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TRAFFIC SAFETY DEMONSTRATION PROGRAM MODELING SYSTEM

VOLUME III: Citizens Band Radio Model

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16. Abstract

The Traffic Safety Demonstration Program Modeling System (DEMON) is an interactive computer model for use in the analysis of individual NHTSA demonstration projects. Ongoing projects are currently being analyzed using this system, and new or alternative concepts may also be modeled. Volume I of this report is a technical summary of the modeling system. Volume II documents the DEMON system access, and mathematical assumptions made. Volume III documents a specialized model of the use of citizens band radio by highway patrol. Appendices are given in Volume IV.

This volume describes the Citizens Band (CB) radio model, designed to measure the role of CB units in a Highway Patrol emergency response system. A mathematical simulation, the model is used to describe the geography, dynamics, and emergency response situations (e.g., accidents, road hazards and speeders) for a given set of assumed conditions. The model can measure changes in the detection, notification and response times of a system, as conditions are allowed to vary. It evaluates the activities on the highway and compares the emergency response times for when the Highway Patrol is assumed to have a CB communication system and when it does not, i.e., under experimental and control situations.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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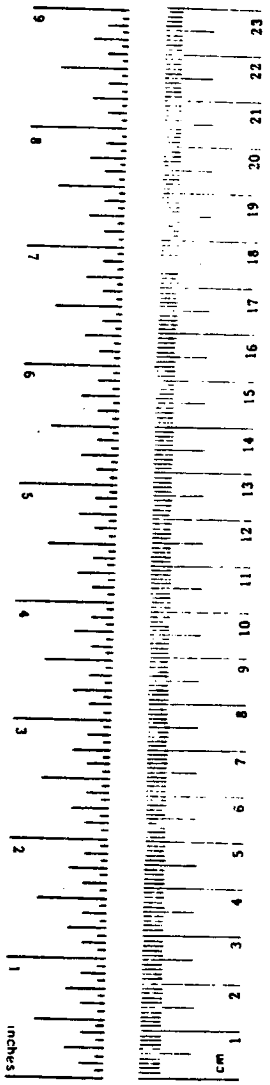
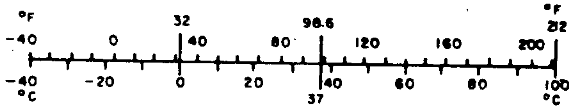
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I INTRODUCTION

One goal of the National Highway Traffic Safety Administration (NHTSA), pursuant to the Highway Safety Act of 1966 and Standard 11, Emergency Medical Services, has been to "develop, upgrade, and professionalize the prehospital emergency medical care system, enhance its life-sustaining quality, encourage its establishment where it does not yet exist, and achieve complete system development."[1] Citizens Band (CB) radio is in widespread use, and NHTSA's National Emergency Aid Radio (NEAR) program is intended to make use of this existing resource to improve emergency communication and thereby help to achieve the goals of Standard 11. The specific objectives of the NEAR program are to:

- "Provide prompt identification and reporting of highway safety incidents under a range of emergency conditions.
- Make public safety services more readily available to the motoring public.
- Enhance citizen participation in highway safety, including the formation of citizen adjuncts to assist professional public safety agencies in the performance of their highway safety duties.
- Provide an interface between volunteer CB groups and public safety agencies for the coordination and management of resources necessary to provide assistance and relay information concerning transportation safety or other citizen emergency needs."[1]

To achieve these objectives, mobile CB radio may be made a more effective tool for emergency communication. The existing system of

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[1] "Citizens Band Communication Manual," NHTSA, 1976.

volunteer CB monitors[1] is being expanded, with the goal of providing 24-hour coverage throughout the nation. The function of the NEAR monitor is to receive emergency messages transmitted by mobile CB units and to relay the messages by telephone to the appropriate public safety agency, e.g., police, fire department, or an ambulance.

Further improvement of the CB emergency communication system could be achieved by having more widespread installation of CB radios in police patrol vehicles. The use of CB radios in the patrol vehicles would made direct communication possible between CB mobile units and patrol vehicles; this innovation could substantially reduce reporting time and response time.

To further this concept, NHTSA is funding a demonstration project[2] involving the use of CB radios in Highway Patrol vehicles in New York. The main goal of the project is to measure the effectiveness of CB radio as a means to improve highway safety by increased emergency reporting. As a demonstration project, these activities will be carried forth under an experimental situation, i.e., a control group (no CB in Highway Patrol vehicles) will be utilized. State patrols in a number of states have similar projects underway or planned, with varying degrees of attention to experimental techniques.

In this report, an approach to the problem is discussed. The approach entails using a computer simulation model as a tool to help design such

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[1] Volunteer CB monitoring is currently provided in many sections of the country by REACT (Radio Emergency Associated Citizens Teams), ALERT (Affiliated League of Emergency Radio Teams), and the Citizens Radio Watch.

[2] Detailed Plan for Citizens Band Radio Highway Safety Evaluation Project, New York State Police, 1976.

experiments. The model can simulate accidents, road hazards and speeders, and the response of Highway Patrol units when notified through various communication links, including CB radio. The model was intended by NHTSA to be a design and evaluation tool for experiments such as the one currently being conducted in New York and for other states. Therefore, the program can simulate experimental (CB units in the Highway Patrol vehicles) and control (no CB units in the Highway Patrol vehicles) areas and can compute statistics from both areas for comparison.

The model can be accessed via terminal and is highly interactive. The analyst is requested to input data variable values, totally prompted by the computer and requiring no previous computer experience of the analyst.

For a given situation modeled, the output displayed provides for a comparison among alternative ways of detecting an emergency or hazard event and notifying the authorities. The time from occurrence of the event to response on scene of a Highway Patrol vehicle is the basic measure of effectiveness of a particular scheme.

There are many uses for a computer model of this sort. First, in SRI's experience, one of the biggest problems in this type of research project (especially enforcement projects) is that the designers have no preliminary estimates concerning the extent to which experimental and control areas might vary in their outcome. The model can, by predicting results, save the designer from many misconceptions. For example, if the model predicts a very small difference in response time between experimental and control areas, the designer knows that he may have to increase the number of incidents observed to preserve the required statistical confidence level.

Secondly, the model can indicate which communication links (e.g., citizen telephone to Highway Patrol, CB radio direct to Highway Patrol, CB radio to NEAR monitor to Highway Patrol base) are important in determining actual detection, notification and response times. These dominant links might differ by the study area or areas chosen, e.g., urban freeway or rural highway.

Thirdly, the model can be used to try out changes in patrol operations. For example, one could test the effect of increasing or decreasing the number of patrol vehicles on the road.

The following sections give details of the mathematical aspects of the modeling, instructions for users and some examples of output. Section II gives a general model description. Section III gives the instructions for interactive use of the model. Section IV gives the mathematical assumptions and computer program description. In Section IV, the iterations required to achieve convergence within desired confidence bounds are discussed.

II MODEL DESCRIPTION

The Citizens Band (CB) radio model is designed to measure the role of CB units in a Highway Patrol emergency response system. A mathematical simulation, the model is used to describe the geography, dynamics, and emergency response situations (e.g., accidents) for a given set of assumed conditions. The model can measure changes in the detection, notification and response times of the response system as conditions are allowed to vary. It evaluates the activities on the highway and compares the emergency response times for when the Highway Patrol is assumed to have a CB communication system and when it does not, i.e., under experimental and control situations.

The method of modeling is a simulation. In the simulation, an iteration consists of a positioning of an event and all vehicles. Next, all vehicles are "moved" along the roadway, some of which act to attempt to report the situation to the authorities, as they view it. The simulation, then, consists of a number of these events, i.e., a sequence of iterations. Each iteration is completed when a Highway Patrol officer is on scene.

