIMENSION PROB(701*)
EXTERNAL FUN
INTEGER II**
EQUIVALENCE (II(I), K1)
CHECK THE RIGHT LANE ONLY
FDISL=0.0
RDISL=0.0
FDIST=0.0
RDIST=0.0
ACPTNO=0.0
FACT=0.75
IL=1
IF(1LE*6# GO TO 70
CALL SODAP(I, IDW, INDEX, J, ASPD1, ASPD2, P1, P3, GAPT1, CARLN1, CARLN3,
1 N5)
CHSPD=(ASPD1*1.47*ACMAX)/1.47
IF(CHSPD<GT, D SPD) CHSPD=0.0
IF(ASP03*GT, 0.01) GO TO 9
FCHSPD=CHSPD
GO TO 40
3 FDISL+P3=P2=CARLN3
   IF(FDISL+GT+(PL2=PCL))FDISL=(PL2=PCL)
   CALL CNG1(ChSPD,ASPD3,ASPD,CL,FDF,RDISL,FACT)
   IF(FDISL+LT+RDISL)GO TO 5
   FCSPD=CHSPD
   GO TO 40
5 CALL PARA(CL,ASPD,AA,BA)
   ACCL=(AA+BA-ASPD)+1+47
   TSPD=(ASPD+1+47+ACCL)+1+47
   IF(TSPD+GE+CHSPD)GO TO 10
   CALL CNG1(TSPD,ASPD3,ASPD,CL,FDF,RDISL,FACT)
   IF(FDISL+LT+RDISL)GO TO 10
   FCSPD=TSPD
   GO TO 40
10 CALL CNG1(ASPD,ASPD3,ASPD,CL,FDF,RDISL,FACT)
   IF(FDISL+LT+RDISL)GO TO 20
   FCSPD=ASPD
   GO TO 40
20 CALL NUCHAR(AD,BA,ASPD,ASPDNU,DELX)
   TSPD=ASPDNU+1+47
   IF(TSPD+LT+30+01)TSPD=30+0
   CALL CNG1(TSPD,ASPD3,ASPD,CL,FDF,RDISL,FACT)
   IF(FDISL+LT+RDISL)GO TO 30
   FCSPD=TSPD
   GO TO 40
30 TSPD1=(ASPD+1+47+ACMN1)+1+47
   IF(TSPD1+LT+30+01)TSPD1=30+0
   IF(TSPD1+GE+TSPD1)GO TO 70
   CALL CNG1(TSPD1,ASPD3,ASPD,CL,FDF,RDISL,FACT)
   IF(FDISL+LT+RDISL)GO TO 70
   FCSPD=TSPD1
   GO TO 40
C CHECK THE TRAIL
40 IF(ASPD+LE+0+0)GO TO 60
   FDIST=PI-PI=CLD=5+47+ASPD+FCSPD1
   CALL CNG1(ASPD1,FCSPD,ASPD1,CL,FCR,FACT)
IF(FDIST<LT>RDIST)GO TO 70
LANE CHANGE MAY TAKE PLACE
CHECK THE PROBABILITY OF ACCEPTANCE,
RELSPE=(ASPD1-FCHSPD)
CALL PROBIT(GAPT1,RELSPE,FOG,F1G,F2G,ZDEV1)
CALL RANDU(IFLCE1,Y,ARDNO)
1XFLC=ITY
CALL ACCEPT(ZDEV,PROB,ARDNO,ACPTNO)
IF(ACPTNO)60+60,70
60 NULANE=1L
SPEED=FCHSPD
INDLC=1
GO TO 60
70 SPEED=0.0
INDLC=0
NULANE=0
RETURN
END

SUBROUTINE PRNORM(PROB,FUN*)
DIMENSION PROB1,701*
JNT=10
XNT=JNT
X0=3.5
Y0=0.002
PROB1=0.0002
DO 10 I=2,701
ZI 1
Z=ZI/100-3.51
H=1.2/2/XNT
H2=H/2
Y=Y0
X=X0
DO 11 J=1,JNT
T1=H*FUNJX*
T2=H*FUNJX*H2*
T3=H*FUNJX*H2*
11 CONTINUE
Ta=H*FUN1*H*
Y=Y+1/2*Z2*Z2+3*Z4/6
X=X*H
PROB11*Y
YO=Y
X0=Z
10 CONTINUE
RETURN
END
FUNCTION FUN1*
FUN=1.0/SQRT(2.0/7.0)*EXP(-0.5*X**2)
RETURN
END
SUBROUTINE PROBIT(X1,X2,A,B1,B2,Z)
Z=A+B1*LOG10(X1)+B2*X2
RETURN
END
SUBROUTINE ACCEPT(Z,PROB,ARDNO,ACPTNO)
DIMENSION PROB(100)
1 IF(Z<.5*5.15*10)
5 ACPT=.0*
GO TO 25
10 IF(Z>.5*15.15*20)
15 I=100+Z*.351*
ACPT=PROB(I)
GO TO 25
20 ACPT=1.00
25 ACPTNO=ARDNO-ACPT
RETURN
END
SUBROUTINE ENTERTIME(IDW,INDEX,IXV,IXD,IXF,IXEX,IXA,IXFR,FPXT,
INVEN,TCLOCK,NL,NXR,NB,VLOTOT,COF,VNAX,FPCV)
COMMON /P/TIMEIN,TIMELC,ADLC,BDLC,POST,DSPEED,PSPEED,ASPEED,
IND,INVEN,IPL,IX1,IXPT,IDO
COMMON /U/K1,K2,K3,K4
INTEGER*2 IPKD(2)
EQUIVALENCE (IPKD(11)*K1)
DIMENSION INDEX(1500,4),IDW(700,5)
DIMENSION TCLK(C,5)
DIMENSION FPXET(5,6)
DIMENSION FPCV(5)
DIMENSION C0F*14
INTEGER II14
EQUIVALENCE (II14*K1)
CHECK IF ANY VEHICLE ENTERS IN THE SYSTEM DURING THE NEXT TIME PER
TIMNX=TIME+1
IND=0
INPT=0
FNL=NL
AVL=VOLTOT/FNL
DO 706 ILN=1,NL
IF (I1MNX=TCLK(ILN)+LE+0,01) GO TO 700
IF (I1MNX=TCLK(ILN)+LE+1) GO TO 251
CALL VENGEN(VOLTOT,VOL,TIMCLK,ILN,IXFR)
TCLK(ILN)=TCLK(C)+TIMCLK
IF (TCLK(ILN)+GE+TIMNX) GO TO 700
251 NVEH=NVEH+1
IF (ILN+GT+3) GO TO 250
CALL RANDU11XV,1Y,YFL
IXV=1Y
IF (YFL+LT+FPCV(ILN)) GO TO 252
250 IVEH=17
GO TO 253
252 IVEH=34
253 CL=IVEH
AM=C0F+ILN*VMAX
IF (IVEH=EQ.34) AM=0.5*AM
S=0.05*AM
CALL GAUSS11XG,5*AM,V
IF (V+GT+VMAX) GO TO 254
DSPD=V
GO TO 255
254 DSPD=VMAX
C ASSIGN A FOLLOWING DISTANCE FACTOR
255 SDF=0.1
AMF=1.0
CALL GAUSS(IXF,SDF,AMF,FDF)
DO 256 IJ=1,NXR
IJX)=NXR,i=i+1
CALL RANDU(IREFIX,1,1,Y,RXT)
IREFIX=1
IF(RXT.LE.FPEXT(ILN,1,JX)) GO TO 257
256 CONTINUE
IXIT=0
GO TO 262
54
257 IXIT=IJX
262 TIMEIN=T_CLOCK)ILN
TIMELC=TIMEIN
X_CLOCK=TIME
TIME NEXT=TIMEIN
IXT=IXIT
TMN=TIMEIN
TLC=TIME
C FIND THE TENTATIVE ACTUAL SPEED
265 TENSOP=DSPD
266 DO 292 LB=1,NB
JTEM=NB-LBJ+1
IF(IDW(JTEM,ILN),GT,0) GO TO 291
292 CONTINUE
SPACE=0.0
TSPD=0.0
TGAP=0.0
DSPD=TENSOP
GO TO 296
291 DO 293 M=1,4
i(IDW(JTEM,ILN),M)
293 CONTINUE
CALL UNPACK(IPKD)
TPOST=POST

