EFFECTS OF DRIVER CHARACTERISTICS AND TRAFFIC COMPOSITION ON TRAFFIC FLOW

by

Gaylynn Golden

Project Report submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTERS

in

Information Systems

APPROVED:

Roy M. Wnek

Roy Wnek, Chairman

C. Egyhazy

W. Frakes

W. Frakes

May, 1994

Blacksburg, Virginia

EFFECTS OF DRIVER CHARACTERISTICS AND TRAFFIC COMPOSITION ON TRAFFIC FLOW

by

Gaylynn Golden

Roy Wnek: Chairman
Information Systems: Department

ABSTRACT

This paper describes the development of simulation models for a variety of traffic flow scenarios. The major goal of the models was to evaluate the effects of driver characteristics and traffic composition on traffic flow. The five scenarios modeled and their respective objectives were as follows:

1. Vehicles switching lanes to increase speed. Objectives were thruput and number of lane switches.
2. Vehicles merging into an adjacent lane. Objectives were distance traveled before merging and number of collisions during lane switching.
3. Vehicles switching from the left or right lane into the center lane. Objectives were number of collisions and number of near misses during lane switching.
4. Vehicles passing on a two-lane bidirectional road. Objective was number of collisions during passing.
5. Vehicles switching from the center lane to the left or right lane to avoid an impassible obstacle. Objectives were number of collisions during lane switching and number of collisions with obstacle.

Various driver characteristics were implemented in the models. The concept of preoccupation/attentiveness was factored into the models through the use of varied reaction times. Other driver characteristics were incorporated in the models via the assignment of vehicle speed. The models provided for a wide variety of driver types. Examples are as follows:

1. Drivers in a hurry.
2. Tourists or drivers unfamiliar with the area.
3. Law-abiding drivers.
4. Aggressive and passive drivers.
5. Young, inexperienced drivers.
6. Tired truck drivers.

The driver characteristics were varied via percentage allocations entered at run-time. The traffic composition for the models consisted of automobiles and multi-axle vehicles of fixed lengths. The percentages for each vehicle type were also entered at run-time.

The scope and level of detail for each model was delineated with assumptions. General assumptions made included the following:

1. An autombile is 10 feet long, a multi-axle vehicle is 30 feet long.
2. The width of a lane is such that only one vehicle can be accommodated at a time.
3. A vehicle is considered to be entirely in one lane or another.
4. A vehicle switches lanes instaneously.
5. The reaction time of an attentive driver is normally distributed with a mean of .5; the reaction time of a preoccupied driver is normally distributed with a mean of .7. Three standard deviations are included to ensure complete population coverage.
6. A collision between two vehicles results in the termination of the vehicle causing the collision; the other vehicle continues.

Implementation of these models was performed using the student version of the simulation language GPSS/H. The models were validated, but not verified, against their real world counterparts. Test results showed that select driver characteristics can affect traffic flow; however, the effect of traffic composition was relatively unshown.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Each year the number of automobiles and trucks traveling the highways of Virginia increases. Consequently, new highways are being built and old highways are undergoing renovations to accommodate the increased traffic flow. A recent newspaper article described the scenario: "Commuters wearying their way from downtown jobs to four-bedroom colonials...families vacationing to Florida and Disney World....Big-rig truckers who know time is money and they're losing both stranded on this stretch of...highway."[1] In Northern Virginia, transportation services are given top priority by the local government and transportation issues are often included in the campaign promises of both local and state political office candidates. A 1983 study on urban transportation networks stated that "The growth of our population, industry and economy has put a serious burden on traffic management in the form of congestion, pollution, safety, etc. Solutions to many of these problems are continually being sought. One of the most viable and promising solutions to relieve traffic congestion has been the use of digital computers to monitor and regulate the traffic flow."[2]

PREVIOUS WORK IN TRAFFIC FLOW SIMULATIONS

Improving the existing highway networks and designing future highways to better accommodate the increasing traffic flow requires detailed information on the relationship between control strategies and the resulting quality of traffic flow. Computer simulations can provide this data and allow for the evaluation of a wide spectrum of traffic management designs within the structure of controlled experiments.

The modeling of traffic flow with computers has been performed for several decades. Initially, these studies focused on alternative traffic management schemes. In a special report for the Transportation Research Board in 1981, David Gibson categorizes the types of models developed as intersection, arterial, network, freeway, and corridor models.[3] Intersection models are developed for use in optimizing and analyzing traffic at intersections. One example is the Signal Operations Analysis Package (SOAP), developed by the University of Florida Transportation Research Center[3]. This model allows for the examination and evaluation of a wide range of intersection signal design alternatives. This is an optimization model which generates solutions for cycle length, phasing, and left-turn analysis. Traffic engineers at the Virginia Department of Transportation continue to use this model for intersection analysis. Another intersection model is TEXAS, developed by the University of Texas[3], which provides for the detailed evaluation of traffic performance at isolated intersections. The effects of roadway changes, driver and vehicle characteristics changes, intersection control, lane control, and signal-timing plan effects on single intersection operations can be examined. Arterial models are developed to examine improvements to existing roadways, such as adding turn lanes and bus pullouts, which will decrease traffic congestion. One of the widely used arterial models is PASSER II (Progressive Analysis and Signal System Evaluation Routine), developed by the Texas Transporation Institute[3]. PASSER II determines the optimum progression along arterials while considering phasing sequences. Inputs such as turning movements, saturation flow rates, distances between intersections, and average link speed allow a wide variety of scenarios to be simulated. Network models are developed to evaluate techniques for improving traffic flow. NETSIM, developed by KLD Associates[3], is a widely used network simulation model which represents vehicles as single entities rather than groups. NETSIM was primarily designed for the testing of alternative control strategies under conditions of heavy demand and is specifically applicable to the evaluation of dynamically controlled signal systems which use real-time traffic surveillance data. Freeway models are developed to evaluate economical solutions for traffic congested roadways where expansion is not feasible. These models investigate providing higher vehicle occupancy, controlling the rate of access to the freeway, relieving bottlenecks caused by weaving and inadequate merging lanes, and detection of incidents to permit improved response through traffic control measures. The Freeway Priority lane model, PRIFRE[3], was the first reliable model for evaluating the effect of high occupany vehicle lanes. PRIFRE calculates the total travel time under normal freeway operation and under any number of different lane priority options and compares the results. Savings or losses are presented in the output. FREQ3CP, developed by the Institute of Transportation Studies (ITS) at Berkeley[3], is an example of a freeway model that is used to determine the entry control strategy, such as metering rates and priority cut-off levels, that is best for a given objective. The final category, corridor models, is concerned with all of the areas described above. The problems which occur at intersections, on arterial highways, within road networks and along freeways are viewed as interconnected. A corridor model typically consists of several models whose combined capabilities cover the areas of concern. The Integrated Traffic Simulation model, INTRAS, is but one example of a freeway corridor model.[4] INTRAS is a vehicle-specific time-stepping simulation designed to realistically represent traffic and traffic control in a variety of freeway scenarios.

A second phase of computer simulation programs for traffic analysis consisted of creating systems which combined traffic simulation programs with computer graphics. The Urban Traffic Control System-Network Simulation-Interactive Computer Graphics (UTCS/NETSIM/ICG) simulation program is an excellent example of this trend[5]. The NETSIM program simulates the traffic flows on the network and provides detector inputs to the UTCS program which is serving as the master controller. The UTCS program generates surveillence and status reports in addition to controlling the simulation. The ICG program provides interactive data input to NETSIM, graphic output displays of queue length and signal indications, and graphic output displays of cumulative link performance results.

Moving ahead one decade unveils the ongoing development of traffic simulations which take into account route selection and behavioral considerations. These simulations seek to obtain realistic results for scenarios which allow a vehicle to choose between one or more routes. CONTRAM, a simulation program originally developed in 1978 by the Transport and Road Research Laboratory in the United Kingdom, is a dynamic assignment model which represents queueing delays as they vary in time and the associated routing changes. Recent modifications and extensions to CONTRAM allow the user to estimate the performance of traffic networks under a wider variety of traffic control policy and route guidance strategy combinations.[6] The intent of these modifications is to estimate the network-wide effect of local interactions. Another direction currently under investigation is the dynamic modeling and control of a multi-destination traffic network. In a paper published by Markos Papageorgiou and Albert Messmer[7], a model is described which consists of three interacting components - a traffic flow component which describes the traffic flow evolution along network links; a traffic composition component which describes the propagation of traffic composition for substreams with different destinations; and a dynamic assignment component which routes traffic substreams in a manner which guarantees user optimum conditions in real time. One of the unique features in this model is the use of feedback in the development of the assignment portion of the model to achieve user optimum conditions.

NEW DIRECTIONS FOR TRAFFIC FLOW SIMULATIONS

In Springfield, Virginia, three major highways intersect. Commuters, locals, tourists, and truckers enter a mixing bowl infamous for its long delays, unpredictable merging, sporadic lane changing, and frequent accidents. The proposed solution consists of 21 lanes divided into interstate through lanes, local connector lanes, and HOV lanes. The quantity of merging, lane switching, and passing which will occur in the new design could be estimated via computer simulation. To be realistic, exterior conditions - such as types of drivers, road and weather conditions, and time of day - would need to be incorporated.

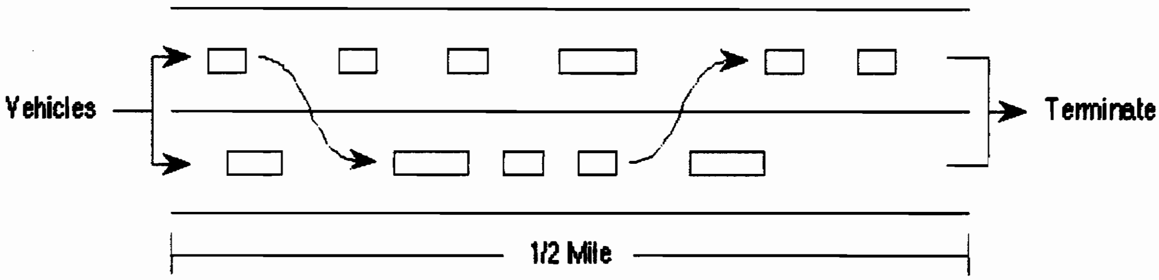
Driver characteristics can have a noticeable affect on a traffic scenario. The traits associated with, for example, local and through traffic, tourists and commuters, inexperienced and seasoned drivers, cause variations in the outcome of a traffic flow simulation. A recent newspaper article stated "...It's just impossible for local traffic to mix with through traffic without a lot of wrecks...Most accidents result from cars merging and weaving between lanes as drivers enter or exit."[1] Vehicle speed, passing decisions, attentiveness, and familiarity with the area all play a role in traffic flow. Pavement conditions, visibility, and rush hour traffic are a few examples of non-driver factors which also affect the outcome of traffic flow. Simulations which take these additional criteria into account are a new direction for traffic modeling.

SIMULATION METHODOLOGY

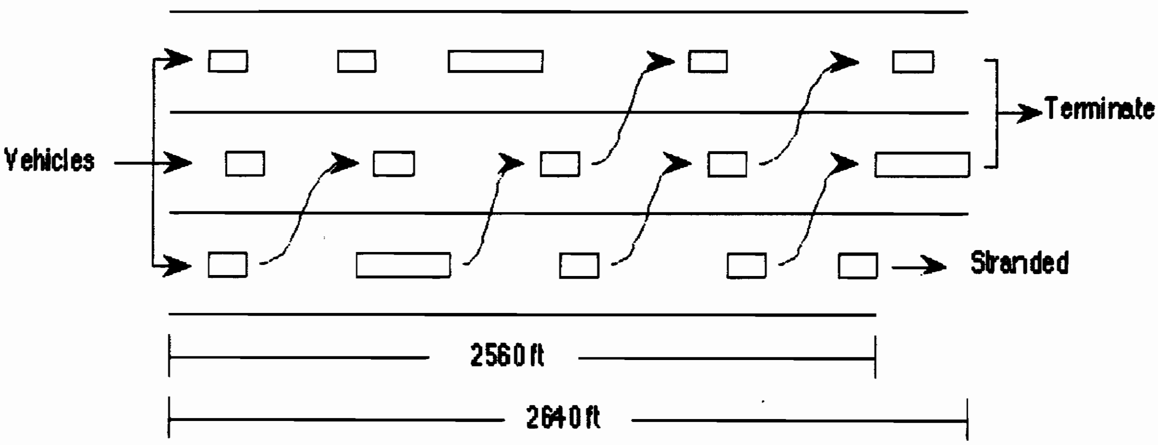
The first step in this modeling process was to outline the scenarios to be modeled. After examining the local highway systems, two basic components became apparent - lane switching and merging. Various conditions exist which may cause a vehicle to switch lanes or merge. Most often vehicles switch lanes to increase their speed of travel; in other instances, vehicles switch lanes to position themselves for an exit ramp or a division of lanes in the highway. Merging typically occurs when one lane is ending. These concepts were the basis for the five models developed.

The first model, depicted in Figure 1, examined two lanes of traffic with vehicles switching lanes in an attempt to increase their speed of travel. The second model, depicted in Figure 2, included the possibility of lane switching and added the concept of merging. In the third model, lane switching was again examined. This time, however, the intent of vehicles was to position themselves for an upcoming division of lanes. This model, depicted in Figure 3, allowed vehicles in the left and right lanes to switch to the center lane. The fourth model was a look at a two-lane bi-directional road. Vehicles in the right lane attempted to pass the vehicle in front of them while vehicles in the left lane traveled straight through, as shown in Figure 4. The final model, depicted in Figure 5, was a variation of the third model. In the fifth model, there was an impassible obstacle in the center lane which forced vehicles in that lane to switch to either the left or right lane. Further details on these five scenarios are contained in Appendix A.