The model distinguishes between three types of traffic hazards and emergencies:

- Accidents
- Fixed (non-moving) non-accident events
- Moving non-accident events (speeding).

In the first situation--accidents--the Highway Patrol and citizens are assumed to act with high priorities. The second case would include stalled vehicles, ice or trash on the road, and the like, and would not enjoy such a high-priority response. TUe third type of event differs from the first two in that the emergency is itself moving, creating new detection and tracking problems. Each type of event has its own scheme for communication links possible. These links were discussed with practicing patrol officers, CB advocates and NHTSA experts in the field before being implemented in the model.

Each type of event is discussed briefly below.

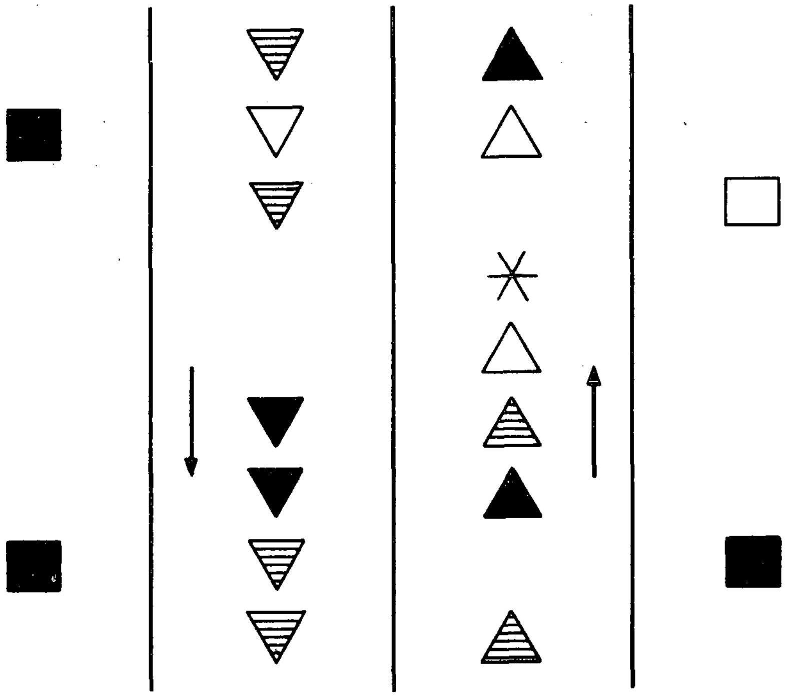
A. Accidents

A two-way highway is defined mathematically with a given total roadway length. A single state Highway Patrol base station and (possibly several) CB base stations, such as NEAR monitors, are positioned on and off the highway, with the positions being dependent on input parameters. Vehicles in traffic are all moving at a uniform, input-determined speed. They are spaced according to exponentially distributed distances. Each vehicle is assigned or not assigned as having a CB unit, based on a given density of CB units assumed to be on the highway. Vehicles with CB units have a higher probability of notifying the authorities of an accident (via their CB units) than vehicles without CB units. The latter would inform the Highway Patrol of an accident by telephone. The Highway Patrol units (the exact number of units being an input parameter) are spaced uniformly on the highway, with a + or - tolerance, also input. The speed of the patrol units is the same as that of the citizen vehicles, but the patrol speed is allowed to increase when a unit is responding to a reported accident.

1. The Simulation

For a single iteration, the vehicle locations on the two-direction highway might be viewed as shown on Figure 1. The simulation evaluates a given set of conditions and parameters, first assuming that the patrol cars all have CB units and then assuming that they do not. These evaluations are simulated simultaneously and independently.

For a given iteration of the accident simulation, the model positions the accident randomly on the highway. The number and position of non-patrol



△ = Highway Patrol Vehicle

◬ = Vehicle With No CB Unit

▲ = Vehicle With CB Unit

□ = Highway Patrol Base Station

■ = CB Base Station

✳ = Accident or Other Event

FIGURE 1 POSITIONING OF VEHICLES ON THE TWO-DIRECTION HIGHWAY FOR ONE ITERATION vehicles on the highway during an iteration is determined by an assumed vehicle/road density. The Highway Patrol units are also positioned, and the simulation then "moves" all vehicles in both directions at the given uniform speed. As the vehicles move, the accident is "seen" by a citizen (with or without a CB) or by a Highway Patrol unit. Depending on CB range and other assumed response-time variables, the times for a Highway Patrol unit to respond to the scene of the accident are determined. The basic inputs are held constant, and the simulation is iterated a number of times so that an average of the detection, notification and response times can be computed for interpretation.

A set of values for input variables is defined by the analyst to be used for a number of iterations. After viewing the results involving average detection, notification and response times, new values of the variables may be defined and further iterations may be analyzed. The variables which may be defined by the analyst for the accident simulation are as follows (the variables with asterisks have related probability distributions from which variation, iteration-to-iteration, in a given analysis, is obtained):

- Roadway--Length of road, average speed of traffic, traffic volume*
- Highway Patrol Vehicles--Number of units, maximum variation*, emergency speed
- Highway Patrol Base Station--Location, time to dispatch report
- CB Mobile Units--Percentage of vehicles with CBs*, ranges of CBs, times to relay message
- CB Base Stations--Number of stations, locations, times to dispatch reports, ranges
- Citizens in Non-CB Vehicles--Probability of citizen action (telephoning Highway Patrol versus no action)*, time required to reach a telephone.

For example, the asterisked variable "traffic volume" provides the mean for exponentially distributed distances between vehicles. For an analysis, the mean distance between vehicles would always have that value, but for each iteration the distances between vehicles on the road would vary about this mean. This, coupled with the random positioning of an accident provides a variation of the relative locations, from iteration to iteration.

The variables "percentage of vehicles with CB" and "probability of citizen action" represent discrete probability distributions. For example, if the probability of a citizen leaving the roadway to telephone report an accident is .5, then about one-half of the non-CB equipped vehicles will be designated to do this, should they see the accident. The designation will change for each iteration so that different vehicles located along the road will be so designated, each time. The "maximum variation" provides the interval parameter for the variations from equal spacing of Highway Patrol vehicles. This variation follows a uniform distribution.

2. Communication Links

For accidents, several possible communication links were considered. The possibilities were narrowed to nine which were judged to be the most common occurrences of detection of an accident and following relay of the message until the Highway Patrol is notified and a patrol vehicle is on scene. These links are listed in Table 1. Note that for a control situation (no CB in the HP vehicle) links 3 and 4 are not used. If the HP base station does not have a CB receiving unit, links 5 and 6 are not used. If no CB base stations are included in an experiment, links 7 and 8 are not used.

The model considers the times to detection, notification, and response as separate time intervals. The time sequence of events starts at time zero with the beginning of an iteration. The time to detection occurs when a vehicle (citizen, CB, or Highway Patrol) passes the accident and is designated as one that will then attempt to notify the Highway Patrol.

Table 1

COMMUNICATION LINK SYMBOLS AND DESCRIPTIONS

No.	Symbol	Description
1.	HP	Highway Patrol vehicle sees event
2.	CIT→HPBS→HP	Citizen sees event, pulls off road and telephones Highway Patrol base station, which dispatches Highway Patrol vehicle
3.	CB→HP	CB vehicle sees event, stops at scene, and transmits to Highway Patrol vehicle with CB
4.	CB→CB→HP	CB vehicle sees event, stops at scene, and relays to another citizen with CB, who transmits (moving) to Highway Patrol vehicle with CB
5.	CB→HPBS→HP	CB vehicle sees event, stops at scene, transmits to Highway Patrol base station, which dispatches Highway Patrol vehicle
6.	CB→CB→HPBS→HP	CB vehicle sees event, stops at scene, and relays to another citizen with CB, who transmits (moving) to Highway Patrol base station, which dispatches Highway Patrol vehicle
7.	CB→CBBS→HPBS→HP	CB vehicle sees event, stops at scene and transmits to CB base station, which calls Highway Patrol base station, which dispatches Highway Patrol vehicle
8.	CB→CB→CBBS→HPBS→HP	CB vehicle sees event, stops at scene, and relays to another citizen with CB, who transmits (moving) to CB base station, which calls Highway Patrol base station which dispatches Highway Patrol vehicle.