INDEX(IDW(JBLOCK*ILH),M)=II(M)

CONTINUE

RETURN

END

SUBROUTINE SOGP(IL,1DW,INDEX,J,ASPDD,ASPDD3,PL,P3,GAP1)
1 CARLNI, CARLNI+NB*
C IT IS A ROUTINE FOR SEARCHING GAP IN ANY ADJACENT LANE
COMMON /P/TIMEIN,TIMELC,ADLC,BDLC,POST,DSPEED,PSPEED,ASPEED,
1 INO,IVEH,IPL,IXIT,INPT,IDF
COMMON /U/K1,K2,K3,K4
INTEGER*2 IPKD(2)
EQUIVALENCE (IPKD(1)*K1)
INTEGER II(1)*
EQUIVALENCE (II(1)*K1)
DIMENSION INDEX(1500*4*IDW700,5*)

C FIND THE FIRST ADJACENT GAP
BNB=NB
J1=J-1
DO 10 INB=1,J1
JB=J-INB
IF(IDW(JB,IL1)*GT*0) GO TO 7
10 CONTINUE
P3=NB+17
ASPDD3=0*0
GO TO 11
7 DO 803 M=1+4
II(M)=INDEX(IDW(JB,IL1)*M)
803 CONTINUE
CALL UNPACK(IPKD)
POST1=POST
BNL=JB
ASPDD3=ASPEED
CARLNI=IVEH
P3=BNB=BNL*17*POST1
C CHECK THE TRAIL CAR
11 DO 26 MM=1+N1
       JT1=J-MM-1
       IF(JT1+G1+N1#) GO TO 27
       IF(IDW(JT1+IL)#G1#0) GO TO 9
26 CONTINUE
27 P1=0.0
604 CONTINUE
   ASPD1=1.0
   GO TO 13
9 DO 604 M=1+4
   I(M)=INDEX(IDW(JT1+IL)#M)
13 GAP1=0.0
604 CONTINUE
   CALL UNPACK(IPKD)
   POST1=POST
   ASPD1=ASPEED
   CARL1=IVEH
   BNF=JT1
   P1=BNB#BNF#17#POST1
   GAP1=(P3-P1)
   GAPT1=GAP1/I(M)47#ASPD1#
   RETURN
END
SUBROUTINE XTRAMP (INDEX, IDW, IDWX, IDWR, NVEH, TIME, NXR, LXTRM, LDCLH,
   IML, NB, NOR, LONRM, IVXT, WTIME)
COMMON /S/ TIMEIN, TIMEELC, ADLC, BDLC, POST, OSPEED, PSPEED, ASPEED,
   IVEH, IPL, IXIT, INPT, IDP
COMMON /U/ K1, K2, K3, K4
INTEGER II#2 IPKD(D2)
EQUIVALENCE (IPKD(1), K1)
INTEGER II#4*'
EQUIVALENCE (I(1), K1)
DIMENSION INDEX(1500, 4, 4, IDW(700, 5, 10, 1)
DIMENSION IDWR(86, 4)
DIMENSION IDWX(86, 6)
DIMENSION LDCLH(6, 1, LXTRM(16, 14)
DIMENSION LONRM(14)
DIMENSION IVXT(6)
CALL UPDATE(INDEX, IDW, IDWR, IDX, NVEH, NOUT, NL, NB, NOR, LONRM, NXR)
1LXTRM*
STIME=DIS2/J11*47*ASPDR*
TOCP=TIME*TIME
GO TO 175
C
MOVE THE OFF=RAMP CARS
30 DO 31 JJR=1, LBXT
JRK=JRK-JJR
IF(JRK.LE.0) GO TO 32
IF(IDWR/JRK+1*GT.0) GO TO 34
CONTINUE
C
31 THERE IS NO CAR IN FRONT OF IT
32 IF(ASPDR.LT.1*VMAXR) GO TO 33
IF(ASPDR.EQ.*VMAXR) GO TO 41
CALL NUCHA(ADR, BRK, ASPDR, ASPDN, DELX)
ASPEED=ASPDU/1*47
IF(ASPEED.LT.*VMAXR)ASPEED=VMAXR
GO TO 101
33 CALL PARACL(VMAXR, AA, BA*
ACCL=1*AA-BA*ASPDR**1*47
ASPEED=1*ASPDR**1*47*ACCL**1*47
IF(ASPEED.LT.*VMAXR) ASPEED=VMAXR
GO TO 10
34 DO 35 M=1,4
35 II=M+(INDEX, IDWX, JRK+1*IR+1*M*
CALL UMP(CX1, 1PKD*
ASPDLR=ASPEED
PSDLR=PSPEED
PSLR=POST
PCLR=VEH
BRK=JRK
PLR=1*XTRM-BRK+1*POST
PL1=PLR-PSR=PCLR
IF(ASPDLR.GT.ASPDLR) GO TO 40
IF(ASPDLR.LT.*VMAXR) GO TO 38
IF(ASPDLR.LT.*VMAXR)GO TO 10