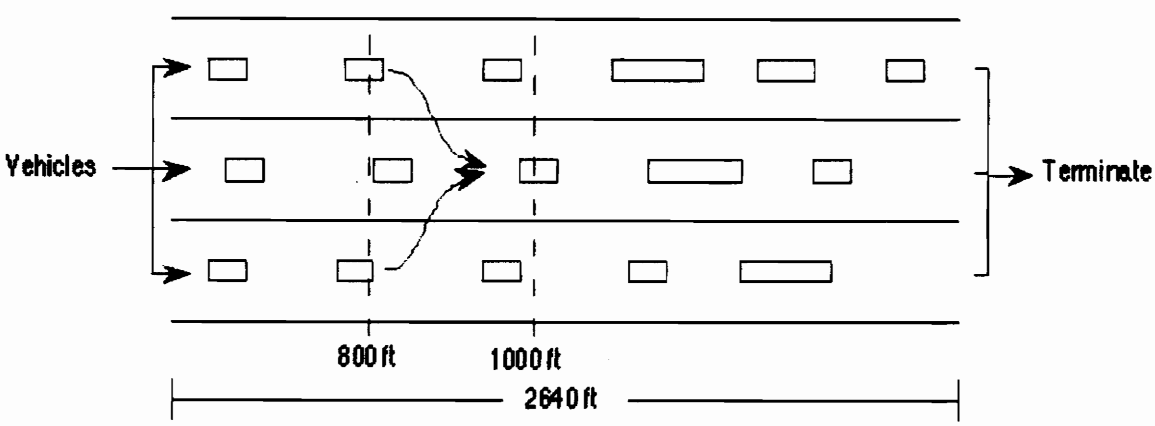
During the selection of the scenarios to be modeled, the scope and level of detail to be addressed was determined. Scope is the extent of the system and its environment which is included in the model. Level of detail is the intricacy of the model entities and the complexity of their interactions. The scope for the models presented in this paper was a 1/2 mile segment of highway. In general, opposing traffic was ignored. As were outside influences such as road conditions (e.g. construction, pot-holes, detours), weather conditions other than those specifically mentioned in a model, natural disasters (e.g. animals on the highway, death of vehicle drivers), and unexpected vehicle failures (e.g. flat tires, braking problems, running out of gas). There was assumed to be a never ending flow of traffic entering and exiting the 1/2 mile segment. The level of detail chosen for



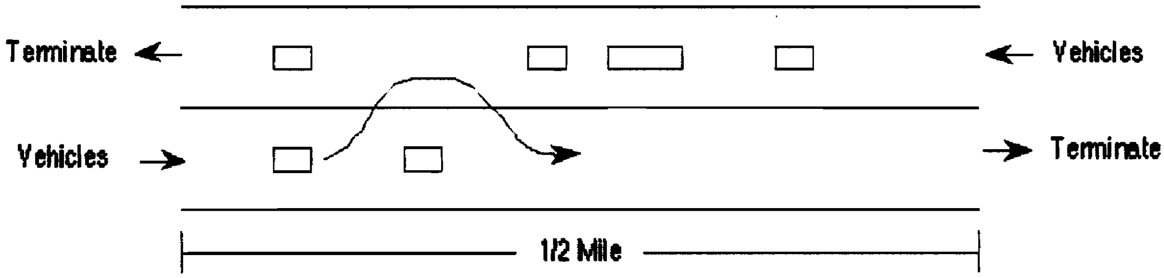
Model 1 Diagram
Figure 1



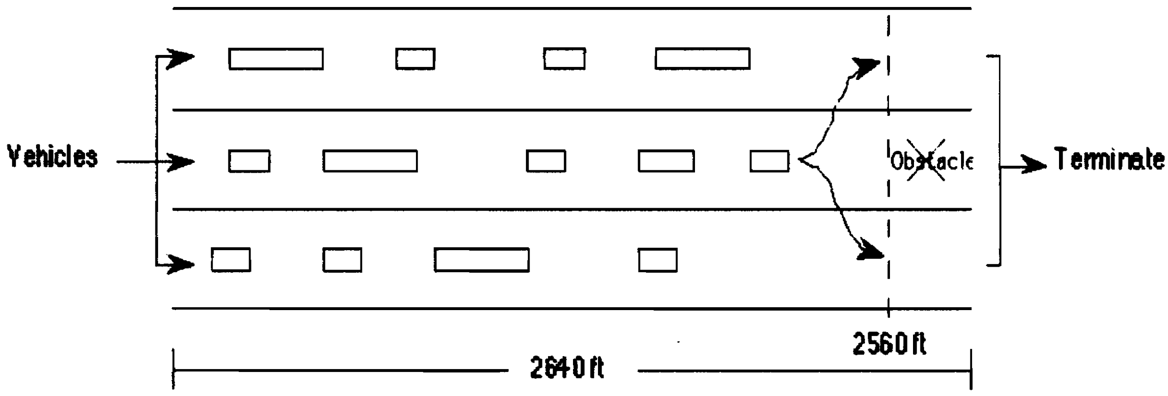
Model 2 Diagram
Figure 2



Model 3 Diagram
Figure 3



Model 4 Diagram
Figure 4



Model 5 Diagram
Figure 5

model entities began with a vehicle being treated as a single entity. The number of occupants of a vehicle was not considered. Nor were differences in vehicle size and mechanical ability, with the exception of a provision for multi-axle vehicles (hereafter referred to as trucks). The width of a lane was assumed to only accommodate one vehicle at a time and vehicles were either in one lane or another. The 1/2 mile strip of highway was viewed as 66 segments of 40 feet each. Each model specified the number of vehicles which could occupy a segment simultaneously. A complete list of the general assumptions made is included in Appendix A.

The next step revolved around identifying driver characteristics, time of day, road conditions, and weather conditions for the various model scenarios. In a study conducted by the Institute for Research in Public Safety[8], an analysis was perfomed to examine the characteristics and collision producing errors of accident and traffic violation prone drivers. The objective was to determine if certain individuals are more likely than others to be repeatedly involved in traffic accidents or traffic violations. The study compared individuals on the "basis of age, sex,...and 23 different causes which were either attributed to the driver, vehicle or environment. These include inattention, internal distraction, external distraction, improper lookout, decision errors,...excessive speed, inadequate signals, improper evasive actions,...and experience or exposure; overall environmental factors, and specific types of environmental causes such as slick roads,...and ambience related causes (e.g. weather and transient traffic situations)."[8] Several of these causal factors were incorporated into the scenarios developed. The characteristic of preoccupation denotes a state of being engrossed in thought in matters not of immediate importance to the driving task. Momentary distractions arose when a driver's attention was shifted away from the driving task for the amount of time required to, for instance, change a radio station, adjust a seat, or turn on the air conditioner. The concept of improper driving technique was incorporated via drivers who were in a hurry and therefore driving at unsafe speeds. The possibility of performance errors was represented in the third model by drivers who hesitated when merging. The driver characteristic of experience/exposure was factored into the models via a wide range of possible reaction times. Environmental and ambience related causes were incorporated into the models by specifying time of day and weather condtions for each scenario.

The final step of preparation was to address the required assumptions for the individual models. For example, the criteria for determining when a collision occurred, the criteria for assigning the speed of a vehicle, and the criteria for lane switching or merging. The individual model descriptions in Appendix A contain a list of the pertinent assumptions that were made.

IMPLEMENTATION

The first decision in the implementation stage was the selection of a computer language. Either a simulation language or a general-purpose language may be used for model development. Advantages to using a simulation language include: provision of a natural framework for simulation modeling; automatic provision of most of the features needed in programming a simulation model, which results in a decrease in programming time; provision for dynamic storage allocation during execution; superior error detection because many potential types of errors have been identified and are checked for automatically; and the resulting models are easier to modify. Arguments for using a general-purpose language also exist and include such reasons as: most modelers already know a general-purpose language but may not know a simulaiton language; general-purpose languages are accessible on virtually every computer; and general-purpose languages provide greater programming flexibility. When a decision is made to use a simulation language, a different set of criteria must be considered for the selection of a particular simulation language. Law and Kelton suggest that the following criteria be considered: types of systems that will be simulated; number of simulation studies likely to be done; quality of the language's documentation; ease of learning the language; and the flexibility and power of the language.[9]

The decision to use a simulation language for this model development effort simplified the actual program implementation and allowed for a concentrated effort on the replication of real-world scenarios. The GPSS/H (student version)[10] simulation language was chosen because it was readily available, is well documented, and possesses both flexibility and programming power. In addition, GPSS/H employs the process-interaction approach to modeling. In a process-interaction approach, a system is modeled by writing a process routine which delineates everything that happens to a transaction as it moves through its corresponding process. The term process-interaction is derived from the fact that at any given time, a system may contain many processes (transactions) interacting with each other and competing for a set of resources. This approach is ideal for traffic flow simulation.

The core of each model was the highway representation. As stated previously, the highway was viewed as 66 segments of 40 feet each for a total of 1/2 mile. The number of vehicles allowed to reside in a segment at one time was limited and therefore provisions for determining when a segment was "full" were needed. GPSS/H provides several alternatives for this situation. Facilities and storages are entity types which can be used to monitor the number of transactions in a particular location. GPSS/H automatically compiles statistics on the use of the facilities and storages throughout a simulation run. However, the overhead involved in using facilities and storages is quite large, up to 64 bytes per entity. Another alternative is to use an amper-variable as a counter. The counter can be incremented when a transaction enters a location and decremented when the transaction leaves. The current value of the counter can be used to determine whether or not additional transactions can enter a location. A disadvantage to this method is the lack of automatic statistics gathering; a major advantage is the small memory requirement, 6 bytes per amper-variable. For the traffic scenarios being simulated, the storage statistics provided by GPSS/H were not necessary. Therefore, the decision was made to use an array of counters for each lane. This simplified approach proved to be extremely effective and flexible, as well as requiring significantly less memory.

The major goals of the traffic simulations were to study the effect of driver characteristics and traffic composition on traffic flow. Consequently, a provision for run-time input of these types of variables was incorporated. When the simulations were executed, the user was asked to enter percentage allocations for the appropriate driver characteristics and for the percentage of automobiles versus trucks. The objectives and contributing factors for each model are contained in Table 1. In an attempt to successfully simulate a real-world scenario, realistic parameters for driver reaction time, vehicle speed, and vehicle length were sought. The Transportation and Traffic Engineering Handbook[11], though dated, proved to be an excellent source for this information.

Table 1
Model Objectives and Contributing Factors

	Objective(s)	Contributing Factors
Model 1	Thruput Time Number of Lane Switches	Preoccupied/Attentive In a hurry/Unfamiliar/Law-abiding (vehicle speed) Traffic Composition
Model 2	Merge Distance Number of Collisions	Preoccupied/Attentive Immediate/Hesitate/Wait (tendency when merging) Traffic Composition

Table 1 (continued)

Model 3	Number of Collisions Number of Near Misses	Preoccupied/Attentive Percent Changing from Left Lane Percent Changing from Right Lane Traffic Composition
Model 4	Number of Collisions	Drowsy/Alert Type of Vehicle Passing Type of Vehicle being Passed Traffic Composition
Model 5	Number of Collisions Number of Collisions with Obstacle	Preoccupied/Alert Traffic Composition

Model 1 - Switching Lanes

The first step towards implementation was the determination of an objective. For this traffic scenario, the data of concern was the average time required to travel the 1/2 mile segment and the number of lane switches occurring during the simulation run.

The description for Model 1 (contained in Appendix A), specified that it was midday on a weekday and the sun was shining. These circumstances affected the spacing between vehicles on the highway. Midday on a weekday indicated that the traffic flow was moderate and there was room for vehicles to maneuver between lanes. Good visibility and dry pavement indicated that up to three automobiles or one truck per highway segment was allowable. To accommodate the variety of driver types described in the traffic scenario, the following driver characteristics were requested at run-time:

Percentage of drivers which are preoccupied
(remainder are considered to be attentive)
Percentage of drivers which are in a hurry
Percentage of drivers which are unfamiliar with the area
(remainder are considered to have recently received speeding tickets)

The actual assignment of driver characteristics and traffic composition to the transactions was an integral part of every model. The reaction time assigned to a transaction depended first on whether the driver was "preoccupied" or "attentive". The base value associated with this trait was then submitted to a normal distribution. The result of the normal distribution was multipled by a randomly selected standard deviation of 1, 2, or 3. This ensured that virtually the entire population was covered. Thus, an attentive driver might be "momentarily distracted" and a preoccupied driver might pay attention at the right moment. The driver characterstics of "in a hurry", "unfamiliar with the area", and "recently received speeding tickets" were used to determine the speed of the vehicles. Drivers in a hurry were assigned a fast speed within a 10 mph range; drivers unfamiliar with the area (e.g. tourists) were assigned a slightly lower speed within a 15 mph range; and drivers who had recently received a speeding ticket were assigned the speed limit plus or minus 2 mph.

Another basic component of all five models was the simulation of traversing the highway in a particular lane. The concept for this portion of the simulation was as follows:

Vehicle enters a lane
Test the lane counter for the current segment to see if there is room for the vehicle to enter
If unable to enter, the vehicle terminates as a collision
If able to enter, the lane counter is incremented by the size of the vehicle and the vehicle advances for the length of time required to traverse 40 feet at the assigned speed
The vehicle leaves the segment, decrementing the lane counter
Test if the 1/2 mile has been traversed
If it has, vehicle terminates successfully
It it has not, vehicle increments to the next segment and continues down the highway in the same lane

A dataflow diagram for this concept, using GPSS/H symbols, is contained in Appendix A, Figure 6. In order to provide for switching lanes, this concept had to be slightly altered. After determining that the end of the highway had not been reached, a test was performed to determine if the vehicle's maximum speed was at least 10 mph greater than the current speed. If it was not, the vehicle continued in the same lane. If the current speed was too low, the vehicle attempted to switch to the other lane. This process incorporated the driver reaction time described previously. When the vehicle determined it could switch to another lane, it waited the length of time associated with it's reaction time then increased it's speed by fifteen percent and attempted to enter the new lane. By this time, however, the targeted lane may no longer have had room for another vehicle, in which case a collision occurred. The dataflow diagram for this concept is contained in Appendix A, Figure 7.

The development of Model 1 provided a framework for the remaining models. The software for the assignment of driver characteristics, traffic composition, and basic lane movement were reusable with only minor modifications.

Model 2 - Merging

The objectives of this model were to determine the average distance traveled before a vehicle merged, the number of collisions occurring during the merge process, and the number of vehicles stranded (unable to merge).