The conditions that determine whether such a vehicle will notify the patrol are based on the input probabilities for the particular run, as described above. The time to notification is the elapsed time from detection until a Highway Patrol unit or base station is informed of the accident. The time to response is the time from notification to the time a patrol unit is on the scene. Of course, the times to detection, notification, and response are the same if the first vehicle to detect the accident is a Highway Patrol unit.

Table 2 summarizes the output by link for a given parameter set and number of iterations. Note that for some of the output, the CB relay modes are combined with their non-relay counterparts.

3. Output Material

Output tables provide the average time computed for three discrete time intervals: Accident to Detection, Detection to Notification, and Notification to Response. Tables 3 and 4 are examples of these tables. They are the result of simulating 1,000 accidents using data derived to reflect standard conditions in a CB demonstration project. Parameters used for these tables are given in Table 5.

Table 3 presents mean times in the Experimental Area for five different possible composite communication links (relay links not treated separately), and Table 4 presents mean times in the Control Area for three possible composite communication links. The best of all possible times (all links) for the links in the experimental area and control area are given separately. In the tables the first column is Accident to Detection; the second, Detection to Notification; the third, Notification to Response; and the last, Accident to Response or Total.

Looking at Table 3, one notes that the mean detection time for the Highway Patrol alone is 18.53 minutes, and that this is also the mean total time, since for this response mode the notification and response times

Table 2

SUMMARY OF CITIZENS BAND RADIO OUTPUT

Output Data	Links Studied
Experimental area	
Average times for ● Detection ● Notification ● Response	1, 2, 3 and 4 combined, 5 and 6 combined, 7 and 8 combined
Percentage of events that the link had shortest time to ● Notification ● Response	1, 2, 3, 4, 5, 6, 7, 8
Control area	
Average times for ● Detection ● Notification ● Response	1, 2, 7 and 8 combined
Percentage of events that the link had shortest time to ● Notification ● Response	1, 2, 7, 8

Table 3

EXAMPLE AVERAGE TIMES FOR THE EXPERIMENTAL AREA

	Average Times			
Communication Link	Accident to Detection	Detection to Notification	Notification to Response	Total
Highway Patrol (HP) alone	18.53	0.0	0.0	18.53
Citizen phone to HP base	0.11	10.00	6.91	17.02
CB radio to HP unit	0.28	6.11	2.52	12.74
CB radio to HP base	0.28	21.31	6.71	28.30
CB radio to CB base, phone to HP base	0.28	22.23	6.83	29.35
Best of all possible times				9.77

Table 4

EXAMPLE AVERAGE TIMES FOR THE CONTROL AREA

	Average Times			
Communication Link	Accident to Detection	Detection to Notification	Notification to Response	Total
Highway Patrol (HP) alone	18.53	0.0	0.0	18.53
Citizen phone to HP base	0.11	10.00	6.91	17.02
CB radio to CB base, phone to HP base	0.28	22.23	6.83	29.35
Best of all possible times				12.59

Table 5

PARAMETERS FOR EXAMPLE

Roadway

Length: 100 miles
Speed of traffic: 55 m.p.h.
Traffic volume: 1,000 vehicles/hour
Percent vehicles with CB: 10%

Ranges

CB mobile unit: 4 mile radius
Base station: 10 mile radius

Highway Patrol Units

Number of units: 4
Equal spacing tolerance: - 10 miles
Emergency speed: 80 m.p.h.

Highway Patrol Base Station

Location: 33 miles along the road
Dispatch time to mobile units: 0.5 minute

CB Base Station

Location: 67 miles along the road, 1 mile off of road
Time to phone Highway Patrol base station: 1 minute

Citizens (no CB unit in Vehicle):

Probability of reporting to Highway Patrol: .25
Time to phone Highway Patrol: 10 minutes

CB Mobile Unit

Transmission time: .1 minute

are zero. Further examination shows that, on the average, the "citizen phone to HP base" link had the shortest detection time, but a lengthy notification time, reflecting the time required to reach a telephone. The "CB radio to HP unit" link has the lowest detection plus notification time, .28 plus 6.11 minutes. It is important to note that an iteration is not complete until every link has independently completed its sequence. Therefore, for the given situation, these times may be fairly compared, link to link.

For comparison between experimental and control areas the "best of all possible times" may be examined. This is simply the mean, over all the accidents, of the lowest times for each accident (any link). In general, the link having the lowest times is different for each accident. Comparing the best of all possible times on Table 3 and 4, one notes that for this situation, response time has improved from 12.59 minutes (control) to 9.77 minutes (experimental). This improvement is solely related to the addition of CB in Highway Patrol vehicles and in the Highway Patrol base station. The amount of improvement depends, of course, on the input parameters, especially Highway Patrol unit density, CB density, and traffic volume.

Another type of table presents the percentage of accidents for which a communication link had minimum time. This is displayed for two cumulative time periods: from Accident Occurrence to Notification (denoted by Notification) and the total time; from Accident Occurrence to Response (denoted by Response). Tables 6 and 7 are examples of this type of table using the same parameters. Table 6 is for the experimental area with eight possible communication links and Table 7 is for the control area with four possible communication links. There are more links considered for these tables because the relay modes are treated separately. The percentages reflect the frequency of link minimum times, i.e. (the number of accidents where a particular link had minimum time ÷ the number of iterations) x 100%.

These tables are most easily understood by example. In the experimental area, for example, it can be seen that in 4.2 of the simulated accidents, the Highway Patrol unit arrived on the scene before any other links

Table 6

EXAMPLE MINIMUM TIMES IN THE EXPERIMENTAL AREA

Communication Link	Percentage of Accidents for Which Link Had Minimum Time To Notification	 To Response
HP alone	4.2	4.2
Citizen phone to HP base	6.2	5.9
CB radio direct to HP unit	29.6	29.7
CB radio to HP base	13.8	13.7
CB radio to CB base, phone to HP base	12.4	11.1
CB radio relay to HP unit	18.2	20.5
CB radio relay to HP base	7.9	7.5
CB radio relay to CB base, phone to HP	7.7	7.4

Table 7

EXAMPLE MINIMUM TIMES IN THE CONTROL AREA

Communication Link	Percentage of Accidents for Which Link Had Minimum Time To Notification	 To Response
HP alone	26.4	28.4
Citizen phone to HP base	43.2	42.1
CB radio to CB base, phone to HP base	16.8	16.2
CB radio relay to CB base, phone to HP	13.6	13.3

could complete the reporting, and in 29.6 of the accidents, the accident was reported first by a CB unit radioing directly to a Highway Patrol unit. Considering the last six CB links to Highway Patrol units, we see that in a total of 60 percent of the accidents, a CB unit to a Highway Patrol unit link resulted in the minimum detection plus notification time. Total time, detection to notification to response are also expressed in the columns to the right. These figures are easily compared to the control area where the number of possible communication links is smaller.

The last type of table available for one set of parameters presents the distribution of times for the best of all possible times in both the experimental and control area. Table 8 is an example of such a table, again using the same parameters.

This table shows, for example, that in the experimental area the detection plus notification time was less than 5 minutes in 73.1 percent of the accidents, compared to 39.27 in the control area. In the control area, total response time exceeded 10 minutes in 62.4 percent of the accidents, but this is improved to 45.1 percent in the experimental area.