RDIS=(CLR+1*47*ASPDR)*DFD*Q.5*1*47*ASPDR
IF(RDIS=LE*FDIS) GO TO 41
10 CALL NUCHAR(ADR*BDR*ASPDR*ASPDR+4*DELX)
ASPEED=ASPDR+1*47
GO TO 101
36 CALL PARA(VALVAR)*AA*BA*
ACCL=AA-BA*ASPDR+1*47
TSPD=ASPDR+1*47+ACCL*1*47
IF(TSPD=GT*VALVAR) TSPD=VALVAR
IF(TSPD=LE*ASPDR) GO TO 37
CONST+1*0.03*1)TSPD=ASPDR+1*47
GO TO 38
37 CONST+1*0
38 RDIS=1*CLR+1*47*CONST*TSPD**0.5*DFD+1*47*0.5*ASPDR*TSPD
IF(RDIS=GT*FDIS) GO TO 41
ASPEED=TSPD
GO TO 100
40 CONST+1*0.03*1)ASPDR=ASPDR+1*47
RDIS=1*CLR+1*47*CONST*ASPDR+0.5*DFD+1*47*ASPDR
IF(RDIS=LE*FDIS) GO TO 41
ASPEED=ASPDR
GO TO 100
41 ASPEED=ASPDR
400 DELX=0.5*1*47*ASPDR*ASPEED
410 CALL CHAR3(DELX*JR*POST*POST+NLOC)
IF(IDWX=NLOC*IR=LE*0* GO TO 103
WRITE16*102
102 FORMAT12X,B\&ACCIDENT TAKES PLACE IN XRMLOG\*
GO TO 175
103 IDWX=NLOC*IR=1*IDWX*JR*IR*
IDWNL=1*IDWX*NLOC*IR*
ASPEED=ASPDR
PASPEED=ASPDR
IVNF=CLR
ADLC=ADR
BDLC=BDR
IXIT=IXTR
TIMEIN=TMXR
TIMECL=YLCR
IPL=IPLR
IMPT=INPTR
PIDF=(PDF+0.001)*100*
IDF=FIX0P
CALL PACK(IPKD#)
DO 150 M=1,6
150 INDEX1(IDWNL+M+1+II)M*
175 IDWXJR+R=0
200 CONTINUE
RETURN
END
SUBROUTINE GECHV1(JKRN,P,IXT,INDEX1,IDW,X,POS,P,ASPD,CL,PDF,
1WULDC,L,INDC,PPOST,PSPEED,A2,BD,JDCLN,DSPO,IXFLC,PROB,FOC,F16,F2G,
2NB,LXTRM,LDCLN,
COMMON /PJ/ TIMEIN,TIMELC,ADLC,BDLC,PPOST,PSPEED,PSPEED,AASPEED,
1 1 IND1LVEHX,JPL,IXIT,INPTR,DF
COMMON /U/ K1,K2,K3,K4
INTEGER PKD(12)
EQUIVALENCE (IPKD(1),K1)
INTEGER II(4)
EQUIVALENCE (II(1),K1)
DIMENSION INDEX1(1500+II,1D)700+B
DIMENSION IDWX(186)+6
DIMENSION JDCLN(6)
DIMENSION LDCLN(3+ILXTRM)6*
VMAX=39+0
VMIN=12+0
ACMIN=-20+0
NB=NB
LXT=LXTRM+1XT*
LBXT=LXTRM+1XT=LDCLN+1XT*
ADC=LDCLN+1XT*
ATRM=LXT
123
124
125
126
127
128
129
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
22
DCLH=1;DCLN1(IXT)*17
DN=1800-DCLN=17*
DIMENSION PROB701I
P2X=P2-DN
FACT=0=4
C
CHECK THE FRONT CAR ON THE ACCELERATION LANE
DO 31 JIR=1,LXT
JRK=JRN=JIR
IF JIR.LT.LXT GO TO 32
IF JIR.LT.LXT GO TO 34
31 CONTINUE
C
THERE IS NO CAR IN FRONT OF IT
32 ASPPD=0=0
P9=ADC=17*
CARLNL=0=0
GO TO 36
34 DO 35 KM=1,4
35 ILIM=INDEX11DVRXJ IRK,IXT*,M*
CALL UNPACK11PKD*
ASPPD=ASPEED
PSPD=PSPEED
POSNL=POST
CARLNL=INVEM
BRK=JRK
P3=2TRM=BRK=17*.POSNL
C
CHECK THE TRAIL CAR
36 DO 36 J=1,LXT
J1=JRN=JIR-1
IF J1.GT.LXT GO TO 40
IF J1.GT.LXT GO TO 45
36 CONTINUE
40 ASPD=1=0
P1=0=0
CARLNF=0=0
GO TO 50
45 DO 50 KM=1,4
50 CONTINUE
78 TSPDL=ASPĐL+47*ACHMIN!*1+47
    IF TSPDL>L*VMIN* TSPDL=VMIN
    IF TSPDL<6E* TSPDL GO TO 150
CALL CHG111*TSPDL+ASPDL+ASPDL*CL+DFDF+RD15L*FACT#
    IF PD2DL+LT+RD15L* GO TO 150
FCHSPD=TSPDL
100 DELX=1+47*0.5*1*ASPDL*FCHSPD#
    CHECK THE TRAIL CAR
    IF (ASPDL*LE.0.0) GO TO 125
FDIST=P2K+P1*CL+DELX
CALL CHG111*ASPDL+FCHSPD+ASPDL+CAR+NF*DFDF+RD15T*FACT#
    IF FDIST+LT+RD15T* GO TO 150
    CAR MAY WEAVE TO DECELERATION LANE
125 CALL CHAR3(DELX+JXRMP+POS+POST+NUBLCC)
    INDLC=1
    SPEED=FCHSPD
    GO TO 200
150 TPDST=O.O
    NUBLCC=O
    INDLC=O
    SPEED=O.O
200 RETURN
END