The description for Model 2 (see Appendix A), specified that it was midday on a weekday and the sun was shining. These circumstances affected the spacing between vehicles on the highway. Midday on a weekday indicated that the traffic flow was moderate and there was room for vehicles to maneuver between lanes. Good visibility and dry pavement indicated that up to three automobiles or one truck per highway segment was allowable. To accommodate the variety of driver types described in the scenario, the following driver characteristics were requested at run-time:

Percentage of drivers which are preoccupied
(remainder are assumed to be attentive)
Percentage of drivers which are inclined to merge immediately
Percentage of drivers which are inclined to hesitate before merging
(remainder are assumed to wait until the last moment before merging)

The methodology used in Model 1 for the assignment of the driver characteristic preoccupied/attentive was reused in Model 2. The Model 1 methodology for the assignment of traffic flow composition was modified to allow for three lanes of traffic instead of two. The driver characteristics "merge immediately", "hesitate", and "wait" were used to determine when a vehicle would attempt to merge from the right lane into the center lane. "Merge immediately" implied that the vehicle began attempting to merge at the beginning of the simulation; "hesitate" implied that the vehicle attempted to merge at random, sometime after the beginning of the simulation; "wait" implied that the vehicle did not attempt to merge until only one highway segment remained in the right lane. These conditions were intended to represent the real-world drivers who are conscientious, passive, or aggresive.

The basic concept for traversing the highway in a particular lane was employed in Model 2 to represent the left lane of traffic. These vehicles were moving at high speeds, straight down the highway. The center lane of traffic employed the expanded concept which provided for lane switching to increase speed. The implementation of the right lane, which contained the vehicles required to merge, began with the basic lane concept and incorporated modifications for merging. The impetus for a vehicle to merge was based on the associated driver characteristic, as described in the previous paragraph. Once it was determined that a vehicle was ready to merge, the following process was executed:

Test for adequate room in the center lane for vehicle to enter
If inadequate, the vehicle continues in own lane
If adequate, the vehicle waits for the length of time associated with it's reaction time
Assign a vehicle speed appropriate for the center lane
Test again for room in the center lane for vehicle to enter
If no room, the vehicle terminates as a collision
If still room, the vehicle enters the center lane

A vehicle was considered stranded if it reached the end of the right lane.

Model 3 - Switching to Same Lane

The objectives of this model were to determine the number of collisions and the number of near misses occurring when vehicles switch lanes. The description for Model 3 (see Appendix A), specified that it was a rainy night outside the JFK stadium and a Redskins game had just ended. These circumstances affected the spacing between vehicles on the highway. Night-time, outside the JFK stadium, after a Redskins game indicated that the traffic flow was moderate and there was room for vehicles to maneuver between lanes. Reduced visibility and wet pavement indicated that only two automobiles or one truck per highway segment could safely be allowed. To accommodate the variety of driver types described in the scenario, the following driver characteristics were requested at run-time:

Percentage of drivers which are preoccupied
(remainder are assumed to be attentive)

To allow for testing the affect of increased/decreased percentages of vehicles switching lanes, the following information was requested at run-time:

Percentage of vehicles which will need to switch from the left lane
Percentage of vehicles which will need to switch from the right lane

The methodology used in Model 1 for the assignment of the driver characteristic preoccupied/attentive was reused in Model 3; as was the Model 2 methodology for assignment of traffic flow composition.

The basic concept for traversing the highway in a particular lane was employed to represent the center lane of traffic. The left and right lanes differed from the center lane only in that they allowed for the possibility of a vehicle switching to the center lane. Vehicles in the left and right lanes were given the opportunity to switch lanes over a span of 240 feet. The real-world scenario being modeled was the need to switch lanes in order to position for an upcoming division in the highway (e.g. 2 lanes go to Maryland, 2 lanes go to Virginia). If it was determined that a vehicle would attempt to switch lanes, the process executed was as follows:

Test for adequate room for vehicle to switch lanes
If inadequate room, continue in own lane
If room, wait for the length of time associated with vehicle's reaction time
Increase vehicle speed by 10%
Test again for adequate room for vehicle to switch lanes
If no room, the vehicle terminates as a collision
If room, and the vehicle is the third automobile in a segment, a near miss occurs
Vehicle enters the center lane

The implementation of Model 3, although relying heavily on the implementations of Models 1 and 2, resulted in several new concepts which were reused in subsequent models.

Model 4 - Passing

The objectives of this model were to determine the number of collisions occurring during a passing scenario. The description for Model 4 (see Appendix A), specified that it was a moonlit night on a backroad between interstate highways. These circumstances affected the spacing between vehicles on the highway. Night-time on a secondary road implied that the traffic flow was light and there was room for vehicles to pass. Good visibility and dry pavement indicated that up to three automobiles or one truck per highway segment was allowable. To accommodate the variety of driver types described in the scenario, the following driver characteristics were requested at run-time:

Percentage of drivers which are drowsy
(remainder are assumed to be alert)

To accommodate the variety of passing situations described in the scenario, the following information was requested at run-time:

Select a passing scenario: automobile passing automobile, automobile passing truck, truck passing automobile, or truck passing truck
Select a speed scenario: slow vehicle passing a slow vehicle, fast vehicle passing a slow vehicle, or fast vehicle passing a fast vehicle

The speed scenario of a slow vehicle passing a fast vehicle was deemed unrealistic and therefore not included.

The methodology used in Model 1 for the assignment of the driver characteristic preoccupied/attentive was reused in Model 4 for the determination of drowsy/alert and the associated possible variations. A flow of traffic was generated for the left lane (non-passing lane) and the basic lane concept was implemented for the vehicles traveling in this lane. The traffic flow for the right lane (passing lane) was structured to generate two vehicles at a time, corresponding to the scenario selections made at run-time, on eight separate occasions. This provided for the enactment of the passing scenario multiple times within one simulation run.

The implementation of the passing scenario was based on the concept used in Model 1 for switching lanes. Modifications were required, however, to move the vehicle back into its original lane after it passed the lead vehicle. This was accomplished as follows:

Wait for the length of time associated with vehicle's reaction time
Test for adequate room in the left lane to enter
If inadequate, vehicle terminates as a collision
If adequate, enter left lane and advance for one segment
Increment to next segment
Test for adequate room to return to right lane
If adequate, return to right lane
If inadequate, remain in left lane
Loop back to second step of this process

The implementation of Model 4 was the most challenging because of the requirement to simulate a vehicle passing another vehicle before returning to the original lane. Several concepts for the generation of the vehicles in the right lane as well as for the passing scenario were reviewed and discarded before the final version was developed.

Model 5 - Obstacle in Center Lane

The objectives of this model were to determine the number of collisions between vehicles switching lanes and the number of collisions with the obstacle in the center lane. The description for Model 5 (see Appendix A), specified that it was midday on a weekday and foggy. These circumstances affected the spacing between vehicles on the highway. Midday on a weekday indicated that the traffic flow was moderate and there was room for vehicles to maneuver between lanes. Greatly reduced visibility indicated that only two automobiles or one truck per highway segment could safely be allowed. To accommodate the variety of driver types described in the scenario, the following driver characteristics were requested at run-time:

Percentage of drivers which are preoccupied
(remainder are assumed to be attentive)

The methodology used in Model 1 for the assignment of the driver characteristic preoccupied/attentive was reused in this model; as was the Model 2 methodology for assignment of traffic flow composition.

The basic concept for traversing the highway in a particular lane was employed in Model 5 to represent both the left and right lanes of traffic. The implementation for the restriction of two automobiles or one truck per lane segment (developed in Model 3) was reused in this model. The center lane concept was roughly based on the right lane of Model 2. Modifications were implemented to test when the obstacle became visible to a vehicle, when the obstacle had been struck by a vehicle, and which lane a vehicle would attempt to switch to first. Once a vehicle had seen the obstacle, the process executed was as follows:

Choose left or right lane at random
Test for adequate room for the vehicle to switch to selected lane
If inadequate, wait for the length of time associated with vehicle's reaction time and try the other lane
If adequate, wait for the length of time associated with vehicle's reaction time

Test again for adequate room for the vehicle to switch lanes
If inadequate, the vehicle terminates as a collision
If adequate, assign a vehicle speed appropriate for the lane being entered
Vehicle enters the selected lane

If trying the other lane, test for adequate room to enter
If inadequate, continue in own lane
If adequate, wait for the length of time associated with reaction time
Test again for room to enter lane
If inadequate, vehicle terminates as a collision
If adequate, assign vehicle speed appropriate for the lane being entered
Vehicle enters the selected lane

The implementation of Model 5 was the least difficult. Combining various components from the previously developed models resulted in a framework for this model which needed only minor modifications.

TESTING PROCESS

The phrase "testing software" can be interpreted several ways. Some view testing as a process which verifys that requirements have been satisfied; others suggest that testing is the attempt to find errors in the software. Frakes, Fox, and Nejmeh define the testing process as follows: "The essence of testing is verifying that life-cycle objects conform to specifications. Testing is not just for code; it should be done on all life-cycle products. The purpose of testing is to ensure software quality. Testing methods may be either manual or automated. The tester should believe that the software is incorrect, and that his or her job is to prove that software is incorrect by finding concrete examples of the incorrectness."[12] The determination of correctness for a simulation model involves two phases. Validation is determining how accurately the real world scenario has been modeled. Verification is comparing the performance of the model with the performance of the real world scenario. Only the first phase, validation, was performed for these models due to time constraints and the unavailability of comparable real world statistics.

GPSS/H provides capabilities which simplify the testing of simulation programs. Basic programming errors, such as undefined variables and illegal statements, are flagged when the program is compiled. Pre- and post-simulation output tables provide the information required for analyzing logic errors. An entity dictionary lists the tables, functions, and amper-variables which are used in the program. A symbol table lists all of the symbols referenced in the program with their definitions and a list of the statement numbers that reference the symbol. The most useful table provided is a listing of each statement along with the number of transactions that executed the statement. This data allows the tester to examine the path transactions took during the simulation. It is an invaluable tool during testing. Other data provided at the end of the simulation run includes the resulting output for any specified tables or save values and the usage statistics for any facilities, servers, or queues declared.

To facilitate the testing of these models, several lines of output were generated at the end of the simulation. This data was written to a file which could be viewed after the simulation. Samples of this output data are contained in Appendix A, Figure 8. The data gathered during testing, for the various models, is contained in Appendix A, Tables 2 though 6.

<u>Model Testing</u>

The testing of the first model was the most time consuming. The concepts for assigning driver characteristics and traffic composition required numerous iterations. This portion of the program required the transfer of transactions based on the percentages entered at run-time. During the testing process for this portion of the program, the GPSS/H table containing the statements and their execution counts was used to verify the software. By evaluating the number of transactions entering the various assignment statements, a determination of correctness was made. Another major implementation problem uncovered during the testing phase was the use of "LET" statements instead of "BLET" statements for incrementing and decrementing the lane counters. A "LET" statement is executed at the beginning of the program, a "BLET" statement is executed when a transaction passes through it. This problem was also resolved via the use of the statement execution table. General testing of the other models was relatively simple. Corrections made to Model 1 were transferred to the subsequent models as appropriate. Once the models were proven to be functioning as designed, it was time to test their ability to simulate the assigned real-world scenarios.

For Model 1, the data submitted at run-time was varied to examine the effects of driver characteristics and traffic composition on the average thruput, number of lane switches and number of collisions occurring during lane switching. The effect of preoccupied versus attentive drivers was found to be almost negligible. This was most likely due to the small variance in reaction time between the two. The effect of the driver characteristics "in a hurry", "unfamiliar with the area", and "recently received speeding tickets" on the output data was noticeable. The average time required to traverse the 1/2 mile segment decreased as the percentage of "in a hurry" increased; conversely, an increase in the percentage of "recently received speeding tickets" caused an increase in the thruput time. These results were as expected, since the vehicle speeds associated with the characteristics were quite varied. The number of lane switches occurring appeared to depend primarily on the driver characteristic "unfamiliar with the area". This would be due to the wide range of assigned vehicle speeds possible; resulting in an increased number of vehicles attempting to increase their speed. The cause of increases and decreases in the number of collisions during lane switching was difficult to determine. It was expected that the driver characteristic preoccupied/attentive or the traffic composition would cause a variance. However, the tests failed to provide adequate data for that, or any other conclusion. Similarly, the effect of traffic composition on this simulation overall was undeterminable. The rate at which vehicles arrived for the lanes was manipulated during initial testing stages to provide a moderate flow. Unfortunately, non-event related collisions occur at a rate higher than expected. This is most likely due to the fact that the simulation was unable to model the act of vehicles modifying their speed as necessary to avoid rear-end collisions.

To test Model 2, the data submitted at run-time was varied to examine the effects of driver characteristics and traffic composition on the average distance traveled before merging, the number of vehicles stranded, and the number of collisions occurring during merging. The effect of preoccupied versus attentive drivers was again found to be almost negligible. The effect of the driver characteristics "merge immediately", "hesitate", and "wait until last moment" on the output data, however, was noticeable. The average distance traveled before merging decreased as the percentage of "wait until the last moment" decreased; as did the number of vehicles stranded. The number of collisions occurring during merging appeared to be somewhat dependent on the traffic composition; although it was expected that the preoccupied/attentive driver characteristic would also have had an affect. As with Model 1, the rate at which vehicles arrived for the lanes was manipulated during initial testing stages to provide a moderate flow. Unfortunately, the simulation was unable to model the act of vehicles modifying their speed as necessary to avoid rear-end collisions, so the number of non-event related collisions occurred at an alarmingly high rate. The majority of these collisions were in the center lane as vehicles from the right lane merged.

For testing Model 3, the data submitted at run-time was varied to examine the effects of driver characteristics, percentage of vehicles switching to the center lane, and traffic composition on the number of collisions and near misses occurring during lane switching. As before, the effect of preoccupied versus attentive drivers was found to be almost negligible. The effect of the varied percentages of vehicles switching to the center lane, however, was perceptible. As the percentages increased for either lane or both, the number of collisions occurring during switching increased dramatically and the number of non-event related collisions also rose. The traffic composition also played a role in the number of collisions during switching. As the percentage of trucks increased, so did the number of collisions. It was believed that the traffic composition would play a role in the number of near misses occurring. Unfortunately, the occurrence of near misses appeared to be virtually unrelated to any single condition. As previously mentioned, the simulation was unable to model the act of vehicles modifying their speed as necessary to avoid rear-end collisions, so an unacceptable number of non-event related collisions continued to occur.

The testing process for Model 4 was concerned, primarily, with the effect of the passing scenarios in combination with the speed scenarios. The effects of driver characteristics and traffic composition were secondary; and justifiable since neither one appeared to influence the output results. A collision occurred during passing for one of the following three reasons: a vehicle in the left lane collided with the passing vehicle, the vehicle being passed collided with the passing vehicle when it re-entered the lane, or the vehicle passing collided with a vehicle in the left lane. The only scenarios resulting in collisions during passing or in the passing lane were the two involving trucks. An automobile passing a truck always resulted in a collision in the passing lane. A truck passing either a truck or an automobile resulted in a collision in the passing lane as well as collisions during passing.