B. Simulation of Non-accident Events

Since the nature and urgency of response for non-accident events would, in most cases, differ from that for accidents, two separate versions of the model have been made available for non-accident events--one for moving events and one for non-moving events.

1. Fixed Events

For fixed events, the output tables are the same as for accidents except that no relay links are used, because of the nature of the event. For accidents, the first CB vehicle on scene stops; for fixed event they do not. HP units dispatched to the scene or otherwise notified of a fixed event proceed to the scene at regular speed, without using emergency speed.

Table 8

EXAMPLE DISTRIBUTION OF TIMES (BEST OF ALL POSSIBLE) IN THE EXPERIMENTAL AND CONTROL AREAS

	Distribution of Times			
	Experimental Area		Control Area	
Times (minutes)	To Notification (percent)	To Response (percent)	To Notification (percent)	To Response (percent)
From 0.0 to 5.0	73.1	32.8	39.2	19.2
From 5.0 to 10.0	15.5	22.1	17.2	18.4
From 10.0 to 15.0	6.4	21.1	43.6	24.5
From 15.0 to 20.0	0.0	16.1	0.0	20.4
From 20.0 to 25.0	0.0	5.3	0.0	14.2
From 25.0	0.0	2.1	0.0	3.3
	100.0%	100.0%	100.0%	100.0%

Emergency speed is used to get to an accident or apprehend a speeder. All vehicles--CB, citizen or HP--have a probability of reporting a fixed event. This probability may be adjusted according to the particular fixed event being simulated.

2. Moving Events

The output tables shown for accidents apply to moving, i.e., speeding, events with an additional table for speeders who are not apprehended. While the basic concept of moving events is similar to fixed events, the fact that the event is moving along the roadway allows for escape. In addition, a speeder is permitted to slow down with a certain probability, when in full view of an HP vehicle, resulting in no apprehension. Mean times and minimum times are computed as for other types of events but are, naturally, based only on events in which apprehension occurred.

The apprehension procedure for speeders is proposed as a reasonable one. If an HP unit is a parameter-specified distance behind the speeder, traveling in the same direction, the unit will pursue the speeder, who will possibly escape. If a speeder passes the HP unit, and does not slow down, the HP unit is assumed to apprehend. If an HP unit observes a speeder going in the opposite direction, other HP units going in the same direction as the speeder will be alerted. If an HP unit is behind the speeder, within the specified distance, this unit will pursue the speeder. An HP unit ahead of the speeder will also be alerted. If this unit is a parameter-specified distance away, the unit will pull off the road and wait for the speeder, then apprehend. The apprehension procedure applies when HP units have been notified by a CB mobile unit or the HP base station, as well as another HP mobile unit.

III INTERACTIVE USE OF THE MODEL

This section serves as an elementary user's guide. It describes the steps involved in accessing the CB simulation model, the data input for the model, and model output. This section proceeds in order, according to the interactive conversation which would appear to the user sitting at a terminal.

A. Accessing the CB Simulation Model

The user first logs onto the computer and calls the DEMON program (see Volume I, Section IV).

```
IKJ54012A ENTER LOGON -
LOGON 'account initials/terminal-id/box number'
KEYWORD? [redacted]
WCUSTMK LOGON IN PROGRESS AT 08:28:53 ON MAY 9, 1977
   ****** DCRT TSO ******
TSO LINE 166
READY
EX DEMON2
```

The following conversation allows entrance to the CB model:

```
WELCOME TO DEMON

DO YOU WANT TO USE THE CITIZENS BAND RADIO SIMULATION MODEL?
..
Y
```

B. Data Input Required for Accident Simulation

The CB model simulates three types of events: accidents; fixed, non-accident events; or moving, non-accident events. The data input varies according to type of event. So, the user must first specify the type of event desired to be simulated.

```
CITIZENS BAND RADIO SIMULATION MODEL

WHAT TYPE OF EVENT DO YOU WANT TO SIMULATE:
1.  ACCIDENTS
2.  FIXED,NON-ACCIDENT EVENTS
3.  MOVING,NON-ACCIDENT EVENTS

ENTER NUMBER FOR DESIRED TYPE OF EVENT
..
1
```

The response "1" indicates that accidents are to be simulated.

1. Base Parameters

Seventeen base parameters are used for simulating all three event types. They are divided into the following seven categories:

```
1.  ROAD
2.  HIGHWAY PATROL UNITS
3.  HIGHWAY PATROL BASE STATION
4.  CITIZEN BAND MOBILE UNIDS
5.  CITIZEN BAND BASE STATIONS
6.  CITIZEN
7.  RANGES
```

After identifying the seven categories of base parameters, the user is requested, in sequence, to specify each of the 17 parameters. Values specified here are those described in Section II.

a. Road Parameters

There are three road parameters to be specified.

```
1.  ROAD PARAMETERS

WHAT IS THE LENGTH OF THE ROAD (IN MILES)?
..
100

WHAT IS THE AVERAGE SPEED ON THE ROAD (IN MILES PER HOUR)?
..
55

WHAT IS THE ONE-WAY TRAFFIC VOLUME (IN VEHICLES/HOUR)?
..
1000
```

Each question will identify the units of measurement needed. For example, the road length is to be in miles. The user inputs the number desired and hits the carriage return which signals the computer that input is complete. There are built-in checks for data limits, and error messages will indicate if the input data are incorrect. For example, road length cannot be zero. If incorrect data are input, the question will be asked again, after the message.

b. Highway Patrol Units Parameters

Next, the user will be requested to specify two HP unit parameters.

```
2.   HIGHWAY PATROL UNITS PARAMETERS

HOW MANY HIGHWAY PATROL UNITS ARE ON THE ROAD?
..
4

WHAT IS THE TOLERANCE ON SPACING OF HIGHWAY PATROL UNITS (IN MILES)?
..
10
```

First, the user is asked to specify how many Highway Patrol mobile units are on the road. There should be at least one. Next, the user is asked to specify the spacing tolerance for the Highway Patrol mobile units. The spacing of the units is assumed to be uniformly distributed about equidistant points, e.g., if there are four units on a 100-mile road, the units are first placed 25 miles apart, then, for a specified 10-mile spacing tolerance, the units are moved to be 25 miles apart plus or minus up to 10 miles, and thus, they can be from 5 to 45 miles apart.

c. Highway Patrol Base Station Parameters

Next, the user will be requested to specify two Highway Patrol base station parameters. There is assumed to be one Highway

Patrol base station on the road, and the user is first asked to specify its location. To simplify this, an example is first given for the data expected. A reply of "Y" for "YES" indicates that the user would like to see the example. An "N" response for "NO" would bypass the example.

```
3.   HIGHWAY PATROL BASE STATION

NEXT, YOU MUST SPECIFY THE LOCATION OF THE HIGHWAY PATROL BASE

DO YOU WANT TO SEE AN EXAMPLE OF HOW TO INPUT COORDINATES
OF THE BASE STATIONS?
..
Y



                       EXAMPLE LOCATION OF A BASE STATION

                              (4 MILES ALONG ROAD,
                           3 MILES FROM CENTER LINE)



                         --
                         -
                         --
                         -
                         --
                         -
                         --      .(4,3)
                         -
                         --
                         -
                         --
                         -                                   ROAD
                         0-I-I-I-I-I-I-I-I-I-I-I-I-I-I-I    LENGTH
                                    CENTER LINE
```

As can be seen from the example above, two coordinates are expected. The first coordinate identifies the number of miles from the start of the road to the base station, and the second coordinate identifies the number of miles from the center line of the road. In the example, the base station is four miles from the start of the road and three miles to the side of the road. The two coordinates must be input in series, separated by a comma. After the example is given, the user is asked to input the desired coordinates for base station location. The input given here shows a base station location of 33 miles along the road and on the immediate roadside:

```
WHAT ARE THE COORDINATES OF THE HIGHWAY PATROL BASE STATION?
..
33,0
```

If the user inputs a negative number for the second coordinate, this means that there is no HP base station. This will also suppress occurrence of the communication link involving the CB vehicle transmitting to the HP base station. For the experimental area, the HP base station is also a CB receiving station in that it can receive CB messages from CB vehicles.