SUBROUTINE XRMLOG JIR,IR,INDEX,IDX,LATRM#
COMMON /P/ TIMEIN,TIMELC,ADLC,BDLC*POST+PSPEED*PSPEED+ASPEED,
    IND,IVEH,IPL,IXIT,INPT,IXDF
COMMON /K1/K1*K2*K3,K4
INTEGER*2 IPKD(12)
EQUIVALENCE (IPKD(1),K1)
INTEGER I114*4
EQUIVALENCE (I114(1),K1)
DIMENSION INDEX(1500*4*)
DIMENSION IDX(86*6)
DIMENSION LATRM(1*)
VMINR=20*O
ACHMINR=20*O
IF ASPEED < LT * VMAXR# ASPEED = VMAXR
GO TO 101
33 CALL PARACL1 VMAXR, AA, BA#
ACCL# = AA - BA * ASPD# = 147
ASPEED = 1 * ASPD# = 147 / 147
IF ASPEED > GT * VMAXR# ASPEED = VMAXR
GO TO 100
34 DO 35 N = 1, 4
35 I1K# = INDEX(I1DK), JRK#, IR#, M#
CALL UNPACK1 IPKD#
ASPD#L = ASPEED
PSPD#L = PSPEED
PSOLR = P0ST
PCLR = IVEN
BRK = JRK
P2LR# = XTRM = BRK# = 17, POSLR
FD1# = P2LR# = P2R# = PCLR
IF ASPD#L > ASPD#L GO TO 40
IF ASPD#L < LT * VMAXR# GO TO 36
IF ASPD#L < GT * VMAXR# GO TO 10
RD1# = (CLR# = ASPD#L) * FDF# = 0.5 + 1.47 * ASPD#
IF RD1# <= FD1# GO TO 41
10 CALL NUCHAR (ADR, DFR, ASPD#L, ASPD#U, DELX1)
ASPEED = ASPD#U / 1.47
GO TO 101
36 CALL PARACL1 VMAXR, AA, BA#
ACCL# = AA - BA * ASPD# = 147
TSP# = ASPD# = 147 / 147
IF TSP# > GT * VMAXR# TSP# = VMAXR
IF TSP# < LE * ASPD# L GO TO 37
CONST = 1 + 0.033 * TSP# = ASPD#L = 147
GO TO 38
37 CONST = 1 + 0
38 RD1# = (CLR# = 147 / CONST = TSP# = 0.5 * FDF# = 1.47 # 0.5) * ASPD#L TSP# =
IF RD1# > GT * FD1# GO TO 41
ASPEED = TSP#
GO TO 100
40 CONST=1.0*0.035#ASPDLR=ASPDLR#1#47
RDLS=1CLR=1.47#CONST=ASPDLR#0.5#PDEL.1#47#ASPDLR
IF(RDL$LE.PDL$) GO TO 41
ASPDLR=ASPDLR
GO TO 100
41 ASPDLR=ASPDLR
100 DELX=0.0#1.47#ASPDLR#ASPDLR
101 CALL CHAR(DELX, JR, POSTR, POST, NUBLOC)
102 IF(IDW$NUBLOC*IR$#LE.0#) GO TO 103
WRITE(6,102)
103 IDW$NUBLOC*IR$=IDW$JR*IR$
104 IDWBL=IDW$NUBLOC*IR$
105 ASPDLR=ASPDLR
106 PSPEED=ASPDLR
107 IV=CLR
108 ADL=ADR
109 PBL=BBR
110 IX=1IXTR
111 TIMEIN=TMNR
112 TIMELC=TLCR
113 IPL=IPLR
114 IN1=INPTR
115 FD1=1(FDF#0.001)100
116 FD1=FDF
117 CALL PACK11PKD#
118 GO 150 H=1.5
119 GO 150 H=1.5
120 INDEX=IDW$IDWBL*H=#111H
121 IDW$JR*IR$=0
122 RETURN
END
SUBROUTINE DECV1(ASPDLR,ADRL,PD,CL,IXTR,INDEX,IDW,LC,LC,LC,ASPDLR)
1P,TPOST*NUBLOC*IND$PDEL.1#LXTR
COMMON/P/TIM$P/TIM$LC,ADRL,BBL$POST,PSPEED,ASPDLR
1 IND,IVEH,IPL,IXIT,INPT,IDF
COMMON /U/ K1,K2,K3,K4
INTEGER*2 IPKD(2)
EQUIVALENCE (IPKD(1),K1)
INTEGER II(6)
EQUIVALENCE (II(1),K1)
DIMENSION INDEX(1300,4)
DIMENSION IDW(86*6)
DIMENSION JDCLN(6)
DIMENSION LDCLN(6*6)*,LXTRM)*
VMAXR=35.0
VMINR=12.0
ACMINR=20.0
BNB=NB
LDC=LDCLN+1*IXT*
LXT=LXTRM+1*IXT*
KTRM=LXT
DCLN=JDCLN(IXT)
DN=JBNB-DCLN#*17.0
DO 100 JX=1,LDC
JX=JXT-JX+1
1 IF(IDW(JJX,IXT),GT,0) GO TO 30
20 CONTINUE
C THERE IS NO CAR IN DECELERATION LANE
1 IF(Aspd,GT,VMAXR) GO TO 25
DELT=1.47*ASPD
SPEED=ASPD
DDX=P2+DELT
1 IF(DDX,GT,P) DDX=P
2 DX=DDX+DN
IF (DDX,GT,0.0) GO TO 60
3 GO TO 70
25 CALL NUCHAR(AO,BD,ASPD,ASPDNU,DELT)
SPEED=ASPDNU+1.47
DXX=P2+DELT
1 IF(DDX,GT,P) DDX=P
50 RDIST=(CL+FCHSPD*1.47*CONST)*DFD*0.4  
FDIST=PLX=CLX=DX  
IF(FDIST<LT*RDIST) GO TO 55  
SPEED=CHSPD  
GO TO 60  
55 FCHSPD=(ASPD*1.47*ACMINR)/1.47  
IF(FCHSPD<LT*VMINR) FCHSPD=VMINR  
IF(FCHSPD=GE*CHSPD) GO TO 70  
DELX=1.47*0.8*(ASPD*FCHSPD)  
DDX=PL2+DELX  
IF((DDX=GT=PL) DDX=P  
DX=DDX=DN  
IF((DX=LE=0.0) GO TO 70  
FDIST=PLX=CLX=DX  
IF((FCHSPD=LE=ASPD) GO TO 52  
CONST=1.0*0.033*(FCHSPD=ASPD)*1.47  
GO TO 56  
52 CONST=1.0  
56 RDIST=(CL+FCHSPD*1.47*CONST)*DFD*0.4  
IF(FDIST<LT*RDIST) GO TO 70  
SPEED=FCHSPD  
60 JX=96  
POSX=0.0  
CALL_CHAR3(DX,JX,POSX,TPOST,NUBLOC)  
INDLC=1  
GO TO 250  
70 TPOST=0.0  
NUBLOC=0  
INDLC=0  
SPEED=0.0  
250 RETURN  
END
SUBROUTINE CNG1(SPD1, SPD2, SPD3, CL, FD, F, RD, FACT)

SPD1 IS THE UPDATED SPEED OF THE TRAIL CAR
SPD2 IS THE SPEED OF THE LEAD CAR
SPD3 IS THE CURRENT SPEED OF THE TRAIL CAR

IF (SPD1 ≤ SPD2) GO TO 3

CONST = 1 + 0.039 * (SPD1 - SPD2) * 1.47
GO TO 5

3 CONST = 1.0

5 DIS = CL * SPD1 * 1.47 * CONST = FDF
RDIS = DIS * FACT = 1.47 * (SPD1 - SPD3) * 0.5
RETURN
END

SUBROUTINE SPCNG1(CL, SPD, AVSPD, ASPEED, F, IXSP, VOL, TPV, POST)

10 IF (FDT ≥ DELSP) GO TO 10

FDT = DELSP - (AVSPC - DELSP) * ALOG(RNSP)
IF (FDT ≥ DELSP) GO TO 10

FDT = DELSP

10 TPV(I) = FDT + TPV(I)
BIN = TPV(I) / 17
JIN = BIN
FJIN = JIN
POST = 17 - (BIN - FJIN) * 17
JJIN = JIN + 1
RETURN
END
SUBROUTINE PARACLJDSPD*AA*BA*
X1=0.80847
X2=0.15800747
X3=0.00089692
X4=0.22501
X5=0.00327593
X6=0.0001766
AA=X1*X2*DSPD*X3*DSPD**2
BA=X4*X5*DSPD*X6*DSPD**2
RETURN
END