For testing Model 5, the only inputs to be varied were the driver characteristic preoccupied/attentive and the traffic composition. The output results of interest were the number of collisions occurring during switching lanes and the number of collisions with the obstacle. The driver characteristic preoccupied/attentive, once again failed to make a difference. The traffic composition, however, caused fluctuations in the number of collisions occurring during switching lanes. As the percentage of trucks increased, so did the number of collisions. The number of collisions with the obstacle were infrequent and apparently unassociated with the input criteria.

SUMMARY

The importance of determining an appropriate scope and level of detail for a model can not be emphasized enough. This step defines the boundaries for the model development. During the definition stage for the traffic flow models, the major scope issues were the length of the highway segment to be examined and the length of time to simulate. The decision to examine a 1/2 mile segment for 15 minutes was primarily based on memory constraints. The level of detail decisions that were made revolved around the representation of traffic and the driver characteristics of concern. Traffic was represented with a single entity for each vehicle, unlike simulations in the early 80's which viewed traffic as platoons. The selection of driver characteristics was one of the most difficult. The basis for the decision was the affect the characteristic would have on traffic flow. The decision was made to be concerned with reaction time and vehicle speed, hence the inclusion of traits pertaining to, for example, attentiveness, familiarity with the area, and aggressiveness.

The uniformity of the simulation results would undoubtable have improved if Monte Carlo analysis had been performed. This analysis is a technique for mitigating causal dependance in random systems. Typically this analysis is performed by including a loop in the simulation program which causes the simulation to be executed multiple times during one run. The output results are then averaged over the number of times the simulation was executed. This concept was not incorporated in the models due to GPSS/H student version constraints on the number of statements allowed in a model. The lack of an identifiable effect from the driver characteristic preoccupied/attentive is of some concern. The values used for the associated reaction times were from a reliable source, however the manner in which they were incorporated into the models appears to be unrealistic.

The next step taken should be the verification of the simulation model results. This will require the accumulation of thruput and collision data for the five scenarios modeled. It is unlikely that statistics which take into account the driver characteristics and vehicle speeds investigated in these models will be readily available. However, even data which overlooks these factors would be useful for an initial verification effort.

Future enhancements to these models should include Monte Carlo analysis and a new approach to the incorporation of driver reaction times. In addition, the incorporation of details such as the use of signals, driver blind spots, and varied lengths of automobiles and trucks would add to the realism of the scenarios. Other scenarios of interest for modeling are vehicles weaving among multiple lanes, traffic merging into the left lane from an on-ramp, and the affect that distractions from the opposite side of the highway have on traffic flow. Converting to the standard GPSS/H simulation language should allow for the incorporation of enhancements as well as an expansion of scope and level of detail.

REFERENCES

1. Fehr, Stephen C., "Virginia's 21-Lane Solution," The Washington Post, February 1994.

2. Michalopoulos, P., Plum, R., and Okutani, I., Development and Evaluation of Optimal Control Strategies for Urban Transportation Networks, Department of Civil Engineering, University of Minnesota, March 1983.

3. Gibson, D., "Available Computer Models for Traffic Analysis," The Application of Traffic Simulation Models, Special Report 194, National Academy of Sciences Washington, D.C., 1981.

4. May, A. D., "Models for Freeway Corridor Analysis," The Application of Traffic Simulation Models, Special Report 194, National Academy of Sciences Washington, D.C., 1981.

5. Eiger, A. and Chin, S., The Development of UTCS/NETSIM/ICG: An Integrated Urban Traffic Control System - Network Simulation - Interactive Computer Graphics Program, Rensselaer Polytechnic Institute, 1982.

6. Smith, M. J. and Ghali, M. O., "New Dynamic Model to Evaluate the Performance of Urban Traffic Control Systems and Route Guidance Strategies," In-Vehicle Information Systems: Modeling Traffic Networks and Behavioral Considerations, 1991.

7. Papageorgiou M. and Messmer, A., "Dynamic Network Traffic Assignment and Route Guidance Via Feedback Regulation," In-Vehicle Information Systems: Modeling Traffic Networks and Behavioral Considerations, 1991.

8. McDonald, S. T., Tri-Level Study: Modification Task 5: An Examination of Driver Characteristics and Collision Producing Errors of Accident and Traffic Violation Repeaters, Institute for Research in Public Safety, 1977.

9. Law, A. M. and Kelton, W. D., Simulation Modeling and Analysis. New York: McGraw-Hill,1982.

10. Schriber, T. J., An Introduction to Simulation Using GPSS/H. New York: John Wiley and Sons, 1991.

11. Institute of Traffic Engineers, Transportation and Traffic Engineering Handbook. Englewood Cliffs, N.J.: Prentice Hall, 1976.

12. Frakes, W. B., Fox, C. J., and Nejmeh, B. A., Software Engineering in the Unix/C Environment. Englewood Cliffs, N.J.: Prentice Hall, 1991.

APPENDIX A

GENERAL ASSUMPTIONS

The following assumptions apply to each of the five models.

1. An automobile is 10 feet long.
2. A truck is 30 feet long.
3. The width of a lane can only accommodate one vehicle at a time.
4. A vehicle is considered to be entirely in one lane or another.
5. When a vehicle switches lanes, the move is instaneous.
6. The reaction time of a driver is dependent on the following two traits:
   - driver is attentive – reaction time mean of .5 with a standard deviation of .1 times 1, 2, or 3 (to cover 100% of population)
   - driver is preoccupied – reaction time mean of .7 with a standard deviation of .1 times 1, 2, or 3 (to cover 100% of population)
7. A collision between two vehicles results in the termination of the vehicle causing the collision; the other vehicle is allowed to continue traversing the highway.

MODEL 1 SCENARIO: SWITCHING LANES

Scene:

A four-lane divided highway. Traffic consists of automobiles and trucks. It is midday on a weekday and the sun is shining. Vehicles attempt to switch lanes if their desired maximum speed is at least 10 mph greater than their current speed.

Circumstances:

Allow for a variety of driver types. For example: young, inexperienced drivers; middle-aged tourists; older, experienced drivers; drivers late for an appointment; drivers that are very attentive; drivers who become momentarily distracted (e.g. changing radio stations); or drivers that are preoccupied (e.g. talking with passengers).

Objective:

Speed thruput. Detemine time required to travel a 1/2 mile strip of the highway. Keep track of the number of lane switches occurring.

Assumptions:

1. The pavement is dry.
2. The traffic flow is moderate (i.e. not grid-locked, there is room to maneuver).
3. The speed at which drivers travel depends on the following three traits:
   - driver in a hurry – speed will range between 60 and 70 mph
   - driver unfamiliar with the area – speed will range between 35 and 65 mph
   - driver recently receiving a speeding ticket – speed will range between 53 and 57 mph
4. The standard deviations associated with the reaction times will account for attentive drivers who momentarily become distracted, preoccupied drivers who happen to be paying attention at just the right time, and other such permutations.
5. The 1/2 mile is divided into 66 segments of 40 feet. Each segment can hold either 3

automobiles or one truck.
6. A vehicle attempting to enter a segment which already contains either 3 automobiles or one truck will cause a collision.
7. There is no limit to the number of times a driver may switch lanes.
8. A driver switching lanes will increase his speed by 15%, attempting to reach his maximum speed.
9 The speed at which a vehicle travels does not fluctuate - with the exception of the situation described in Assumption 8.

MODEL 2 SCENARIO: MERGING

Scene:

A six-lane divided highway narrowing to four-lanes. Traffic consists of automobiles and trucks. It is midday on a weekday and the sun is shining. Vehicles in the left lane are moving at their desired pace straight down the highway. Vehicles in the center lane attempt to switch to the left lane if their desired maximum speed is at least 10 mph greater than their current speed. Vehicles in the right lane must merge into the center lane because their lane is ending.

The first indication of narrowing is given at the beginning of the 1/2 mile highway segment. The right lane ends at 2560 feet.

Circumstances:

Allow for a variety of driver types. For example: young, inexperienced drivers; older, experienced drivers; drivers that are very attentive; drivers who become momentarily distracted (e.g. changing radio stations); drivers that are preoccupied (e.g. talking with passengers); drivers who begin merging as soon as they realize their lane is ending; aggressive drivers who try to get as far ahead as possible before merging; passive drivers who tend to hesitate as they try to merge.

Objective:

Merge distance. Detemine average distance traveled by a vehicle before merging into the center lane. Keep track of the number of collisions occuring and the number of vehicles stranded in the right lane.

Assumptions:
1. See Model 1, assumptions 1, 2, 4, 5, and 6.
2. The speed at which drivers travel depends on their lane:
   - left lane – speed will range between 60 and 70 mph
   - center lane – speed will range between 55 and 65 mph
   - right lane – speed will range between 45 and 55 mph
3. A driver switching to another lane will increase his speed to one that is appropriate for the lane he is entering.
4. The point at which a driver attempts to merge from the right lane into the center lane is dependent on the following three traits:
   - drivers who immediately attempt to merge
   - drivers who hesitate when attempting to merge

- drivers who wait until the last possible moment to merge

5. A driver with a tendency to merge immediately, will begin trying to merge immediately but may
take several attempts before succeeding or causing a collision.
6. A driver with a tendency to hesitate, will attempt to merge at random beginning immediately.
7. A driver with a tendency to wait till the last moment before merging, will wait until 40 feet before the lane ends to try and merge.
8. A vehicle which reaches the end of the right lane will be considered stranded.
9. The speed at which a vehicle travels does not fluctuate - with the exception of the situation described in Assumption 3.

MODEL 3 SCENARIO: SWITCHING TO SAME LANE

Scene:

A six-lane divided highway. Traffic consists of automobiles and trucks. It is a rainy night outside the JFK stadium and a Redskins game just ended. One side of the highway (the one we are concerned with) splits off in two directions, with two lanes going each direction, at 1040 feet into the 1/2 mile segment of interest. Indications of this split begin at 800 feet . Consequently, vehicles in the left and right lanes may switch to the center lane.

Circumstances:

Allow for a variety of driver types. For example: young, inexperienced drivers; older, experienced drivers; drivers that are very attentive; drivers who become momentarily distracted (e.g. changing radio stations); or drivers that are preoccupied (e.g. talking with passengers).

Objective:

Crash potential. Detemine number of collisions and number of near misses occurring.

Assumptions:

1. See Model 1, assumption 4 and 6.
2. The speed at which drivers travel depends on their lane:
   - left lane – speed will range between 55 and 65 mph
   - center lane – speed will range between 55 and 60 mph
   - right lane – speed will range between 45 and 50 mph
3. Allow extra spacing between vehicles due to wet pavement and reduced visibility.
4. The 1/2 mile is divided into 66 segments of 40 feet each. Each segment can hold either 2 automobiles or one truck; except during a lane switch when a third automobile will be allowed to enter a segment containing 2 automobiles.
5. An automobile attempting to enter a lane which contains 2 automobiles will cause a near miss.
6. A vehicle in the left or right lane will decide to switch to the center lane based on the percentages entered at run time for that lane.

7. A vehicle may attempt to switch lanes between 800 and 1040 feet.
8. A driver switching to another lane will increase his speed by 10%.
9. The speed at which a vehicle travels does not fluctuate - with the exception of the situtation described in Assumption 8.

MODEL 4 SCENARIO: PASSING

Scene:

A two-lane bi-directional road. Traffic consists of automobiles and trucks. It is a moonlit night on a backroad between interstate highways. Vehicles traveling in the left lane are going straight down the 1/2 mile road, they have a yellow stripe and thus are not attempting to pass. The traffic of concern in the right lane is one of the following situations: an automobile attempting to pass an automobile, an automobile attempting to pass a truck, a truck attempting to pass an automobile, or a truck attempting to pass a truck. The speed of the vehicles is one of the following: a slow vehicle coming up behind a slow vehicle, a fast vehicle coming up behind a slow vehicle, or a fast vehicle coming up behind a fast vehicle.

Circumstances:

Allow for a variety of driver types. For example: college kids headed home; traveling salesmen; new truck drivers; truck or automobile drivers who have been on the road 8 - 16 hours; or truck drivers just leaving a truckstop.

Objective:

Crash potential. Keep track of the number of the number of collisions occurring in each lane and during passing.

Assumptions:

1. See Model 1, assumptions 1 and 6.
2. The standard deviations associated with the reaction times will account for drivers which are used to night time travel and alert, drivers which are drowsy (momentary attention lapses), and drivers which are exhausted and can barely keep their eyes open (and don't always).
3. The road is divided into 66 segments of 40 feet each. Each segment can hold either 3 automobiles or 1 truck.
4. The vehicles for the passing scenario are first generated 100 seconds into the simulation to allow for the existance of a flow of traffic from the opposite direction.
5. The speed of the vehicles traveling in the left lane is dependent on whether the vehicle is an automobile or truck. An automobile's speed will range between 50 and 80 mph; a truck's speed will range between 60 and 70 mph.
6. The speed of the vehicle being passed will depend on runtime input, as will the speed of the vehicle passing. The ranges are as follows:
   - slow vehicle ranges between 50 and 60 mph
   - fast vehicle ranges between 70 and 80 mph
7. The only relevant traffic in the right lane will be the two vehicles involved in the passing scenario.

8. A vehicle in the process of passing will stay in the left lane until capable of safely returning to the right lane or colliding with a vehicle in the left lane.
9. Eight instances of the "passing" scenario are generated during the simulation.
10. The speed at which a vehicle travels, in the left lane, does not fluctuate.
11. The speed for the vehicle attempting to pass increases by 15% during a pass attempt.
12. The reaction time of the driver will determine the amount of time passing between checking if a lane is clear and actually attempting to enter the lane.

MODEL 5 SCENARIO: OBSTACLE IN CENTER LANE

Scene:

A six-lane divided highway. Traffic consists of automobiles and trucks. It is midday on a weekday and foggy. One side of the highway (the one we are concerned with) has an impassible obstacle in the center lane at 2600 feet. Due to the fog, the obstacle is not visible until 2520 feet.

Circumstances:

Allow for a variety of driver types. For example: young, inexperienced drivers; older, experienced drivers; drivers late for an appointment; drivers that are very attentive; drivers who become momentarily distracted (e.g. changing radio stations); or drivers that are preoccupied (e.g. talking with passengers).