The second data item requested for the Highway Patrol base station is the time involved for the dispatcher to contact a mobile unit via normal radio transmission. The range of the police radio covers the total length of the highway.

```
WHAT IS THE TIME REQUIRED FOR THE HIGHWAY PATROL DISPATCHER TO SEND
A MESSAGE TO A HIGHWAY PATROL UNIT (IN MINUTES)?
..
.5
```

d. Citizen Band Mobile Units Parameters

Next, the user is requested to specify two CB mobile unit parameters.

```
4.  CITIZEN BAND MOBILE UNITS PARAMETERS

WHAT IS THE PROBABILITY THAT A VEHICLE WILL HAVE A CB RADIO?
..
.1

WHAT IS THE AVERAGE TIME TO SEND A CITIZENS BAND MESSAGE (IN MINUTES)?
..
1
```

First, the user must specify the proportion of vehicles on the road with CB radios in terms of a probability (S1). In the example given, 10 percent of the vehicles on the road have CB radios, or a probability of .10. The second parameter specifies the time for a CB mobile unit to transmit a CB message.

e. Citizen Band Base Station Parameters

Next, the user is requested to specify three CB base station parameters.

```
5.  CITIZENS BAND BASE STATIONS PARAMETERS

HOW MANY CITIZENS BAND BASE STATIONS ARE ON THE ROAD?
..
1

WHAT ARE THE COORDINATES OF CITIZENS BAND BASE STATION NUMBER    1 ?
..
67.1

WHAT IS THE AVERAGE TIME FOR THE CITIZENS BAND BASE STATION OPERATOR
TO CALL THE HIGHWAY PATROL BASE STATION BY PHONE (IN MINUTES)?
..
1
```

Although there is assumed to be only one Highway Patrol base station on the road, there may be more than one Citizens Band base station. The user is first asked to specify the number of CB base stations on the road and then is asked for their locations. If the user inputs zero CB base stations, this will suppress all link occurrences involving CB base stations. Finally, the average time required for the CB base station operator to phone the HP base station must be specified.

f. Citizen Parameters

One citizen parameter must be specified.

```
6.  CITIZEN PARAMETERS

WHAT TIME IS REQUIRED FOR A CITIZEN TO PHONE IN AN EMERGENCY (IN MINUTES)?
..
10
```

g. Range Parameters

Two range parameters must be specified.

```
7.  RANGE PARAMETERS

WHAT IS THE RANGE OF THE CITIZENS BAND MOBILE UNITS (IN MILES)?
..
4

WHAT IS THE RANGE OF THE BASE STATIONS (IN MILES)?
..
10
```

The first range value to be specified is the receiving range of the CB mobile unit in miles. This number is the radius. The Highway Patrol unit CB range is assumed to be the same as that of the citizen vehicle CB unit.

Next, the user is asked to specify the range (receiving) of the base stations in miles. This range is used for both the CB and HP base stations. Once again, this number represents a radius.

This completes the data input required for the base parameters. Next, there are parameters which are specific to the type of event. Since accidents were requested at the beginning of the input sequence, the model would now proceed to special parameters for accidents.

2. Accident Parameters

In addition to the base parameters, two additional parameters must be specified for accidents.

```
TWO ADDITIONAL PARAMETERS MUST BE SPECIFIED FOR ACCIDENTS

WHAT IS THE AVERAGE EMERGENCY SPEED OF THE HIGHWAY PATROL UNITS
(IN MILES/HOUR)?
..
30

WHAT IS THE PROBABILITY THAT A CITIZEN WILL REPORT AN EMERGENCY TO THE HIGHWAY
PATROL?
..
.25
```

It is assumed that once the Highway Patrol unit is informed of an accident, it will travel at an emergency speed to reach the scene of the accident. The user is asked to specify this average emergency speed. Finally, the probability that a citizen will report an emergency to the HP must be specified.

This completes all parameter specification for simulation of an accident event.

3. Additional User-Supplied Information

Three additional questions are asked of the user before the output.

First, the user is given a chance to go back and make changes in any parameters desired.

In the example below, first the user is showsn the base parameter categories and asked to enter the number for the parameter type to be changed. An asterisk in response signals that the user does not want to change any parameter values.

```
DO YOU WANT TO CHANGE ANY OF THE PARAMETERS?
..
Y

BASE PARAMETER TYPES:
1.   ROAD
2.   HIGHWAY PATROL UNITS
3.   HIGHWAY PATROL BASE STATION
4.   CITIZEN BAND MOBILE UNITS
5.   CITIZEN BAND BASE STATIONS
6.   CITIZEN
7.   RANGES

ENTER DESIRED PARAMETER TYPE
..
1
```

If a parameter type number had been indicated, the current values would be displayed followed by a sequence of questions, one for each parameter. An answer "Y", indicating a desire to change that parameter, is followed by a request for a new value. An answer of "N" ships to the next parameter.

The two additional parameters for accidents may now be changed in the same manner.

```
ADDITIONAL PARAMETERS TO CHANGE FOR ACCIDENTS

PARAMETER TYPES:
1.   EMERGENCY SPEED OF THE HIGHWAY PATROL
2.   THE PROBABILITY THAT A CITIZEN WILL REPORT AN EMERGENCY

ENTER DESIRED PARAMETER TYPE
..
◆
```

Next, the user is asked to declare the number of iterations to be performed. The example given shows 1000 iterations requested, which will simulate 1000 accident events.

```
HOW MANY ITERATIONS WOULD YOU LIKE TO PERFORM?
..
1000
```

Finally, there is an output table which gives a time distribution. The user is asked to select a time interval (in minutes) and the number of time intervals to be displayed. In the example given, the user is requesting 6 sets of 5-minute intervals:

```
ONE OF THE OUTPUT TABLES IS A DISTRIBUTION OF TIME FOR NOTIFICATION
AND RESPONSE.
WHAT TIME INTERVAL WOULD YOU LIKE TO USE IN THIS TABLE (IN MINUTES)?
HOW MANY SETS OF THIS TIME INTERVAL WOULD YOU LIKE TO SEE?
..
5,6
```

C. Citizens Band Output Tables for Accidents

Four types of output tables are available. Each is described below:

1. Average Times

First, the Average time (with standard deviation) is computed for three discrete time intervals: Accident to Detection, Detection to Notification, and Notification to Response. Detection is defined as the time at which a vehicle begins an action sequence (link). Notification refers to Highway Patrol awareness of the situation (mobile unit or base) and response means Highway Patrol unit on the scene. Two cumulative time intervals are output: Accident to Notification and then, total, Accident to Response. Tables are given for the Experimental Area for five different possible composite communication links and for the Control Area for three possible communication links. The best of all possible times for the links in the Experimental Area and Control Area are given separately. The tables follow. The first column is Accident to Detection; the second, Detection to Notification; the third, Accident to Detection to Notification; the fourth, Notification to Response; and last, Accident to Response or Total.

```
                              CITIZEN BAND OUTPUT

                               EXPERIMENTAL AREA

                                              AVERAGE TIMES (S.D.) TO
                                                        DET.
                                           DETEC-  NOTIFI-  AND
          COMMUNICATION LINK                TION   CATION   NOT.    RESPONSE   TOTAL

HIGHWAY PATROL (HP) ALONE                   13.53    0.0    13.53     0.0      13.53
                                          ( 13.0) ( 0.0) ( 13.0) (  0.0)  (  13.0)
CITIZEN PHONE TO HP BASE                    0.11   10.00   10.11     6.91     17.02
                                          (  0.1) ( 0.0) (  0.3) (  4.4)  (   4.4)
CB RADIO TO HP UNIT                         0.23    6.11    6.34     2.52     12.74
                                          (  0.3) ( 5.6) (  5.6) (  0.3)  (  10.1)
CB RADIO TO HP BASE                         0.28   21.31   21.59     6.71     28.30
                                          (  0.3) (13.3) ( 13.3) (  4.5)  (  19.3)
CB RADIO TO CB BASE,PHONE TO HP BASE        0.23   22.23   22.52     6.33     29.35
                                          (  0.3) (13.3) ( 13.3) (  4.4)  (  19.2)
BEST OF ALL POSSIBLE TIMES                  0.07    0.0     3.21     0.0       9.77
                                          (  0.1) ( 0.0) (  2.3) (  0.0)  (   6.7)
```