SUBROUTINE CHAR3JDELX,J+POS*POST*NUBLOC*
B=DELX/I7*
NB=B
B1=NB
P=I8-B1**17*
B2=J-NB
P1=POS*P
IFJJP1=17,*GE.0,0* GO TO 37
POST=P1
NUBLOC=B2
GO TO 2
37 POST=P1=17*
NUBLOC=B2-1*
2 RETURN
END

SUBROUTINE NUSDPL*ASPDL*FSPC*ASPD*PCL*CL*FDX*FD
A=0.0714*FD
B=1.47*FD*0.735-0.0714*ASPD*FD
C=0.735*ASPD-PCL-CL*FD
D=B**2+14.*A*C
TSPD*=B*SQRDTD**/12.*A*
RETURN
END
SUBROUTINE RAMP(IXFCL, IR, JR, INDEX, IDW, IOWR, BOG, BIG, B2G
180L, R1L, B2L, PROB, JBG, IMR, IG, LDW, IONRM, INTR, INX, NMVRGE

IDW IS THE INDEX OF RAMP VEHICLE
IR IS THE LANE INDEX OF THE RAMP VEHICLE
COMMON /F/S TIMECLC, ADLC, SDLNC, POST, DSPEED, PSPEED, ASPEED,
1 INDIVCH, IFL, IXIT, INPT, IDF
COMMON /UU/ K1, K2, K3, K4
INTEGER/2 IPUK121Z1
EQUIVALENCE (IPKD1(1), X1)
DIMENSION INDEX(150044, IDW(70043))
DIMENSION IDWR(186, 4), JACLN(4), RCLOCK(4)
DIMENSION JBG(4)
DIMENSION LONRM4*
INTEGER II(4)
EQUIVALENCE (II(1), K1)
DIMENSION PROB(701)
ACMIND=200
VMAX=1000
VMAX=3500
VMAX=1200
VMIN=300
FVMIN=0.5*VMIN
INPT=0
FDISL=0
RDISL=0
FDIST=0
RDIST=0
ADIS=0
CDIS=0
ACPTNO=10
LON=LONRMJIR*
ON=LON
BNB=0
IDWJIR=IDWR(JR, IR)
IF(JR.GT.1) GO TO 8999
8999 DO 901 M=1,4
   II(M)=INDEX(IDWJIR*M)
901 CONTINUE
   CALL UNPACK1IPED*
   ASPDR=ASPEED
   PSSDR=PSPEED
   DSPDR=DSPEED
   IXTR=IXIT
   TNKR=TIMEIN
   TCR=TIMECL
   ADR=ADLC
   BDR=BDLC
   POSTR=POST
   CLR=IVEH
   FIDF=1DF
   FDF=FDF/100*
   ACKR=17.64*Q.074*ASPDRI+1.47
   BNK=JR
   R2R=1ON-BN*K+17**POSTR
   TBGR=1NB-JBGR1JR+17
   SP2R=TBGR-P2R
   C
      THE FOLLOWING LOGIC IS FOR MERGING FROM THE RAMP TO ADJ LANE
      IF(IROUT LE.0* GO TO 913
      IF(I1R+EQ.1R1N* GO TO 9150
5 915 IS=1
   GO TO 9151
9150 IS=NL
9151 JRS=JGR1JR-JLONRM1JR-JR*
   DO 916 JKS=1, NB
      JKS1-JRS-JKS
      IF(JKS1 LE.01 GO TO 9160
      IF(IDWJJKS11IS*GT.0* GO TO 917
916 CONTINUE
9160 PSGL=NB*17
5 SPDL=0.0
   CARLNL=0.0
930 IF (SPDF =LE 1.0) GO TO 9341
PDIST =SP20-PSDF =CLR+L.470.5*(ASPDOR+FCSPD)
RDIST =L.47*SPDF +CLR
IF (PDIST =LT RDIST) GO TO 940

C CHECK IF THE AVAILABLE TIME GAP IS ACCEPTABLE OR NOT
SGAP =PSDF-PSDF
9330 RELSP =0.0
9350 SHGAP =SHGAP +(1.47*SPDF)
9331 CALL RANDU1XFLC (Y,ARDNO)
IXFLC =IV
CALL ACEPT (B2DEV,PROB,ARDNO,ACPTNO)
IF (ACPTNO) 9341,9341,940

C THE CAR MERGES ONTO THE SHOULDER LANE
9341 IMR =1
ION=IR
NVMRG =1DWR1JR*IR
ASPEED =FCSPD
DELX =L.470.5*(ASPRD+ASPEED)
CALL CHAM3 (DELY,ISR,POS,NSTR,POST+NUBLOC+
IF (IDBNUBLGC =LE 0.0) GO TO 9342
WRITE (6,12) IDN,NUBLOC+15
12 FORMAT (1X,"# ACCIDENT TAKES PLACE WITH CAR@1501 IN MERGING@")
GO TO 9480
9342 IDWNUBLGC =15*IDWR1JR*IR
IDWNBL =IDN(NUBLOC+15)
GO TO 899

C THE CAR DOES NOT ACCEPT THE GAP AND REMAINS ON THE ACL LANE
940 IMR =0
ION=IR
NVMRG =0
DO 941 JST =1,LOGN
JTS=JR-JST
IF (JTS =LE 0.0) GO TO 9410
IF (IDWR1 JTS =IR) GT 0.0 GO TO 943
941 CONTINUE
9410 IF JRT IR# 1# GO TO 942
IF JPD OR GT 0# GO TO 939
D# 147# 0 5# VMINR
DD# JON 17# P2R#
IF JDF GE DD GO TO 942
ASPEED# 0 5# VMINR
ADLC# 0 0
BDLC# 0 2
GO TO 950

939 ADIS# 1ON 17# P2R#
CALL CRSACL ADR# BDOR# ASPDR# FVMIN# CRDIS# TEOG#
IF JADIS# GT CRDIS# GO TO 9390
IF JADIS# EQ CRDIS# GO TO 9389
IF JTEQ# LE 1 0# GO TO 942
TX# CRDIS# ADIS# 147# 0 5# JPSDR# ASPDR#
TEQ# EQ# TX
IF JTEQX# LE 1 0# GO TO 942
CALL DSLOPE# ADR# BDOR# FVMIN# ASPDR# TEOQ# BDF#
BDR# BDF

9389 CALL NUCARCH# ADR# BDOR# ASPDR# ASPDNU# DEXL#
ASPEED# ASPDNU# 1 47
IF JASPEED# LT FVMIN# ASPEED# FVMIN
ADLC# BDOR# (ASPEED# ASPEED)
BDLC# BDOR
GO TO 950