Objective:

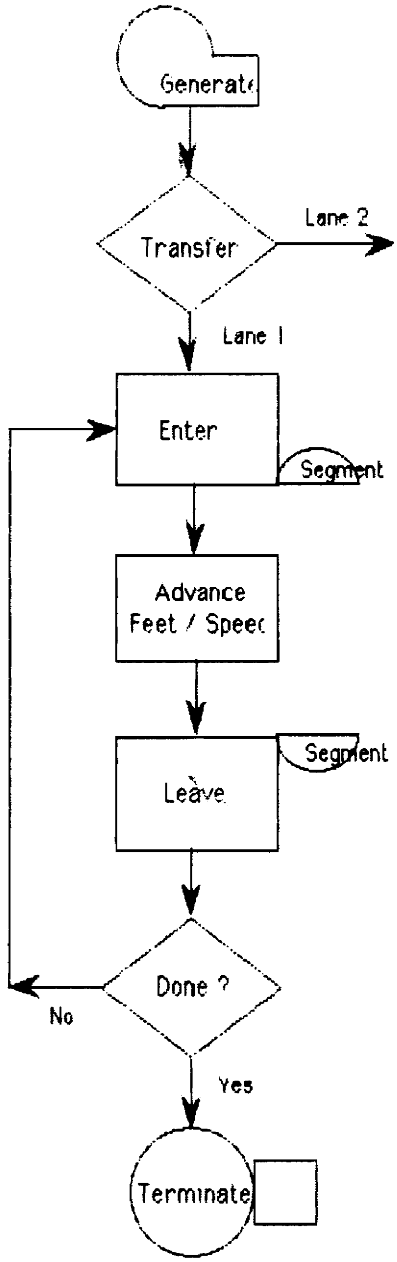
Collision potential. Detemine number of collisions between vehicles and number of collisions with obstacle.

Assumptions:

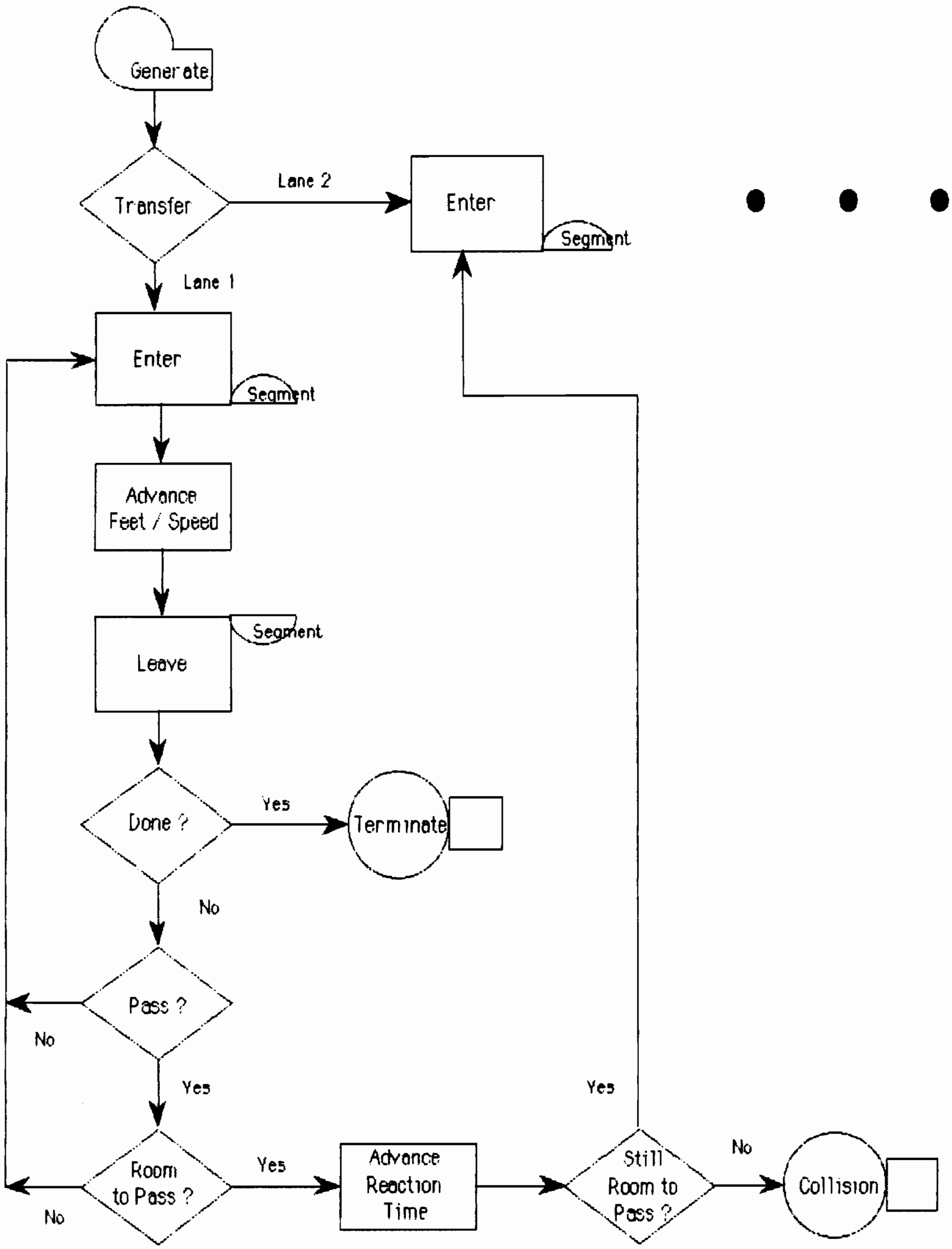
1. See Model 1, assumptions 1, 4, and 6.
2. The speed at which drivers travel depends on their lane:
   - left lane – speed will range between 60 and 70 mph
   - center lane – speed will range between 55 and 65 mph
   - right lane – speed will range between 45 and 55 mph
3. Allow extra spacing between vehicles due to poor visibility.
4. The 1/2 mile is divided into 66 segments of 40 feet each. Each segment can hold either 2 automobiles or one truck; except during a lane switch when a third automobile will be allowed to enter a segment containing 2 automobiles.
5. A vehicle reaching the end of the center lane will have collided with the obstacle.
6. A vehicle in the center lane will try to switch to the right or left lane first at random.
7. A vehicle unable to enter the lane first tried, will attempt to enter the other lane.
8. The reaction time of the driver will determine the amount of time passing before the driver checks the other lane if the first lane checked is full.
9. A vehicle switching lanes will assume a speed appropriate for the lane entered.
10. The speed at which a vehicle travels does not fluctuate - with the exception of the situation described in Assumption 9.

driver checks the other lane if the first lane checked is full.

10. A vehicle switching lanes will assume a speed appropriate for the lane entered.
11. The speed at which a vehicle travels does not fluctuate - with the exception of the situation described in Assumption 10.



Basic Lane Concept
Figure 6



Basic Lane Concept with Lane Switching
Figure 7

% OF DRIVERS PREOCCUPIED: 80 ATTENTIVE: 20
% OF DRIVERS IN A HURRY: 10 UNFAMILIAR: 60 RECENT TICKET: 30
% OF AUTOMOBILES: 70 TRUCKS: 30
AVERAGE TRANSIT TIME FOR 1/2 MILE: 26.88
NUMBER OF COLLISIONS IN OWN LANE: 31 COLLISIONS SWITCHING: 3
NUMBER OF LANE SWITCHES: 515

MODEL 1 SIMULATION OUTPUT

% OF DRIVERS PREOCCUPIED: 10 ATTENTIVE: 90
% OF DRIVERS MERGING IMMEDIATELY: 20 HESITATING: 30 WAITING: 50
% OF AUTOMOBILES: 75 TRUCKS: 25
AVERAGE DISTANCE TRAVELED BEFORE MERGING: 1192.56
NUMBER OF COLLISIONS IN OWN LANE: 274
NUMBER OF COLLISIONS PASSING: 44 COLLISIONS MERGING: 22
NUMBER OF VEHICLES STRANDED: 3

MODEL 2 SIMULATION OUTPUT

% OF DRIVERS PREOCCUPIED: 30 ATTENTIVE: 70
% OF LEFT LANE CHANGING: 10 RIGHT LANE: 10
% OF AUTOMOBILES: 60 TRUCKS: 40
NUMBER OF COLLISIONS IN OWN LANE: 215
NUMBER OF COLLISIONS SWITCHING TO CENTER LANE: 26
NUMBER OF NEAR MISSES DURING LANE SWITCH: 1

MODEL 3 SIMULATION OUTPUT

% OF DRIVERS DROWSY: 20 ALERT: 80
% OF AUTOMOBILES: 70 TRUCKS: 30
SCENARIO IS TRUCK PASSING AUTO
FAST VEHICLE COMING UP ON SLOW VEHICLE
NUMBER OF COLLISIONS IN NON-PASSING LANE: 34 PASSING LANE: 6
NUMBER OF COLLISIONS PASSING: 2

MODEL 4 SIMULATION OUTPUT

% OF DRIVERS PREOCCUPIED: 20 ATTENTIVE: 90
% OF AUTOMOBILES: 40 TRUCKS: 60
NUMBER OF COLLISIONS IN OWN LANE: 208
NUMBER OF COLLISIONS SWITCHING LANES: 23
NUMBER OF COLLISIONS WITH OBSTACLE: 1

MODEL 5 SIMULATION OUTPUT

FIGURE 8

TABLE 2
MODEL 1 TEST RESULTS

% Preocc./ Attentive	% In a Hurry /Unfamiliar /Received Speeding Ticket	%Automobile /Trucks	Number of Vehicles Entering Lanes 1 / 2	Average Thruput	Number of Lane Switches	Collisions in own Lane	Collisions Switching
0 / 100	0 / 0 / 100	75 / 25	167 / 132	29.03	299	0	0
10 / 90	60 / 10 / 30	75 / 25	154 / 145	24.59	420	29	0
30 / 70	20 / 30 / 50	75 / 25	163 / 136	26.92	430	30	0
30 / 70	35 / 30 / 35	70 / 30	161 / 139	26.05	460	25	1
40 / 60	5 / 35 / 60	40 / 60	154 / 146	28.04	388	39	0
50 / 50	40 / 10 / 50	60 / 40	163 / 136	26.46	391	35	0
75 / 25	25 / 45 / 30	90 / 10	154 / 146	26.16	504	11	0
80 / 20	10 / 60 / 30	70 / 30	154 / 145	26.88	515	31	3
80 / 20	10 / 75 / 15	70 / 30	159 / 140	27.10	603	25	5
95 / 5	20 / 50 / 30	80 / 20	154 / 145	26.63	509	26	0

TABLE 3
MODEL 2 TEST RESULTS

% Preocc./ Attentive	% Immediate /Hesitate /Wait	%Automobile /Trucks	Number of Vehicles Entering Lane 1 / 2 / 3	Average Merge Distance	Number Stranded	Collisions in own Lane	Collisions Passing	Collisions Merging
10 / 90	20 / 30 / 50	75 / 25	392/353/380	1192.56	3	274	44	22
10 / 90	50 / 20 / 30	70 / 30	409/351/364	755.66	1	263	70	30
15 / 85	20 / 30 / 50	40 / 60	372/355/398	1138.65	3	412	73	37
30 / 70	30 / 50 / 20	80 / 20	372/355/398	553.64	1	202	39	17
40 / 60	30 / 50 / 20	40 / 60	372/355/398	524.27	2	385	109	44
50 / 50	30 / 40 / 30	75 / 25	409/351/364	775.98	1	241	55	20
50 / 50	10 / 40 / 50	70 / 30	392/353/380	1171.97	4	303	59	8
60 / 40	20 / 30 / 50	40 / 60	392/353/380	1134.71	4	407	82	31
80 / 20	30 / 40 / 30	40 / 60	409/351/364	747.55	1	417	95	28
80 / 20	30 / 40 / 30	75 / 25	409/351/364	775.75	1	248	45	20

TABLE 4
MODEL 3 TEST RESULTS

%Preoccupied/ Attentive	% Changing from Left Lane	% Changing from Right Lane	% Automobiles/ Trucks	Number of Vehicles Entering Lanes 1 / 2 / 3	Collisions in own Lane	Collisions Switching Lanes	Near Misses Switching Lanes
10 / 90	5	5	80 / 20	295 / 309 / 296	109	6	0
10 / 90	5	5	40 / 60	297 / 311 / 292	167	12	0
40 / 60	5	5	80 / 20	292 / 306 / 303	95	6	0
90 / 10	5	5	80 / 20	295 / 309 / 296	103	8	0
20 / 80	30	5	70 / 30	287 / 290 / 323	195	19	0
25 / 75	30	30	75 / 25	306 / 285 / 308	243	25	5
25 / 75	30	30	50 / 50	291 / 297 / 312	292	58	0
20 / 80	10	5	50 / 50	298 / 300 / 301	164	17	0
30 / 70	10	10	40 / 60	325 / 296 / 277	215	26	1
85 / 15	20	15	40 / 60	319 / 281 / 299	272	35	0

TABLE 5
MODEL 4 TEST RESULTS

% Drowsy/ Alert	Type of Vehicle Passing/ being Passed	Speed of Vehicle Passing/ being Passed	% Automobiles/ Trucks in Opposing Lane	Number of Vehciles Entering Left Lane	Collisions in Opposing Lane	Collisions in Passing Lane	Collisions while Passing
20 / 80	Auto / Auto	Slow / Slow	70 / 30	300	34	0	0
20 / 80	Auto / Auto	Fast / Slow	70 / 30	300	34	0	0
20 / 80	Auto / Truck	Slow / Slow	70 / 30	300	34	8	0
20 / 80	Auto / Truck	Fast / Fast	70 / 30	300	34	8	0
20 / 80	Truck / Auto	Slow / Slow	70 / 30	300	34	6	3
20 / 80	Truck / Auto	Fast / Slow	70 / 30	300	34	6	2
20 / 80	Truck / Truck	Slow / Slow	70 / 30	300	34	6	3
20 / 80	Truck / Truck	Fast / Fast	70 / 30	300	34	6	2
60 / 40	Truck / Auto	Slow / Slow	60 / 40	300	42	6	2
90 / 10	Auto / Truck	Fast / Fast	60 / 40	300	42	8	0
30 / 70	Auto / Auto	Fast / Fast	40 / 60	300	54	0	0
30 / 70	Truck / Auto	Fast / Slow	30 / 70	300	46	6	4