CONTROL AREA

COMMUNICATION LINK	AVERAGE TIMES (S.D.) TO DETEC- TION	 NOTIFI- CATION	 DET. AND NOT.	 RESPONSE	 TOTAL
HIGHWAY PATROL (HP) ALONE	13.53	0.0	13.53	0.0	13.53
	(13.0)	(0.0)	(13.0)	(0.0)	(13.0)
CITIZEN PHONE TO HP BASE	0.11	10.00	10.11	6.91	17.02
	(0.1)	(0.0)	(0.2)	(4.4)	(4.4)
CB RADIO TO CB BASE,PHONE TO HP BASE	0.29	22.23	22.52	6.33	28.85
	(0.3)	(18.3)	(18.3)	(4.4)	(19.2)
BEST OF ALL POSSIBLE TIMES	0.07	0.0	6.63	0.0	12.53
	(0.1)	(0.0)	(3.5)	(0.0)	(7.1)

2. <u>Minimum Times</u>

The next type of table presents the percent of accidents for which a (communication) link had minimum time. This is displayed for two cumulative time periods: from Accident occurrence to Notification (denoted by Notification); from Accident occurrence to Response, or Total (denoted by Response). The first table is for the Experimental Area with eight possible communication links and the second table is for the Control Area with four possible communication links. The percentages reflect the frequency of link minimum times, i.e. (the number of accidents where a particular link had minimum time - the number of iterations) x 100 percent.

EXPERIMENTAL AREA

COMMUNICATION LINK	% OF ACCIDENTS FOR WHICH LINK HAD MINIMUM TIME TO NOTIFICATION	 RESPONSE
HP ALONE	4.2%	4.2%
CITIZEN PHONE TO HP BASE	6.2%	5.9%
CB RADIO DIRECT TO HP UNIT IN RANGE	29.6%	29.7%
CB RADIO TO HP BASE	13.3%	13.7%
CB RADIO TO CB BASE, PHONE TO HP BASE	12.4%	11.1%
CB RADIO RELAY TO HP UNIT	19.3%	20.5%
CB RADIO RELAY TO HP BASE	7.9%	7.5%
CB RADIO RELAY TO CB BASE, PHONE TO HP	7.1%	7.4%

```
                              CONTROL AREA

                                               % OF ACCIDENTS FOR WHICH
                                               LINK HAD MINIMUM TIME TO

              COMMUNICATION LINK               NOTIFICATION     RESPONSE

HP ALONE                                            26.4%          28.4%
CITIZEN PHONE TO HP BASE                            43.2%          42.1%
CB RADIO TO CB BASE, PHONE TO HP BASE               16.3%          16.2%
CB RADIO RELAY TO CB BASE, PHONE TO HP              13.6%          13.3%
```

3. Distribution of Times

The next type of table is the distribution of times for the best of all possible times in both the experimental and control area. This table format is user specified. In this case, 6 sets of 5-minute intervals were requested.

```
                                   DISTRIBUTION OF TIMES
                        EXPERIMENTAL AREA                CONTROL AREA
                           TO            TO             TO            TO
      MINUTES         NOTIFICATION    RESPONSE     NOTIFICATION    RESPONSE
                           %             %              %             %

FROM  0.0 TO  5.0         78.1          32.3           39.2          19.2
FROM  5.0 TO 10.0         15.5          22.1           17.2          13.4
FROM 10.0 TO 15.0          6.4          21.1           43.6          24.5
FROM 15.0 TO 20.0          0.0          16.1            0.0          20.4
FROM 20.0 TO 25.0          0.0           5.3            0.0          14.2
FROM 25.0                  0.0           2.1            0.0           8.3
```

4. Table of Parameters

The final type of output table is the table of parameters. The user may elect not to see this table, as it is simply a recapitulation of the parameters originally input.

```
                         TABLE OF BASE PARAMETERS

ROAD                                     CITIZEN

LENGTH:    100.0 MILES                   PHONE TIME:    10.00 MINUTES
SPEED:    55.00 MPH
TRAFFIC VOLUME:     1000.00 VPH
```

```
HIGHWAY PATROL UNITS                         HIGHWAY PATROL BASE STATION

NO. OF HP UNITS:      4                      COORDINATES:    33.00,   0.0
SPACING TOLERANCE:    10.00 MILES            HP DISPATCH TIME:    0.50 MINUTES


CITIZENS BAND MOBILE UNITS                   CITIZENS BAND BASE STATIONS

PROBABILITY VEH. WITH CB:    0.10            NO. OF BASE STATIONS:     1
CB DISPATCH TIME:    1.00 MINUTES            PHONE TIME:    1.00 MINUTES
                                             COORDINATES (  1):    67.00,   1.00


RANGES

CB MOBILE UNIT RANGE:     4.0
BASE STATION RANGE:    10.0



                       ADDITIONAL PARAMETERS FOR ACCIDENTS


 PROBABILITY CITIZEN REPORTS TO HIGHWAY PATROL:                        0.250
 EMERGENCY SPEED OF HIGHWAY PATROL:                                   90.00


 NUMBER OF ACCIDENTS SIMULATED:    1000
```

D. Final Options in CB Simulation

After all output tables have been produced, the user has the following options:

```
RERUN CODES:
1 = CHANGE PARAMETERS
2 = CHANGE TYPE OF EVENT
3 = NUMBER OF ITERATIONS
4 = RETURN TO MAIN PROGRAM
CARRIAGE RETURN = END PROGRAM

ENTER RERUN CODE
..
2
```

A rerun Code of 1 allows the user to return to the CB simulation model with the same type of event to change the input parameters and provide new output. Rerun Code 2 allows the user to simulate a different type of event and change any of the base parameters, if desired. Rerun Code 3 allows the user to change the number of accidents iterations simulated, using the same data parameters. Rerun Code 4 allows the user to return to the DEMON main program and run a different demonstration project through the DEMON modeling system. Finally, if no number is entered and the carriage return is hit, the user leaves the DEMON model and may at this point logoff the computer.

A rerun Code of 2 shown denotes a change to other types of events. The variations from the previous interactive conversation for accidents are now discussed for fixed and moving non-accident events.

E. Variation for Fixed, Non-Accident Events

The second event type that the CB model simulates is fixed, non-accident events. This event type would include such things as stalled vehicles or a fallen tree.