9390 ASPEED# ASPDOR
ADLC# ADR
BDLC# BDOR
GO TO 950

942 ASPEED# 0 0
NUSLOC# 1
POST# 17 0
ADLC# 0 0
BDLC# 0 2
IF JDRN INUSLOC# J# LE 0# GO TO 9420
IF JDRN INUELOC# J# EQ JDR# J# IR# GO TO 9420
WRITE16*13=IDWR\NUBLG\IR*
13 FORMAT12X=ACCIDENT TAKES PLACE WITH CARGS @ON RAMP*
GO TO 9480
9420 IDWR\NUBLG\IR*=IDWR\JR\IR*
IDNBL=IDWR\NUBLG\IR*
GO TO 899
943 DO 944 M=1+4
944 CONTINUE
CALL UNPACK1(IPKD)
ASPDRL*ASPEED
POSLR=POSTCRLNLD=IVEH
BTS=JTS
P2LR=1ON-BTS**17**POSLR
SPCNG=(P2LR-P2R)*CRLNLD-8*0
ADIS=SPCNG
IF(ADIS.LE.8+0) GO TO 945
IF(ASPDRL.GT.0+0) GO TO 9400
D=1470.5*VMINR
DO=ADIS-BD
DO(D.GE.DD) GO TO 945
ASPEED=0.5*VMINR
BDLC=0+2
ADLC=0+0
GO TO 960
9400 CALL CRSACLJADR,BDR,ASPDRL,FVMIN,CRDIS,TEQ*
IF(ADIS.GT.CRDIS) GO TO 9440
IF(ADIS.EQ.CRDIS) GO TO 9439
IF(TEQ.LE.1+0) GO TO 945
TX=CRDIS-ADIS**/11.470.5*PSPDR*ASPDRL
TEQ=TEQ-TX
IF(TEQ.LE.1+0) GO TO 945
CALL DSLOPEJADR,BDR,FVMIN,ASPDRL,TEQX,BDF*
BDR=BDF
9439 CALL NUCHRIJADR,BDR,ASPDRL,ASPDNU,DELX*
ASPEED=ASPDNU/1.47
IF ASPEED<LT=FVMIN= ASPEED=FVMIN
ADLC=BDR(ASPD=ASPEED)
BDLC=BDR
GO TO 950

9440 ASPEED=ASPD
ADLC=ADR
BDLC=BDR
GO TO 950

945 ASPEED=0.0
ADLC=0.0
BDLC=0.2
ZDIS=ON=17=P2LR*CRLNL*8*0
ZDIS=ZDIS=17
TZDIS=ZDIS=17
NUBLOC=ZDIS=11
POST=17,-1ZDIS=TZDIS)
IF IDWR1NUBLOC=IR*LE=0 GO TO 9450
IF IDWR1NUBLOC=IR*EQ=1DWR1JR+IR** GO TO 9450
WRITE6,13=1DWR1NUBLOC=IR*
GO TO 9480

9450 IDWR1NUBLOC=IR*IDWR1JR*IR*
IDWNL=IDWR1NUBLOC*IR*
GO TO 899

950 DELX=1.47=0.5(ASPD=ASPEED)
CALL CHAR(DELAY JR*POST=POST=NUBLOC)
IF IDWR1NUBLOC=IR*LE=0 GO TO 9500
WRITE6,13=1DWR1NUBLOC=IR*
GO TO 9480

9500 IDWR1NUBLOC=IR*IDWR1JR*IR*
IDWNL=IDWR1NUBLOC*IR*)
899 DSPEED=DSPDR
PSPEED=ASPD
IVE=CLR
IXIT=IXTR
FIDF=1PFD*0.001**100*
ACMINR=-20.0
VMAXR=35.0
VMINR=12.0
VMIN=30.0
INPT=0
DO 970 IR=1,NOR
   LON=LONM1;IR* 
   KON=LACLN1;IR*1 
   DO 200 JR=KON+1ON 
      IF1(IDWR)JR*1IR*GT.0* GO TO 20 
   60 TO 200 
   20 IDWR=IDWR(JR,IR) 
   DO 25 N=1,M 
      11(M)=INDEX(IDWR,JR,M) 
      CALL UNPACK(1)PKD* 
      ASPDR=ASPEED 
      DSPDR=DSPEED 
      PSPDR=PSPEED 
      CLR=IVEH 
      ADR=ADLC 
      BDR=BDLC 
      POSTR=POST 
      FDF=1DF 
      FDF=FDF/100* 
      IXTR=IXIT 
      TMNR=TIMEIN 
      TLCR=TIMELC 
      IPLR=IPL 
      INPT=INPT 
      BNR=JR 
   ON=1ON-GNR#17*POSTR 
   DO 31 JR=1,1ON 
   JRK=JR=JIR 
   IF(JRK*LE.0)60 TO 32 
   IF1(IDWR)JRK*IR*GT.0* GO TO 34
31 CONTINUE
   THERE IS NO CAR IN FRONT OF IT
32 IF ASPDR + LT * VMAXR * GO TO 33
   ASPEED = ASPDR
   GO TO 100
33 CALL PARA1 VMAXR + AA * BA
   ACCL = AA * BA * ASPDR * 147
   ASPDR = ASPDR + 147 * ACCL / 147
   IF ASPDR + GT * VMAXR * ASPEED = VMAXR
   GO TO 100
34 GO TO 35 N = 14
35 I1 (N) = INDEX1 (IDWR, [WK, IR, 1 + M)
   CALL UNPACK (1, PKD, ASPDLR = ASPDR)
   PSOLR = PSPEED
   PSOLR = POST
   PCLR = IVEH
   BRK = JKR
   PSDR = (10 * BRK * 17 * PSOLR
   FDIS = PSLR - PSR - PCLR
   IF ASPDR + GT * ASPDLR * GO TO 40
   RDIS = (CLR + 147 * ASPDR) * 0.5 * FDR + 147 * ASPDR
   IF RDIS + LT * FDIS * GO TO 10
   IF (RDG + EQ * FDIS * GO TO 41
   CALL HUCHAR (ADD, BDR, ASPDR, ASPDNU, DELX)
   ASPEED = ASPDNU / 147
   GO TO 100
36 CALL PARA1 VMAXR + AA * BA
   ACCL = AA * BA * ASPDR * 147
   TPSD = ASPDR * 147 * ACCL / 147
   IF TPSD + GT * VMAXR * TPSD = VMAXR
   IF TPSD + LE * ASPDLS * GO TO 27
   CONG = 1 + 0.003 * TPSD * ASPDLR * 147