TABLE 6
MODEL 5 TEST RESULTS

% Preoccupied/ Attentive	% Automobiles/ Trucks	Number of Vehicles Entering Lanes 1 / 2 / 3	Collisions in own Lane	Collisions Switching Lanes	Collisions with Obstacle
20 / 80	75 / 25	309 / 283 / 307	111	14	0
50 / 50	75 / 25	309 / 283 / 307	124	11	0
80 / 20	75 / 25	309 / 283 / 307	117	14	1
20 / 80	70 / 30	309 / 283 / 307	135	12	0
20 / 80	40 / 60	309 / 283 / 307	208	23	1
20 / 80	25 / 75	309 / 283 / 307	237	28	0
50 / 50	70 / 30	309 / 283 / 307	128	21	0
50 / 50	40 / 60	309 / 283 / 307	200	27	0
50 / 50	30 / 70	309 / 283 / 307	220	25	0
80 / 20	70 / 30	309 / 283 / 307	139	16	0
80 / 20	40 / 60	309 / 283 / 307	215	26	1
80 / 20	30 / 70	309 / 283 / 307	228	22	0

```
*Model 1 - SWITCHING LANES
          SIMULATE
          INTEGER     &PREOCC,&RUSHED,&UNFAM
          INTEGER     &AUTOS
          INTEGER     &HWAY,&SEGS
          INTEGER     &LANE1(66),&LANE2(66)
          REAL        &FEET,&TIME
          LET         &SEGS=66
          LET         &FEET=40
          LET         &HWAY=3
*
          PUTPIC
          DRIVERS IN THIS SIMULATION ARE EITHER ATTENTIVE OR PREOCCUPIED.
          PUTPIC
          DRIVERS ARE CATEGORIZED AS EITHER IN A HURRY, UNFAMILIAR WITH THE
          PUTPIC
          AREA, OR RECENTLY RECEIVED A SPEEDING TICKET.  THESE CHARACTERISTICS
          PUTPIC
          AFFECT THEIR REACTION TIMES AND THEIR RANGE OF SPEED.
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS WHICH ARE PREOCCUPIED (REMAINING WILL
          PUTPIC
          BE ATTENTIVE):
          GETLIST     (&PREOCC)
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS IN A HURRY:
          GETLIST     (&RUSHED)
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS UNFAMILIAR WITH THE AREA (REMAINING
          PUTPIC
          WILL HAVE RECENTLY RECEIVED SPEEDING TICKETS):
          GETLIST     (&UNFAM)
          PUTPIC
          ENTER THE PERCENTAGE OF TRAFFIC WHICH IS AUTOMOBILES (REMAINING WILL
          PUTPIC
          BE TRUCKS):
          GETLIST     (&AUTOS)
*  Functions
SPHUR     FUNCTION    RN4,C2     range of speed for drivers in a hurry
0,88/1,117                       feet/second
SPUNF     FUNCTION    RN5,C2     ... for drivers unfamiliar with area
0,51/1,95
SPTRAFF   FUNCTION    RN6,C2     ... for drivers recently receiving speeding ticket
0,78/1,83
*
DEVIATE   FUNCTION    RN7,D3     reaction time standard deviation of 1, 2, and 3
.34,1/.67,2/1,3
*
THRUPUT   TABLE       M1,0,5,500   average time to travel 1/2 mile
*
          GENERATE    3,.05,,,,5PH,6PL  generate vehicles
          TRANSFER    .(&PREOCC*10),,DETREAC1
          ASSIGN      2,ABS(RVNORM(7,.5,(.1*FN(DEVIATE)))),,PL attentive reaction time
          TRANSFER    ,GOON
DETREAC1  ASSIGN     2,ABS(RVNORM(8,.7,(.1*FN(DEVIATE)))),,PL preoccupied reaction
time
GOON      TRANSFER    .((&RUSHED+&UNFAM)*10),,DETCHAR
          ASSIGN      3,FN(SPTRAFF),,PL  received speeding ticket
          ASSIGN      5,83,,PL           max speed
          TRANSFER    ,GOON1
DETCHAR   TRANSFER    .((100-&UNFAM)*10),,DETCHAR2
          ASSIGN      3,FN(SPUNF),,PL    unfamiliar with area
          ASSIGN      5,95,,PL
          TRANSFER    ,GOON1
```

```
DETCHAR2 ASSIGN     3,FN(SPHUR),,PL    in a hurry
         ASSIGN     5,118,,PL
GOON1    TRANSFER   .(&AUTOS*10),,DETAUTO
         ASSIGN     4,3,,PH             truck needs 3 units
         TRANSFER   ,CONT
DETAUTO  ASSIGN     4,1,,PH             auto needs 1 unit
CONT     TRANSFER   .5,LN1,LN2          send to one of the two lanes
*
LN1      ASSIGN     1,1,,PH             pavement segment to enter
CONT1    TEST GE    &HWAY-&LANE1(PH1),PH4,COLLIDE  test for collision entering lane
FITIN    BLET       &LANE1(PH1)=&LANE1(PH1)+PH4  enter pavement segment
         BLET       &TIME=&FEET/PL3
         ADVANCE    &TIME               travel one pavement segment
         BLET       &LANE1(PH1)=&LANE1(PH1)-PH4  leave pavement segment
         ASSIGN     1+,1,,PH            increment to next pavement segment
         TEST LE    PH1,&SEGS,DONE      test for completed strip of roadway
         TEST GE    PL3,PL5,PASS1       if less than max speed, try to pass
NOGO     TRANSFER   ,CONT1              continue down roadway
*
PASS1    TEST GE    &HWAY-&LANE2(PH1),PH4,NOGO  if no room to pass, stay in lane
         ADVANCE    PL2                 wait reaction time before switching
         ASSIGN     3+,(.15*PL3),,PL    increase speed by 15%
         TEST GE    &HWAY-&LANE2(PH1),PH4,COLLIDE2 test for collision switching
         SAVEVALUE  NSWITCH+,1          increment number of lane switches
         TRANSFER   ,FITIN2             go to new lane
*
LN2      ASSIGN     1,1,,PH             pavement segment to enter
CONT2    TEST GE    &HWAY-&LANE2(PH1),PH4,COLLIDE  test for collision entering lane
FITIN2   BLET       &LANE2(PH1)=&LANE2(PH1)+PH4  enter pavement segment
         BLET       &TIME=&FEET/PL3
         ADVANCE    &TIME               travel one pavement segment
         BLET       &LANE2(PH1)=&LANE2(PH1)-PH4 leave pavement segment
         ASSIGN     1+,1,,PH            increment to next pavement segment
         TEST LE    PH1,&SEGS,DONE      completed strip of roadway
         TEST GE    PL3,PL5,PASS2       if less than max speed, try to pass
NOGO2    TRANSFER   ,CONT2              continue down roadway
*
PASS2    TEST GE    &HWAY-&LANE1(PH1),PH4,NOGO2  if no room to pass, stay in lane
         ADVANCE    PL2                 wait reaction time before switching
         ASSIGN     3+,(.15*PL3),,PL    increase speed by 15%
         TEST GE    &HWAY-&LANE1(PH1),PH4,COLLIDE2 test for collision switching
         SAVEVALUE  NSWITCH+,1          increment number of lane switches
         TRANSFER   ,FITIN              go to new lane
*
COLLIDE  SAVEVALUE  NCOLLIS+,1          increment number of collisions
         TERMINATE
COLLIDE2 SAVEVALUE  NCOLLIS2+,1         ...lane switch collisions
         TERMINATE
*
DONE     TABULATE   THRUPUT             keep track of transit time
         TERMINATE                      successful end for that vehicle
*
         GENERATE   900                 execute for 15 minutes
         START      1
         BPUTPIC     FILE=UOUT1,(&PREOCC,100-&PREOCC)
         % OF DRIVERS PREOCCUPIED: **     ATTENTIVE: **
         BPUTPIC     FILE=UOUT1,(&RUSHED,&UNFAM,100-(&RUSHED+&UNFAM))
         % OF DRIVERS IN A HURRY: **  UNFAMILIAR: **   RECENT TICKET: **
         BPUTPIC     FILE=UOUT1,(&AUTOS,100-&AUTOS)
         % OF AUTOMOBILES: **     TRUCKS: **
         BPUTPIC     FILE=UOUT1,(TB$THRUPUT)
         AVERAGE TRANSIT TIME FOR 1/2 MILE:  ***.**
         BPUTPIC     FILE=UOUT1,(X$NCOLLIS,X$NCOLLIS2)
         NUMBER OF COLLISIONS IN OWN LANE: ****   COLLISIONS SWITCHING: ****
```

```
BPUTPIC     FILE=UOUT1,(X$NSWITCH)
NUMBER OF LANE SWITCHES: ******
TERMINATE  1
END
```

```
* Model 2 - MERGING
          SIMULATE
          INTEGER    &PREOCC,&IMMED,&HESIT
          INTEGER    &AUTOS,&LANE1(70),&LANE2(70),&LANE3(70)
          INTEGER    &SEGS,&HWAY
          REAL       &FEET,&TIME
          LET        &FEET=40
          LET        &SEGS=66
          LET        &HWAY=3
*
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS WHICH ARE PREOCCUPIED (REMAINING WILL
          PUTPIC
          BE ATTENTIVE):
          GETLIST    (&PREOCC)
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS INCLINED TO MERGE IMMEDIATELY:
          GETLIST    (&IMMED)
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS INCLINED TO HESITATE (REMAINING
          PUTPIC
          WILL WAIT UNTIL LAST POSSIBLE MOMENT):
          GETLIST    (&HESIT)
          PUTPIC
          ENTER THE PERCENTAGE OF TRAFFIC WHICH IS AUTOMOBILES (REMAINING WILL
          PUTPIC
          BE TRUCKS):
          GETLIST    (&AUTOS)
*
* Functions
SPLEFT    FUNCTION   RN4,C2     range of speed for drivers in left lane
0,88/1,103
SPCENT    FUNCTION   RN5,C2     ... for drivers in the center lane
0,81/1,95
SPRGT     FUNCTION   RN6,C2     ... for drivers in the right lane
0,66/1,81
DEVIATE   FUNCTION   RN7,D3     standard deviations for reaction time
.34,1/.67,2/1,3
*
MERGEDIS  TABLE      &FEET*PH1,0,5,500 average distance traveled before merging
*
          GENERATE   .8,.05,,,,4PH,6PL  generate vehicles
          TRANSFER   .(&PREOCC*10),,DETREAC1
          ASSIGN     2,ABS(RVNORM(7,.5,(.1*FN(DEVIATE)))),,PL attentive reaction time
          TRANSFER   ,GOON
DETREAC1  ASSIGN    2,ABS(RVNORM(8,.7,(.1*FN(DEVIATE)))),,PL preoccupied reaction
time
GOON      TRANSFER   .((&IMMED+&HESIT)*10),,DETCHAR
          ASSIGN     3,3,,PH            waits till last moment to merge
          TRANSFER   ,GOON1
DETCHAR   TRANSFER   .((100-&HESIT)*10),,DETCHAR2
          ASSIGN     3,2,,PH            hesitates before merging
          TRANSFER   ,GOON1
DETCHAR2  ASSIGN     3,1,,PH            merges immediately
GOON1     TRANSFER   .(&AUTOS*10),,DETAUTO
          ASSIGN     4,3,,PH            truck requires 3 units
          TRANSFER   ,CONT
DETAUTO   ASSIGN     4,1,,PH            auto requires 1 unit
CONT      TRANSFER   .33,,LN1           send to lane1, lane2, or lane3
          TRANSFER   .5,LN2,LN3
*
LN1       ASSIGN     1,1,,PH            pavement segment to enter
ENTERLN1  ASSIGN     5,FN(SPLEFT),,PL   assign left lane speed
CONT1     TEST GE    &HWAY-&LANE1(PH1),PH4,COLLIDE  test for collision entering lane
```

```
FITIN     BLET      &LANE1(PH1)=&LANE1(PH1)+PH4 enter pavement segment
          BLET      &TIME=&FEET/PL5
          ADVANCE   &TIME                  travel one pavement segment
          BLET      &LANE1(PH1)=&LANE1(PH1)-PH4 leave pavement segment
          ASSIGN    1+,1,,PH               increment to next pavement segment
          TEST LE   PH1,&SEGS,DONE         completed strip of roadway
          TRANSFER  ,CONT1                 continue down roadway
*
LN2       ASSIGN    1,1,,PH                pavement segment to enter
ENTERLN2  ASSIGN    5,FN(SPCENT),,PL       assign speed for center lane
          ASSIGN    6,95,,PL               max speed desired
CONT2     TEST GE   &HWAY-&LANE2(PH1),PH4,COLLIDE  test for collision entering lane
FITIN2    BLET      &LANE2(PH1)=&LANE2(PH1)+PH4  enter pavement segment
          BLET      &TIME=&FEET/PL5
          ADVANCE   &TIME                  travel one pavement segment
          BLET      &LANE2(PH1)=&LANE2(PH1)-PH4 leave pavement segment
          ASSIGN    1+,1,,PH               increment to next pavement segment
          TEST LE   PH1,&SEGS,DONE         completed strip of roadway
          TEST GE   PL5,PL6,PASS2          if less than max speed, try to pass
          TRANSFER  ,CONT2                 continue down roadway
*
PASS2     TEST GE   &HWAY-&LANE1(PH1),PH4,CONT2 if no room to pass, stay in lane
          ADVANCE   PL2                    wait reaction time before switching
          ASSIGN    5,FN(SPLEFT),,PL       assign left lane speed
          TEST GE   &HWAY-&LANE1(PH1),PH4,COLLIDE2 test for collision entering lane
          TRANSFER  ,FITIN                 go to new lane
*
LN3       ASSIGN    1,1,,PH                pavement segment to enter
          ASSIGN    5,FN(SPRGT),,PL        assign speed for right lane
CONT3     TEST GE   &HWAY-&LANE3(PH1),PH4,COLLIDE
          BLET      &LANE3(PH1)=&LANE3(PH1)+PH4 enter pavement segment
          BLET      &TIME=&FEET/PL5
          ADVANCE   &TIME                  travel one pavement segment
          BLET      &LANE3(PH1)=&LANE3(PH1)-PH4 leave pavement segment
          TEST NE   PH3,1,MERGE            merge immediately
          TEST NE   PH3,2,MAYBE            hesitate before merging
          TEST NE   PH1,&SEGS-3,MERGE      last chance to merge
          TRANSFER  ,NOGO3