The user may initially choose to simulate this event type, or, as in this example, after having run another simulation type (accidents), the user can use a rerun Code of 2 to choose another event type.

```
ENTER RERUN CODE
..
2


WHAT TYPE OF EVENT DO YOU WANT TO SIMULATE:
1.   ACCIDENTS
2.   FIXED,NON-ACCIDENT EVENTS
3.   MOVING,NON-ACCIDENT EVENTS

ENTER NUMBER FOR DESIRED TYPE OF EVENT
..
2
```

In this example, the base parameters have already been specified, so the user is simply asked to specify seven additional parameters needed to simulate fixed, non-accident events.

```
SEVEN ADDITIONAL PARAMETERS MUST BE SPECIFIED FOR FIXED, NON-ACCIDENT EVENTS
```

1. CB Parameters

There are three CB parameters that must be specified.

```
WHAT IS THE DISTANCE PAST THE SCENE OF AN EVENT THAT A CB OPERATOR
WILL TRANSMIT (IN MILES)?
..
5

WHAT IS THE PROBABILITY THAT A CB UNIT WILL REPORT AN EVENT ON THE
SAME SIDE OF THE ROAD?
..
.6

WHAT IS THE PROBABILITY THAT A CB UNIT WILL REPORT AN EVENT ON THE
OPPOSITE SIDE OF THE ROAD?
..
.4
```

2. Citizen Parameters

Two citizen probabilities must be specified.

```
WHAT IS THE PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON THE SAME
SIDE OF THE ROAD?
..
.15

WHAT IS THE PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON THE OPPOSITE
SIDE OF THE ROAD?
..
.05
```

3. Highway Patrol Parameters

Two HP probabilities must next be specified.

```
WHAT IS THE PROBABILITY THAT AN HP UNIT WILL SEE AN EVENT ON THE
SAME SIDE OF THE ROAD AND STOP?
..
.7

WHAT IS THE PROBABILITY THAT AN HP UNIT WILL SEE AN EVENT ON THE
OPPOSITE SIDE OF THE ROAD AND STOP?
..
.5
```

4. Additional User-Supplied Information

Two additional questions are asked of the user before output.

First, the user is given the chance to change the base parameters previously specified or the seven additional parameters for fixed, non-accident events.

```
DO YOU WANT TO CHANGE ANY OF THE PARAMETERS?
..
N
```

Finally, the user is asked to specify the number of iterations to be performed.

```
HOW MANY ITERATIONS WOULD YOU LIKE TO PERFORM?
..
1000
```

F. Citizens Band Output Tables for Fixed, Non-Accident Events

As with accident simulations, four types of output tables are available.

1. Average Time

The first table type is again the average time table for the same time intervals and the same five communication links for the experimental area and three communication links for the control area.

```
                              CITIZEN BAND OUTPUT


                              EXPERIMENTAL AREA

                                               AVERAGE TIMES (S.D.) TO
                                                         DET.
                                         DETEC-  NOTIFI-  AND
          COMMUNICATION LINK              TION   CATION   NOT.   RESPONSE  TOTAL

HIGHWAY PATROL (HP) ALONE                 33.45    0.0    33.45     0.0     33.45
                                        ( 28.6) (  0.0) ( 28.6) (   0.0) ( 28.6)
CITIZEN PHONE TO HP BASE                   0.31   10.00   10.31     9.95    20.25
                                        (  0.3) (  0.0) (  0.3) (   6.6) (  6.7)
CB RADIO TO HP UNIT                        9.03    1.57   12.55     4.19    16.74
                                        (  9.8) (  1.2) ( 11.2) (   3.5) ( 12.1)
CB RADIO TO HP BASE                        0.38    1.95    2.33     9.89    12.22
                                        (  1.0) (  1.6) (  2.0) (   5.9) (  6.4)
CB RADIO TO CB BASE,PHONE TO HP BASE       1.00    2.75    3.75    10.37    14.12

                                        (  1.1) (  1.5) (  1.9) (   6.7) (  7.2)
BEST OF ALL POSSIBLE TIMES                 0.24    0.0     4.38     0.0     13.73
                                        (  0.3) (  0.0) (  3.5) (   0.0) (  3.3)

                              CONTROL AREA

                                               AVERAGE TIMES (S.D.) TO
                                                         DET.
                                         DETEC-  NOTIFI-  AND
          COMMUNICATION LINK              TION   CATION   NOT.   RESPONSE  TOTAL

HIGHWAY PATROL (HP) ALONE                 33.45    0.0    33.45     0.0     33.45
                                        ( 28.6) (  0.0) ( 28.6) (   0.0) ( 28.6)
CITIZEN PHONE TO HP BASE                   0.31   10.00   10.31     9.95    20.25
                                        (  0.3) (  0.0) (  0.3) (   6.6) (  6.7)
CB RADIO TO CB BASE,PHONE TO HP BASE       1.00    2.75    3.75    10.37    14.12
                                        (  1.1) (  1.5) (  1.9) (   6.7) (  7.2)
BEST OF ALL POSSIBLE TIMES                 0.23    0.0     7.50     0.0     16.59
                                        (  0.3) (  0.0) (  3.5) (   0.0) (  3.7)
```

2. Minimum Time

The next two tables present the percent of accidents for which a communication link had minimum time. Unlike the similar tables for accident events, there are only five communication links for the experimental area and three for the control area. The communication links which included a CB radio relay are not used for fixed events. It has been assumed that a CB unit will not relay a message concerning stalled vehicles or other fixed, non-accident events where the urgency is not immediate.

EXPERIMENTAL AREA

COMMUNICATION LINK	% OF ACCIDENTS FOR WHICH LINK HAD MINIMUM TIME TO NOTIFICATION	RESPONSE
HP ALONE	2.9%	30.9%
CITIZEN PHONE TO HP BASE	18.9%	17.3%
CB RADIO DIRECT TO HP UNIT IN RANGE	36.7%	22.0%
CB RADIO TO HP BASE	21.3%	16.2%
CB RADIO TO CB BASE, PHONE TO HP BASE	20.2%	13.6%

CONTROL AREA

COMMUNICATION LINK	% OF ACCIDENTS FOR WHICH LINK HAD MINIMUM TIME TO NOTIFICATION	RESPONSE
HP ALONE	15.4%	41.2%
CITIZEN PHONE TO HP BASE	55.1%	38.9%
CB RADIO TO CB BASE, PHONE TO HP BASE	29.5%	19.9%

3. Distribution of Times

The next table is a distribution of times for the best of all possible times. This table is identical to that presented for accidents.

```
                                            DISTRIBUTION OF TIMES
                                 EXPERIMENTAL AREA            CONTROL AREA
                                  TO            TO             TO            TO
      MINUTES                NOTIFICATION   RESPONSE      NOTIFICATION   RESPONSE
                                  %             %              %             %

  FROM  0.0 TO  5.0              67.3          19.5           32.1           9.9
  FROM  5.0 TO 10.0              13.5          20.5           12.5          14.5
  FROM 10.0 TO 15.0              19.2          19.6           55.4          21.1
  FROM 15.0 TO 20.0               0.0          15.9            0.0          19.7
  FROM 20.0 TO 25.0               0.0          10.3            0.0          15.9
  FROM 25.0                       0.0          14.2            0.0          19.3
```