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GO TO 38
37 CONST=1=0
38 NDIS=CLR,1,47#CONST#TSPD#0,5#FDF,1,47#Q,5#ASPD#TSPD#
IFJPD=GT,FDIS# GO TO 41
ASPEED=TSPD
GO TO 100
40 CONST=1=0,0,33#ASPD=ASPD#1=0,47
RDG=CLR,1,47#CONST#ASPD#0,5#FDF,1,47#ASPD#
IFJPD=LE,FDIS# GO TO 41
CALL NUCHAR(ADR,BRD,ASPD,ASPD#NUL#DELX)
ASPEED=ASPD#NUL#LE,47
IFJASPEED=#GT,ASPD=ASPD#NUL#ASPEED=ASPD#
GO TO 100
41 ASPEED=ASPD
100 DELX=0,0,1,47#ASPD#ASPEED#
CALL CHMR3#DELX,JR=POST#POST#NUL#LE,47
IFJIDWR#IDWR#NUL#IR=LE,0#GO TO 42
WRITE#1=43# IDWR#IDWR#NUL#IZ=IDWR#JR#IR#
43 FORM=12#@ACCIDENT TAKES PLACE WITH CAR# 15#IN RAMLOG#@PCAR#15#
GO TO 175
42 IDWR#IDWR#NUL#IR=IDWR#JR#IR#
IDNUL=IDWR#NUL#JR#IR#
1=1#CLR
1=0,47#ADL#ADR
BDLC=BRD
1=1#IXTR
TIME=TMNR
TIME=TLCR
1=1#PLR
INP=INPR
IFDF=FDF,0,001#100#
IFDF=FDF
CALL PACK1#K0#
DD 150 M=1,4

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150 INDEX1DWNBL, M=II1M*
175 IDHR, JR, IR=0
200 CONTINUE
C CHECK IF ANY CAR ENTERS THE RAMP DURING THE NEXT TIME PRD
C TIMNX=TIME+1.
C IF (TIMNX=RCLOCK(IR)+LET=0=0) GO TO 970
C (TIMNX=RCLOCK(IR)+LET=1=0) GO TO 951
C CALL RAWVEN(IX1,IXR,IRAMCLK,ALPHA1,AVT1,AVT2,IR)
C RCLKC(IR)=RCLOCK(IR)+RAMCLK
C IF (RCLKC(IR)+GET=TIMNX) GO TO 970
C CAR ENTERS THE RAMP
C 951 TIMEIN=RCLOCK(IR)
C TIMELEC=0=0
C CALL RPLD(IX0,IXV,IXEV,IXF,RPOLID,IR,ASPEED,DSPEED,IEXIT,IVEH,
C 11DF=IXAR,IXR,VMAX,RPCV)
C TNSPD=ASPEED
C DSPD=DSPEED
C IXT=IEXIT
C IF=1DF
C BDLC=0=2
C ALC=0=0
C FD=1DF
C FO=1DF/100
C IPL=0
C CL=0
C IND=0
C XRCLK=TIMNX=RCLOCK(IR)
C DO 940 JNR=1,LEN
C JTEM=JNR+JNR=1
C IF (IDHR,JTEM,IR,GT=0) GO TO 941
C 940 CONTINUE
C GO TO 9420
C 941 I(3)=INDEX1DHR(JTEM,IR),31
C CALL UNPACK1PKD
C TPSD=ASPEED
PCL=IVEH
TG=JON-JTEM**17
TGAP=TG+POST=PCL
IF(TENSPD+LE+TSPD) GO TO 9421
CONS=1,0,+0.03*(TENSPD-TSPD)*1.47
SPACE=1.47*TENSPD*XRLCK+(CL+1.47*TENSPD)*CONST)*DFD+10.5
IF(SPACE+LE+TGAP) GO TO 9420
ASPEED=TSPD
GO TO 942
9421 ASPEED=TENSPD
942 SPACE=1.47*ASPEED*XRLCK+CL
IF(TGAP+GE+SPACE) GO TO 943
ASPEED=ITGAP+CL*/11.47*XRLCK*
IF(ASPEED+LT+XMINR ASPEED+XMINR)
GO TO 943
9420 ASPEED=TENSPD
943 ROUTE=1.47*ASPEED*XRLCK
XROUTE=ROUTE/#7
JROUTE=XRUTE
JBLK=JON-JROUTE
XATE=JROUTE
POST=ROUTE=(XRATE+17.1)
ASPEED+ASPEED
DSPEED+DSPEED
IVEH=CL
IDF=IR
7X=XT
IF(TIME+LE+TIME) GO TO 961
IVON(I)=IVON(I)+1
961 NVEH+NVHE+1
1DWR(JRBLK,1)=NVHE
1DBN=IDWR(JRBLK,1)
CALL PACK(IPK)
GO 96A M=1+4
INDEX(IDWBH+M)=11(M)
964 CONTINUE
970 CONTINUE
RETURN
END
SUBROUTINE RANDU(IX, IY, YFL)
IX=IX+65539
IF(IX)=65
5 IY=IY+2147483647
6 YFL=IY
YFL=YFL+.4656613E-9
RETURN
END
SUBROUTINE GAUSS(IX, S, AM, V)
A=0
DO 50 I=1, 12
CALL RANDU(IX, IY, Y)
IX=IY
50 A=A+Y,
V=(A+.6)*S+AM
RETURN
END
SUBROUTINE ASOR(T(A, N))
SORT SUBROUTINE
INTEGER A(N), SAVE
NP=N
1 NP=NP/2
IF(NP) 7, 7, 2
2 K=N-NP
J=1
3 J=J
M=M+NP
4 IF(A(J)-A(M)) 6, 6, 5
5 SAVE=A(J)
A(J)=A(M)
A(M)=SAVE
M=I
I=I+1
IF(I=1) 6,4,4
6 J=J+1
IF(J=K) 3,3,1
7 RETURN
END

SUBROUTINE VOLDIS(VOLTOT, VOL)

IT IS A ROUTINE TO FIND THE VOLUMES IN RESPECTIVE LANES
GO TO (10,20,30,40,41)

10 PCTVOL=0.00103409*(VOLTOT/100)+0.05640909
VOL=PCTVOL*VOLTOT
GO TO 60

20 PCTVOL=0.00900099*(VOLTOT/100)+1.1390910
VOL=PCTVOL*VOLTOT
GO TO 60

30 PCTVOL=2.3204545-.00007954*(VOLTOT/100)
VOL=PCTVOL*VOLTOT
GO TO 60

40 PCTVOL=.28881818-.00093181*(VOLTOT/100)
VOL=PCTVOL*VOLTOT
50 RETURN
END

SUBROUTINE VEHGEN(VOLTOT, VOL, TIMCLK, ILN, IXFR)