MAYBE     TEST G    RN(2),RN(3),MERGE      at random, continue to hesitate
NOGO3     TEST L    PH1,&SEGS-2,STRANDED stranded, never merged
          ASSIGN    1+,1,,PH               increment to next pavement segment
          TRANSFER  ,CONT3
*
MERGE     TEST GE   &HWAY-&LANE2(PH1),PH4,NOGO3 can vehicle merge?
          ADVANCE   PL2                    wait reaction time before merging
          TABULATE  MERGEDIS
          ASSIGN    5,FN(SPCENT),,PL       assign speed for center lane
          ASSIGN    6,95,,PL               max speed desired
          TEST GE   &HWAY-&LANE2(PH1),PH4,COLLIDE3 test for collision entering lane
          TRANSFER  ,FITIN2
*
COLLIDE   SAVEVALUE NCOLLIS+,1             collisions in own lane
          TERMINATE                        end of life for vehicle
COLLIDE2  SAVEVALUE NCOLLIS2+,1            collisions passing
          TERMINATE
COLLIDE3  SAVEVALUE NCOLLIS3+,1            collisions merging
          TERMINATE
STRANDED  SAVEVALUE NSTRAND+,1             vehicles stranded
          TERMINATE
DONE      TERMINATE                        successful end for that vehicle
*
          GENERATE  900                    execute for 15 minutes
          START     1
          BPUTPIC    FILE=UOUT2,(&PREOCC,100-&PREOCC)
```

```
% OF DRIVERS PREOCCUPIED: **     ATTENTIVE: **
BPUTPIC      FILE=UOUT2,(&IMMED,&HESIT,100-(&IMMED+&HESIT))
% OF DRIVERS MERGING IMMEDIATELY: **   HESITATING: **   WAITING: **
BPUTPIC      FILE=UOUT2,(&AUTOS,100-&AUTOS)
% OF AUTOMOBILES: **      TRUCKS: **
BPUTPIC      FILE=UOUT2,(TB$MERGEDIS)
AVERAGE DISTANCE TRAVELED BEFORE MERGING: *****.**
BPUTPIC      FILE=UOUT2,(X$NCOLLIS)
NUMBER OF COLLISIONS IN OWN LANE: ****
BPUTPIC      FILE=UOUT2,(X$NCOLLIS2,X$NCOLLIS3)
NUMBER OF COLLISIONS PASSING: ****   COLLISIONS MERGING: ****
BPUTPIC      FILE=UOUT2,(X$NSTRAND)
NUMBER OF VEHICLES STRANDED: ****
TERMINATE  1
END
```

```
*Model 3 - SWITCHING TO SAME LANE
          SIMULATE
          INTEGER    &PREOCC,&LCHANGE,&RCHANGE
          INTEGER    &AUTOS,&LANE1(66),&LANE2(66),&LANE3(66)
          INTEGER    &SEGS,&HWAY,&SPACE
          REAL       &FEET,&TIME
          LET        &FEET=40
          LET        &SEGS=66
          LET        &HWAY=2
          LET        &SPACE=3

          PUTPIC
          DRIVERS IN THIS SIMULATION ARE EITHER ATTENTIVE OR PREOCCUPIED.
          PUTPIC
          THIS CHARACTERISTIC AFFECTS THEIR REACTION TIMES.
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS WHICH ARE PREOCCUPIED (REMAINING WILL
          PUTPIC
          BE ATTENTIVE):
          GETLIST    (&PREOCC)
          PUTPIC
          ENTER THE PERCENTAGE OF VEHICLES WHICH WILL NEED TO SWITCH FROM THE
          PUTPIC
          LEFT LANE TO THE CENTER LANE:
          GETLIST    (&LCHANGE)
          PUTPIC
          ENTER THE PERCENTAGE OF VEHICLES WHICH WILL NEED TO SWITCH FROM THE
          PUTPIC
          RIGHT LANE TO THE CENTER LANE:
          GETLIST    (&RCHANGE)
          PUTPIC
          ENTER THE PERCENTAGE OF TRAFFIC WHICH IS AUTOMOBILES (REMAINING WILL
          PUTPIC
          BE TRUCKS):
          GETLIST    (&AUTOS)
*
* Functions
SPLEFT    FUNCTION   RN4,C2        range of speed for left lane
0,81/1,95
SPCENT    FUNCTION   RN5,C2        ... for center lane
0,81/1,88
SPRGT     FUNCTION   RN6,C2        ... for right lane
0,66/1,73
DEVIATE   FUNCTION   RN7,D3        standard deviations for reaction time
.34,1/.67,2/1,3
*
          GENERATE   1,.05,,,,4PH,6PL  generate vehicles at half the headway
          TRANSFER   .(&PREOCC*10),,DETREAC1
          ASSIGN     2,ABS(RVNORM(7,.5,(.1*FN(DEVIATE)))),,PL attentive reaction time
          TRANSFER   ,GOON
DETREAC1  ASSIGN     2,ABS(RVNORM(8,.7,(.1*FN(DEVIATE)))),,PL preoccupied reaction
time
GOON      TRANSFER   .(&AUTOS*10),,DETAUTO
          ASSIGN     4,3,,PH            truck needs 3 units
          TRANSFER   ,CONT
DETAUTO   ASSIGN     4,1,,PH            automobile needs 1 unit
CONT      TRANSFER   .33,,LN1           send to one of three lanes
          TRANSFER   .5,LN2,LN3
*
LN1       ASSIGN     1,1,,PH            pavement segment to enter
ENTERLN1  ASSIGN     5,FN(SPLEFT),,PL   assign speed for left lane
CONT1     TEST NE    PH4,3,FITIN        only 2 per segment except for a truck
          TEST GE    &HWAY-&LANE1(PH1),PH4,COLLIDE  test for collision entering lane
          TRANSFER   ,TAKE1
```

```
FITIN      TEST GE    &SPACE-&LANE1(PH1),PH4,COLLIDE
TAKE1      BLET       &LANE1(PH1)=&LANE1(PH1)+PH4  enter segment
           BLET       &TIME=&FEET/PL5
           ADVANCE    &TIME                 travel one pavement segment
           BLET       &LANE1(PH1)=&LANE1(PH1)-PH4   release pavement segment
           ASSIGN     1+,1,,PH              increment to next pavement segment
           TEST LE    PH1,&SEGS,DONE        completed strip of roadway
           TEST L     PH1,20,MAYSW1         may try to switch lanes
           TRANSFER   ,CONT1                continue down roadway
*
MAYSW1     TEST LE    PH1,25,CONT1          switching occurs between
*                                             segments 20 and 25
           TRANSFER   .((100-&LCHANGE)*10),,CONT1 x% need to switch
           TEST GE    &SPACE-&LANE2(PH1),PH4,ENTERLN1  if no room to pass, stay in lane
           ADVANCE    PL2                   wait reaction time before switching
           ASSIGN     5+,(.1*PL5),,PL       increase speed by 10%
           TEST GE    &SPACE-&LANE2(PH1),PH4,COLLIDE2  if full, collision
           TEST NE    PH4,3,MRGLANE2        if truck, near miss N/A
           TEST GE    &HWAY-&LANE2(PH1),PH4,NEARM if this is 3rd auto, near miss
           TRANSFER   ,MRGLANE2
*
NEARM      SAVEVALUE  NMISSES+,1            increment number of near misses
           TRANSFER   ,MRGLANE2
*
LN2        ASSIGN     1,1,,PH               pavement segment to enter
           ASSIGN     5,FN(SPCENT),,PL      assign center lane speed
CONT2      TEST NE    PH4,3,FITIN2          segment holds 2 auto or 1 truck
           TEST GE    &HWAY-&LANE2(PH1),PH4,COLLIDE test for collision entering lane
           TRANSFER   ,MRGLANE2
FITIN2     TEST GE    &SPACE-&LANE2(PH1),PH4,COLLIDE
MRGLANE2   BLET       &LANE2(PH1)=&LANE2(PH1)+PH4 enter pavement segment
           BLET       &TIME=&FEET/PL5
           ADVANCE    &TIME                 travel one pavement segment
           BLET       &LANE2(PH1)=&LANE2(PH1)-PH4 leave pavement segment
           ASSIGN     1+,1,,PH              increment to next pavement segment
           TEST LE    PH1,&SEGS,DONE        completed strip of roadway
           TRANSFER   ,CONT2                continue down roadway
*
LN3        ASSIGN     1,1,,PH               pavement segment to enter
ENTERLN3   ASSIGN     5,FN(SPRGT),,PL       assign right lane speed
CONT3      TEST NE    PH4,3,FITIN3          segment holds 2 autos or 1 truck
           TEST GE    &HWAY-&LANE3(PH1),PH4,COLLIDE test for collision entering lane
           TRANSFER   ,TAKE3
FITIN3     TEST GE    &SPACE-&LANE3(PH1),PH4,COLLIDE
TAKE3      BLET       &LANE3(PH1)=&LANE3(PH1)+PH4 enter pavement segment
           BLET       &TIME=&FEET/PL5
           ADVANCE    &TIME                 travel one pavement segment
           BLET       &LANE3(PH1)=&LANE3(PH1)-PH4 leave pavement segment
           ASSIGN     1+,1,,PH              increment to next pavement segment
           TEST LE    PH1,&SEGS,DONE        reached end of pavement segments?
           TEST L     PH1,20,MAYSW3         may try to switch lanes
           TRANSFER   ,CONT3
*
MAYSW3     TEST LE    PH1,25,CONT3          may try to switch between
*                                             segments 20 and 25
           TRANSFER   .((100-&RCHANGE)*10),,CONT3  a percentage need to switch
           TEST GE    &SPACE-&LANE2(PH1),PH4,ENTERLN3  if no room to pass, stay in lane
           ADVANCE    PL2                   wait reaction time before switching
           ASSIGN     5+,(.1*PL5),,PL       increase speed by 10%
           TEST GE    &SPACE-&LANE2(PH1),PH4,COLLIDE2  if full, collision occurs
           TEST NE    PH4,3,MRGLANE2        if truck, near miss is N/A
           TEST GE    &HWAY-&LANE2(PH1),PH4,NEARM if this is 3rd auto, near miss
           TRANSFER   ,MRGLANE2
```

```
*
COLLIDE   SAVEVALUE  NCOLLIS+,1         increment number of collisions in own lane
          TERMINATE
*
COLLIDE2  SAVEVALUE  NCOLLIS2+,1        ...collisions switching to center lane
          TERMINATE
*
DONE      TERMINATE                     successful end for that vehicle
*
          GENERATE   900                execute for 15 minutes
          START      1
          BPUTPIC    FILE=UOUT3,(&PREOCC,100-&PREOCC)
          % OF DRIVERS PREOCCUPIED: **      ATTENTIVE: **
          BPUTPIC     FILE=UOUT3,(&LCHANGE,&RCHANGE)
          % OF LEFT LANE CHANGING: **       RIGHT LANE: **
          BPUTPIC     FILE=UOUT3,(&AUTOS,100-&AUTOS)
          % OF AUTOMOBILES: **      TRUCKS: **
          BPUTPIC     FILE=UOUT3,(X$NCOLLIS)
          NUMBER OF COLLISIONS IN OWN LANE: ****
          BPUTPIC     FILE=UOUT3,(X$NCOLLIS2)
          NUMBER OF COLLISIONS SWITCHING TO CENTER LANE: ****
          BPUTPIC     FILE=UOUT3,(X$NMISSES)
          NUMBER OF NEAR MISSES DURING LANE SWITCH: ****
          TERMINATE  1
          END
```

```
*Model 4 - PASSING
          SIMULATE
          INTEGER    &PREOCC,&VTYPE,&STYPE
          INTEGER    &AUTOS,&LANE1(66),&LANE2(66)
          INTEGER    &SEGS,&HWAY,&PASSING
          REAL       &FEET
          LET        &FEET=40
          LET        &SEGS=66
          LET        &HWAY=3
          LET        &PASSING=0
*
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS WHICH ARE DROWSY (REST ARE ALERT):
          GETLIST    (&PREOCC)
          PUTPIC     LINES=2
          ENTER A '1' FOR AUTO PASSING AUTO; A '2' FOR AUTO PASSING TRUCK;
          A '3' FOR TRUCK PASSING AUTO; OR A '4' FOR TRUCK PASSING TRUCK:
          GETLIST    (&VTYPE)
          PUTPIC     LINES=2
          ENTER A '1' FOR SLOW PASSING SLOW; A '2' FOR FAST PASSING SLOW;
          OR A '3' FOR FAST PASSING FAST:
          GETLIST    (&STYPE)
          PUTPIC     LINES=2
          ENTER THE PERCENTAGE OF TRAFFIC WHICH IS AUTOMOBILES (REMAINING WILL
          BE TRUCKS):
          GETLIST    (&AUTOS)
* Functions
SPOPPA    FUNCTION   RN3,C2     range of speed for autos
0,73/1,117
SPOPPT    FUNCTION   RN4,C2     ... for trucks
0,88/1,103
SPFAST    FUNCTION   RN5,C2     ... for fast vehicles
0,103/1,117
SPSLOW    FUNCTION   RN6,C2     ... for slow vehicles
0,73/1,88
DEVIATE   FUNCTION   RN7,D3     standard deviations for reaction time
.34,1/.67,2/1,3
*
          GENERATE   3,.05,,,,4PH,2PL   generate vehicles
          TRANSFER   .(&AUTOS*10),,DETAUTO
          ASSIGN     4,3,,PH            truck requires 3 units
          ASSIGN     2,FN(SPOPPT),,PL
          TRANSFER   ,LN1
DETAUTO   ASSIGN     4,1,,PH            auto requires 1 unit
          ASSIGN     2,FN(SPOPPA),,PL
*
LN1       ASSIGN     1,66,,PH           pavement segment to enter
CONT1     TEST NE    &PASSING,1,FITIN1  if vehicle passing, allow room
          TEST GE    &HWAY-&LANE1(PH1),1,COLLIDE  one vehicle per segment
          TRANSFER   ,TRY1
FITIN1    TEST GE    &HWAY-&LANE1(PH1),PH4,COLLIDE3 room for both?
TRY1      BLET       &LANE1(PH1)=&LANE1(PH1)+PH4 enter pavement segment
          ADVANCE    (&FEET/PL2)        travel one pavement segment
          BLET       &LANE1(PH1)=&LANE1(PH1)-PH4 leave pavement segment
          ASSIGN     1-,1,,PH           decrement to next pavement segment
          TEST G     PH1,0,DONE         completed strip of roadway
          TRANSFER   ,CONT1             continue down roadway
*
          GENERATE   100,,100,,,5PH,3PL generate vehicle to be passed
          ASSIGN     5,1,,PH            vehicle indicator
          ASSIGN     1,10,,PH           starting segment
          TEST NE    &VTYPE,1,AAUTO     is vehicle an auto or truck?
          TEST NE    &VTYPE,3,AAUTO
          ASSIGN     4,3,,PH            vehicle is a truck
```

```
          TRANSFER    ,GOON1
AAUTO     ASSIGN      4,1,,PH              vehicle is an auto
GOON1     TEST NE     &STYPE,3,AFAST       is vehicle fast or slow?
          ASSIGN      2,FN(SPSLOW),,PL     vehicle is slow
          TRANSFER    ,REAC
AFAST     ASSIGN      2,FN(SPFAST),,PL     vehicle is fast
*
REAC      TRANSFER    .(&PREOCC*10),,DETREAC1
          ASSIGN      3,ABS(RVNORM(8,.5,(.1*FN(DEVIATE)))),,PL alert
          TRANSFER    ,LN2
DETREAC1  ASSIGN      3,ABS(RVNORM(9,.7,(.1*FN(DEVIATE)))),,PL drowsy
          TRANSFER    ,LN2
*
          GENERATE    100,,100,,,5PH,3PL generate vehicle which will pass
          ASSIGN      1,9,,PH              start one segment behind vehicle
          ASSIGN      5,2,,PH              vehicle indicator
          TEST LE     &VTYPE,2,BTRUCK      is vehicle an auto or truck?
          ASSIGN      4,1,,PH              vehicle is an auto
          TRANSFER    ,GOON2
BTRUCK    ASSIGN      4,3,,PH              vehicle is a truck
GOON2     TEST GE     &STYPE,2,BSLOW       is vehicle fast or slow?
          ASSIGN      2,FN(SPFAST),,PL     vehicle is fast
          TRANSFER    ,REAC
BSLOW     ASSIGN      2,FN(SPSLOW),,PL     vehicle is slow
          TRANSFER    ,REAC
*
LN2       TEST NE     &PASSING,1,TRY2      pass in progress?
          TEST GE     &HWAY-&LANE2(PH1),1,COLLIDE2 one vehicle per segment
          TRANSFER    ,FITIN2
TRY2      TEST GE     &HWAY-&LANE2(PH1),PH4,COLLIDE3 fit during pass?
FITIN2    BLET        &LANE2(PH1)=&LANE2(PH1)+PH4 enter pavement segment
          ADVANCE     (&FEET/PL2)          travel pavement segment
          BLET        &LANE2(PH1)=&LANE2(PH1)-PH4 leave pavement segment
          ASSIGN      1+,1,,PH             increment to next segment
          TEST LE     PH1,&SEGS,DONE2      completed road segment?
          TEST NE     PH5,2,PASS           if passing vehicle, consider passing
          TRANSFER    ,LN2
*
PASS      TEST NE     &PASSING,2,LN2       already passed vehicle
          TEST GE     &HWAY-&LANE1(PH1),PH4,LN2  possible to pass?
          BLET        &PASSING=1           set passing flag
          ADVANCE     PL3                  wait reaction time before passing
STAYL     TEST GE     &HWAY-&LANE1(PH1),PH4,COLLIDE3 collision during pass?
          ASSIGN      2+,(.15*PL2),,PL     increase speed for pass
          BLET        &LANE1(PH1)=&LANE1(PH1)+PH4 enter opposite lane
          ADVANCE     (&FEET/PL2)          travel past vehicle
          BLET        &LANE1(PH1)=&LANE1(PH1)-PH4 leave pavement segment
          ASSIGN      1+,1,,PH             increment to next pavement segment
          TEST GE     &HWAY-&LANE2(PH1),PH4,STAYL get back into own lane?
          BLET        &PASSING=2           set passing flag to already passed
          TRANSFER    ,FITIN2
*
COLLIDE   SAVEVALUE   NCOLLIS+,1           number of collisions in non-passing lane
          TERMINATE                        end of life for that vehicle
COLLIDE2  SAVEVALUE   NCOLLIS2+,1          number of collisions in passing lane
          TERMINATE
COLLIDE3  SAVEVALUE   NCOLLIS3+,1          number of collisions while passing
DONE2     BLET        &PASSING=0
DONE      TERMINATE
*
          GENERATE    900                  execute for 15 minutes
          START       1
          BPUTPIC     LINES=2,FILE=UOUT4,(&PREOCC,100-&PREOCC,&AUTOS,100-&AUTOS)
          % OF DRIVERS DROWSY: **      ALERT: **
```

```
          % OF AUTOMOBILES: **     TRUCKS: **
          TEST E      &VTYPE,1,PRNT2
          BPUTPIC     FILE=UOUT4
          SCENARIO IS AUTO PASSING AUTO
          TRANSFER    ,FINISH
PRNT2     TEST E      &VTYPE,2,PRNT3
          BPUTPIC     FILE=UOUT4
          SCENARIO IS AUTO PASSING TRUCK
          TRANSFER    ,FINISH
PRNT3     TEST E      &VTYPE,3,PRNT4
          BPUTPIC     FILE=UOUT4
          SCENARIO IS TRUCK PASSING AUTO
          TRANSFER    ,FINISH
PRNT4     BPUTPIC     FILE=UOUT4
          SCENARIO IS TRUCK PASSING TRUCK
FINISH    TEST E      &STYPE,1,TRY5
          BPUTPIC     FILE=UOUT4
          SLOW VEHICLE COMING UP ON SLOW VEHICLE
          TRANSFER    ,FINISH2
TRY5      TEST E      &STYPE,2,TRY6
          BPUTPIC     FILE=UOUT4
          FAST VEHICLE COMING UP ON SLOW VEHICLE
          TRANSFER    ,FINISH2
TRY6      BPUTPIC     FILE=UOUT4
          FAST VEHICLE COMING UP ON FAST VEHICLE
FINISH2   BPUTPIC     LINES=2,FILE=UOUT4,(X$NCOLLIS,X$NCOLLIS2,X$NCOLLIS3)
          NUMBER OF COLLISIONS IN NON-PASSING LANE: ****   PASSING LANE: ****
          NUMBER OF COLLISIONS PASSING: ****
          TERMINATE   1
          END
```

```
*Model 5 - OBSTACLE IN CENTER LANE
          SIMULATE
          INTEGER     &PREOCC
          INTEGER     &AUTOS,&LANE1(66),&LANE2(66),&LANE3(66)
          INTEGER     &SEGS,&HWAY,&SPACE
          REAL        &FEET,&TIME
          LET         &FEET=40
          LET         &SEGS=66
          LET         &HWAY=2
          LET         &SPACE=3

          PUTPIC
          DRIVERS IN THIS SIMULATION ARE EITHER ATTENTIVE OR PREOCCUPIED.
          PUTPIC
          THIS CHARACTERISTIC AFFECTS THEIR REACTION TIMES.
          PUTPIC
          ENTER THE PERCENTAGE OF DRIVERS WHICH ARE PREOCCUPIED (REMAINING WILL
          PUTPIC
          BE ATTENTIVE):
          GETLIST     (&PREOCC)
          PUTPIC
          ENTER THE PERCENTAGE OF TRAFFIC WHICH IS AUTOMOBILES (REMAINING WILL
          PUTPIC
          BE TRUCKS):
          GETLIST     (&AUTOS)
*
* Functions
SPLEFT    FUNCTION    RN4,C2        range of speed for left lane
0,88/1,103
SPCENT    FUNCTION    RN5,C2        ... for center lane
0,81/1,95
SPRGT     FUNCTION    RN6,C2        ... for right lane
0,66/1,81
DEVIATE   FUNCTION    RN7,D3        standard deviations for reaction time
.34,1/.67,2/1,3
*
          GENERATE    1,.05,,,,4PH,6PL   generate vehicles
          TRANSFER    .(&PREOCC*10),,DETREAC1
          ASSIGN      2,ABS(RVNORM(7,.5,(.1*FN(DEVIATE)))),,PL attentive reaction time
          TRANSFER    ,GOON
DETREAC1  ASSIGN      2,ABS(RVNORM(8,.7,(.1*FN(DEVIATE)))),,PL preoccupied reaction
time
GOON      TRANSFER    .(&AUTOS*10),,DETAUTO
          ASSIGN      4,3,,PH            truck needs 3 units
          TRANSFER    ,CONT
DETAUTO   ASSIGN      4,1,,PH            automobile needs 1 unit
CONT      TRANSFER    .33,,LN1           send to one of three lanes
          TRANSFER    .5,LN2,LN3
*
LN1       ASSIGN      1,1,,PH            pavement segment to enter
          ASSIGN      5,FN(SPLEFT),,PL   assign speed for left lane
CONT1     TEST NE     PH4,3,FITIN        only 2 per segment except for a truck
          TEST GE     &HWAY-&LANE1(PH1),PH4,COLLIDE test for collision entering lane
          TRANSFER    ,TAKE1
FITIN     TEST GE     &SPACE-&LANE1(PH1),PH4,COLLIDE
TAKE1     BLET        &LANE1(PH1)=&LANE1(PH1)+PH4 enter pavement segment
          BLET        &TIME=&FEET/PL5
          ADVANCE     &TIME              travel one pavement segment
          BLET        &LANE1(PH1)=&LANE1(PH1)-PH4 leave pavement segment
          ASSIGN      1+,1,,PH           increment to next pavement segment
          TEST LE     PH1,&SEGS,DONE     completed strip of roadway?
          TRANSFER    ,CONT1             continue down roadway
*
LN2       ASSIGN      1,1,,PH            pavement segment to enter
```

```
          ASSIGN     5,FN(SPCENT),,PL   assign speed for center lane
CONT2     TEST NE    PH4,3,FITIN2       segment holds 2 auto or 1 truck
          TEST GE    &HWAY-&LANE2(PH1),PH4,COLLIDE test for collision entering lane
          TRANSFER   ,MRGLANE2
FITIN2    TEST GE    &SPACE-&LANE2(PH1),PH4,COLLIDE
MRGLANE2  BLET       &LANE2(PH1)=&LANE2(PH1)+PH4 enter pavement segment
          BLET       &TIME=&FEET/PL5
          ADVANCE    &TIME              travel one pavement segment
          BLET       &LANE2(PH1)=&LANE2(PH1)-PH4 leave pavement segment
          ASSIGN     1+,1,,PH           increment to next pavement segment
          TEST L     PH1,&SEGS-1,OBSTAC hit the obstacle?
          TEST GE    PH1,&SEGS-3,CONT2  haven't seen obstacle yet
          TEST G     RN(2),RN(3),TRY3   random chance of which lane to attempt
*                                         switching into
          TEST GE    &SPACE-&LANE1(PH1),PH4,MAYBE3 fit into lane 1?
          ADVANCE    PL2                wait reaction time before switching
          TEST GE    &SPACE-&LANE1(PH1),PH4,COLLIDE2 collide entering lane?
          ASSIGN     5,FN(SPLEFT),,PL   assign left lane speed
          TRANSFER   ,TAKE1             switch to left lane
MAYBE3    ADVANCE    PL2        wait reaction time before checking other lane
          TEST GE    &SPACE-&LANE3(PH1),PH4,CONT2 fit into lane 3?
          ADVANCE    PL2                wait reaction time before switching
          TEST GE    &SPACE-&LANE3(PH1),PH4,COLLIDE2 collide entering lane?
          ASSIGN     5,FN(SPRGT),,PL    assign right lane speed
          TRANSFER   ,TAKE3             switch to right lane

TRY3      TEST GE    &SPACE-&LANE3(PH1),PH4,MAYBE1 fit into lane 3?
          ADVANCE    PL2                wait reaction time before switching
          TEST GE    &SPACE-&LANE3(PH1),PH4,COLLIDE2 collide entering lane?
          ASSIGN     5,FN(SPRGT),,PL    assign right lane speed
          TRANSFER   ,TAKE3             switch to right lane
MAYBE1    ADVANCE    PL2        wait reaction time before checking other lane
          TEST GE    &SPACE-&LANE1(PH1),PH4,CONT2 fit into lane 1?
          ADVANCE    PL2                wait reaction time before switching
          TEST GE    &SPACE-&LANE1(PH1),PH4,COLLIDE2 collide entering lane?
          ASSIGN     5,FN(SPLEFT),,PL   assign left lane speed
          TRANSFER   ,TAKE1             switch to left lane

*
LN3       ASSIGN     1,1,,PH            assign pavement segment
          ASSIGN     5,FN(SPRGT),,PL    assign right lane speed
CONT3     TEST NE    PH4,3,FITIN3       segment holds 2 autos or 1 truck
          TEST GE    &HWAY-&LANE3(PH1),PH4,COLLIDE collide moving ahead?
          TRANSFER   ,TAKE3
FITIN3    TEST GE    &SPACE-&LANE3(PH1),PH4,COLLIDE
TAKE3     BLET       &LANE3(PH1)=&LANE3(PH1)+PH4 enter pavement segment
          BLET       &TIME=&FEET/PL5
          ADVANCE    &TIME              travel one pavement segment
          BLET       &LANE3(PH1)=&LANE3(PH1)-PH4 leave pavement segment
          ASSIGN     1+,1,,PH           increment to next pavement segment
          TEST LE    PH1,&SEGS,DONE     completed 1/2 mile yet?
          TRANSFER   ,CONT3
*
COLLIDE   SAVEVALUE  NCOLLIS+,1         number of collisions in own lane
          TERMINATE
*
COLLIDE2  SAVEVALUE  NCOLLIS2+,1        number of collisions switching lanes
          TERMINATE
*
OBSTAC    SAVEVALUE  NOBST+,1           number of collision with obstacle
          TERMINATE
*
DONE      TERMINATE                     successful end for that vehicle
*
```

```
GENERATE   900                 execute for 15 minutes
START      1
BPUTPIC      FILE=UOUT5,(&PREOCC,100-&PREOCC)
% OF DRIVERS PREOCCUPIED: **      ATTENTIVE: **
BPUTPIC      FILE=UOUT5,(&AUTOS,100-&AUTOS)
% OF AUTOMOBILES: **      TRUCKS: **
BPUTPIC      FILE=UOUT5,(X$NCOLLIS)
NUMBER OF COLLISIONS IN OWN LANE: ****
BPUTPIC      FILE=UOUT5,(X$NCOLLIS2)
NUMBER OF COLLISIONS SWITCHING LANES: ****
BPUTPIC      FILE=UOUT5,(X$NOBST)
NUMBER OF COLLISIONS WITH OBSTACLE: ****
TERMINATE  1
END
```