IT IS A ROUTINE TO GENERATE VEHICLE IN THE SYSTEM
DISTRIBUTION IS ASSUMED TO BE SHFITED EXPONENTIAL
T IS THE TIME GAP OF ARRIVAL
TM IN IS THE MIN TIME GAP
AVT IS THE AVERAGE TIME GAP
CALL VOLDIS(VOLTOT, VOL, \)
TIMCLK, AVT, VOL, TM IN, VOL
CALL RANDU1, IXFR, IY, YFL, \)
IXFR, IY, \)
T=TM IN-(AVT-TMIN)*ALOG(1.0-YFL)
C SUBROUTINE UPDATE(INDEX, IDW, IDWR, IDWK, NVEH, NOUT, NL, NB, NOLRM, LNXR, LXTRM)
DIMENSION INDEX(1504), IDW(700, 5)
DIMENSION IDWR(6, 4)
DIMENSION IDWK(6, 6)
DIMENSION LONRM(4), LXTRM(6)
C ROUTINE FOR UPDATING THE INDEX OF VEHICLES
NVEH = NVEH + 1
C NOUT IS THE NO. OF THE CAR GOING OUT
DO 220 JOT = 1, NB
DO 220 IOT = 1, NL
IF(IDW(JOT, IOT) .LE. 0) GO TO 220
IF(IDW(JOT, IOT) .LE. NOUT) GO TO 220
IDW(JOT, IOT) = IDW(JOT, IOT) + 1
220 CONTINUE
DO 230 IR = 1, NOLRM
NBR = LONRM(IR)
DO 230 JR = 1, NBR
IF(IDWR(JR, IR) .LE. 0) GO TO 230
IF(IDWR(JR, IR) .LE. NOUT) GO TO 230
IDWR(JR, IR) = IDWR(JR, IR) + 1
230 CONTINUE
DO 240 IX = 1, LNXR
NXTR = LXTRM(IX)
DO 240 JX = 1, NXTR
IF(IDWX(JX, IX) .LE. 0) GO TO 240
IF(IDWX(JX, IX) .LE. NOUT) GO TO 240
IDWX(JX, IX) = IDWX(JX, IX) + 1
240 CONTINUE
DO 250 M = 1, 4
INDEX .IN NOUT, M = 0
C ROUTINE FOR UPDATING THE CHARACTERISTIC
DO 390 NI = NOUT, 1500
NOT=NT+1
DO 330 K=1,4
INDEX(NT+K)=INDEX(NOT+K)
330 CONTINUE
RETURN
END
SUBROUTINE DSCLEPJA,BD,VL,VT,T,BDF
BD0=1.0
502 BD1=(1/4)*ALOG((AD+BD0+1.47*VL)/(AD+BD0+1.47*VT))
FX=1.0+BD1*VL+1.47*AD+BD1*VT+1.47*EXP*BD1*T
IF ABS(FX) .LT. 0.001 GO TO 503
BD0=BD1
GO TO 502
503 BDF=BD0
RETURN
END
SUBROUTINE CR=ACLJAD,BD,ASPD,VMINR,CRDIS,1EQ
1EQ=1.0/BD**ALOG((AD+BD0+1.47*VL)/(AD+BD0+1.47*VT))
x2=1.0+BD*ASPD+1.47*BD**2*EXP*BD*1.47*1.0-1.0/AD/BD**2*1EQ
x1=1.0*0.5*VMINR
CRDIS=x1*x2
RETURN
END
SUBROUTINE NUCHARJAD,BD,ASPD,ASPDNU,DELX*
ASPDNU=1.0+BD*ASPD+1.47*EXP*BD**3/BD**3-1.0/AD/BD*
DELX=1.0+BD*ASPD+1.47*BD**2*1EQ+1.0-1.0/AD/BD*
RETURN
END
SUBROUTINE PACK1PK8/
COMMON/P/ TIMEIN(TMELC*ADLC*BDLC*POST*DSPEED*PSCJED*ASPEED*
IND*JVEH*IPL**IXIT**INPT**IDF
COMMON/U/ K1K2K3K4
INTEGER*/ IP=0(2)
REAL TEST(I)
EQUIVALENCE(TEST(1),TIMEIN)
INTEGER TEST(1)
EQUIVALENCE(TEST(1),KAD)
K=0
DO 1 II=1,2
K=K+1
IF(TEST(I))GT.3276.7) GO TO 500
1 CONTINUE
DO 2 II=3,5
K=K+1
IF(ABS(TEST(I)),GT.25*5) GO TO 500
2 CONTINUE
DO 3 II=6,8
K=K+1
IF(TEST(I),GT.255) GO TO 500
3 CONTINUE
DO 4 II=1,6
K=K+1
IF(TEST(I),GT.285) GO TO 500
4 CONTINUE
FUDGE=.001
IMIN=1TIMEIN+FUDGE**10
IMLC=TIMELC+FUDGE**10
ADL=ABS(ADLC-FUDGE)*10
JADL=ADL
BDL=ABS(BDLC-FUDGE)*10
JBDL=BDL
JSPD=(DSPEED+0.5)
ICLI=(ASPEED+0.5)
Ispd=(ASPEED+0.5)
IOST=POST+FUDGE**10
PMAX(11)=IMIN
PMAX(12)=IMLC
CALL STC(IADL*K2,1)
CALL STC(1BDL*K2,1)
CALL STC(ISPD*K2,2)
CALL STC(IIND*K2,5)
CALL STC(ICL1,K3,0)
CALL STC(ISPD,K3,1)
CALL STC(IOST,K3,2)
CALL STC(IVEH,K3,3)
CALL STC(IPL*K4+0)
CALL STC(INPT*K4+1)
CALL STC(INPT*K4+2)
CALL STC(IDF*K4+3)
RETURN

500 WRITE(*,100) K
100 FORMAT(/1X@SIZE ERROR AT@IS///
RETURN
END

SUBROUTINE UNPACK(IPKD)
COMMON /P/ TIMELC,ADLC,BDLC,POST@DSPEED,PSPEED,ASPEED,
       S,INDV,IVEH, IPL,IXIT,INPT,IDF

COMMON /U/ K1*,K2*,K3*,K4
INTEGER=2 IPKD(2)
IMIN=IPKD(1)
IMLC=IPKD(2)
T=IMIN
TIMEIN=T/10.
T=IMLC
TIMELE=T/10.

CALL GETCAR(IADL,K2*0)
CALL GETCAR(IBDL,K2*1)
CALL GETCAR(JSPD,K2*2)
CALL GETCAR(IND,K2*3)

ADL=IADL
ADLC=ADL/10.
BDL=IBDL
BDLC=BDL/10.
DSPEED=JSPD
SUBROUTINE STC
STORES A CHARACTER FROM THE RIGHT-HAND END OF A FULLWORD
IN A DESIGNATED BYTE IN A STRING

STC
START 0
SAVE 114,12*,*, *
BALR 10+0
USING +10
LM 2*+011*
L 2*012*
L 4*014*
AR 3* *
STC 2*013*
RETURN 114,12*,*, T
END

SUBROUTINE GETCAR
CALL GETCAR TO GET CHAR FROM DISP
TAKES A CHARACTER FROM THE DISP OF A VARIABLE, AT
DISPLACEMENT=DISP, AND PLACES IT RIGHT ADJUSTED IN THE T WORD.

GETCAR
START 0
SAVE 114,12*,*, *
BALR 10+0
USING +10
LM 2*6+011*
L 4*014*
AR 4* *
SR 5* *
ST 5*012*
IC 5*014*
STC 5*312*
RETURN 124,12*,*, T
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