4. Table of Parameters

The final type of output table is the table of parameters. The user may elect not to see this table. The table of base parameters and a list of the seven additional parameters for fixed, non-accident events are presented.

```
DO YOU WANT TO SEE THE TABLE OF PARAMETERS USED IN THIS RUN?


                               TABLE OF BASE PARAMETERS


     ROAD                                      CITIZEN

     LENGTH:    100.0 MILES                    PHONE TIME:    10.00 MINUTES
     SPEED:    55.00 MPH
     TRAFFIC VOLUME:    1000.00 VPH


     HIGHWAY PATROL UNITS                      HIGHWAY PATROL BASE STATION

     NO. OF HP UNITS:     4                    COORDINATES:    33.00,  0.0
     TRACING TOLERANCE:   10.00 MILES          HP DISPATCH TIME:    0.50 MINUTES


     CITIZENS BAND MOBILE UNITS                CITIZENS BAND BASE STATIONS

     PROBABILITY VEH. WITH CB:    0.10         NO. OF BASE STATIONS:     1
     CB DISPATCH TIME:    1.00 MINUTES         PHONE TIME:    1.00 MINUTES
                                               COORDINATES (1):    [illegible].00,   1.00
```

```
RANGES

CB MOBILE UNIT RANGE:     4.0
BASE STATION RANGE:    10.0

            ADDITIONAL PARAMETERS FOR FIXED,NON-ACCIDENT EVENTS

PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON SAME SIDE:              0.150
PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON OPPOSITE SIDE:          0.050

DISTANCE PAST SCENE OF EVENT THAT CB UNIT WILL TRANSMIT:                   5.0
PROBABILITY THAT CB UNIT WILL REPORT AN EVENT ON SAME SIDE:                0.600
PROBABILITY THAT CB UNIT WILL REPORT AN EVENT ON OPPOSITE SIDE:            0.400

PROBABILITY THAT HP UNIT WILL REPORT AN EVENT ON SAME SIDE:                0.700
PROBABILITY THAT HP UNIT WILL REPORT AN EVENT ON OPPOSITE SIDE:            0.500

NUMBER OF ACCIDENTS SIMULATED:    1000
```

G. Variation for Moving, Non-Accident Events

The third event type that the CB model simulates is moving, non-accident events. This event type would include such things as speeders and reckless drivers.

The user may initially choose to simulate this event type; or, as in this example, use a rerun Code of 2 to change from fixed events to moving events.

```
RERUN CODES:
1 = CHANGE PARAMETERS

2 = CHANGE TYPE OF EVENT
3 = NUMBER OF ITERATIONS
4 = RETURN TO MAIN PROGRAM
CARRIAGE RETURN = END PROGRAM

ENTER RERUN CODE
..
2
```

```
WHAT TYPE OF EVENT DO YOU WANT TO SIMULATE:
1.   ACCIDENTS
2.   FIXED,NON-ACCIDENT EVENTS
3.   MOVING,NON-ACCIDENT EVENTS

ENTER NUMBER FOR DESIRED TYPE OF EVENT
..
3
```

Actually, accidents could also be reevaluated at this point.

In this example, the base parameters have already been specified, so the user is asked to specify the 11 additional parameters for moving, non-accident events.

```
FOR SIMULATION TYPE 3, THE FOLLOWING ADDITIONAL PARAMETERS MUST BE SPECIFIED
```

1. CB Parameters

There are three CB parameters that must be specified.

```
WHAT IS THE DISTANCE PAST THE SCENE OF AN EVENT THAT A CB OPERATOR
WILL TRANSMIT (IN MILES)?
..
5

WHAT IS THE PROBABILITY THAT A CB UNIT WILL REPORT AN EVENT ON THE
SAME SIDE OF THE ROAD?
..
.65

WHAT IS THE PROBABILITY THAT A CB UNIT WILL REPORT AN EVENT ON THE
OPPOSITE SIDE OF THE ROAD?
..
.3
```

2. Citizen Parameters

Two citizen probabilities must be specified.

```
WHAT IS THE PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON THE SAME
SIDE OF THE ROAD?
..
.075

WHAT IS THE PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON THE OPPOSITE
SIDE OF THE ROAD?
..
.05
```

3. Highway Patrol Parameters

Four HP parameters must be specified.

```
WHAT IS THE AVERAGE EMERGENCY SPEED OF THE HIGHWAY PATROL UNITS
(IN MILES/HOUR)?
..
80


WHAT IS THE PROBABILITY THAT A HP OFFICER WILL SEE A SPEEDER GOING
IN THE OPPOSITE DIRECTION?
..
.4


WHAT IS THE DISTANCE WITHIN WHICH THE HP OFFICER MUST BE BEHIND A
SPEEDER TO BE ABLE TO CATCH HIM (IN MILES)?
..
.5

WHAT IS THE DISTANCE A HP OFFICER MUST BE AHEAD OF A SPEEDER TO HAVE
TIME TO PULL OFF THE ROAD AND WAIT FOR THE SPEEDER (IN MILES)?
..
5
```

4. Speeder Parameters

Two parameters related to speeders must be specified.

```
WHAT IS THE PROBABILITY THAT A SPEEDER WILL SPEED BY AN HP OFFICER?
..
.1

WHAT IS THE SPEED OF THE SPEEDER (IN MILES/HOUR)?
..
70
```

5. Additional User-Supplied Information

Two additional questions are asked of the user before output.

The user may change any of the parameters.

```
DO YOU WANT TO CHANGE ANY OF THE PARAMETERS?
..
N
```

The user is asked to specify the number of iterations to be performed.

```
HOW MANY ITERATIONS WOULD YOU LIKE TO PERFORM?
..
1000
```

H. Citizens Band Output Tables for Moving, Non-Accident Events

There are five types of output tables for moving, non-accident events.

1. Average Times

The average time for moving, non-accident events has the same time intervals and communication links as for both accidents and fixed, non-accident events.

```
                    CITIZEN BAND OUTPUT



                     EXPERIMENTAL AREA
                                                AVERAGE TIMES (S.D.) TO
                                                                DET.
                                         DETEC-   NOTIFI-   AND
          COMMUNICATION LINK              TION    CATION    NOT.    RESPONSE   TOTAL

HIGHWAY PATROL (HP) ALONE                 23.48     0.0     23.48      0.0      23.48
                                        ( 17.9) (  0.0) ( 17.9) (    0.0) (  17.9)
CITIZEN PHONE TO HP BASE                  0.47    10.00    10.47     19.33     29.79
                                        (  0.5) (  0.0) (  0.5) (    9.9) (   9.9)
CB RADIO TO HP UNIT                       9.24     2.30    11.54     16.21     27.75
                                        (  8.6) (  1.6) (  8.8) (   14.1) (  13.3)
CB RADIO TO HP BASE                      17.78     4.21    21.99     14.04     36.03
                                        (  3.1) (  2.4) (  1.6) (   10.0) (  10.3)
CB RADIO TO CB BASE,PHONE TO HP BASE     47.05     5.20    52.24     16.74     68.98
                                        (  3.2) (  2.3) (  1.7) (   10.3) (  10.9)
BEST OF ALL POSSIBLE TIMES                0.45     0.75     7.51      2.71     17.35
                                        (  0.5) (  1.1) (  3.4) (    5.0) (   9.0)

                       CONTROL AREA

                                                AVERAGE TIMES (S.D.) TO

                                                                DET.
                                         DETEC-   NOTIFI-   AND
          COMMUNICATION LINK              TION    CATION    NOT.    RESPONSE   TOTAL

HIGHWAY PATROL (HP) ALONE                 23.48     0.0     23.48      0.0      23.48
                                        ( 17.9) (  0.0) ( 17.9) (    0.0) (  17.9)
CITIZEN PHONE TO HP BASE                  0.47    10.00    10.47     19.33     29.79
                                        (  0.5) (  0.0) (  0.5) (    9.9) (   9.9)
CB RADIO TO CB BASE,PHONE TO HP BASE     47.05     5.20    52.24     16.74     68.98
                                        (  3.2) (  2.3) (  1.7) (   10.3) (  10.9)
BEST OF ALL POSSIBLE TIMES                0.47     2.49     9.68      6.13     22.34
                                        (  0.5) (  3.1) (  2.2) (    9.1) (  11.9)
```

2. Minimum Times

These tables present the percent of accidents for which a communication link had minimum time. As with fixed, non-accident events, the number of communication links is less than with accident events. The CB relay links are not used.

```
                              EXPERIMENTAL AREA

                                                  % OF ACCIDENTS FOR WHICH
                                                  LINK HAD MINIMUM TIME TO

           COMMUNICATION LINK                     NOTIFICATION     RESPONSE

HP ALONE                                                 6.3%         33.9%
CITIZEN PHONE TO HP BASE                                44.7%         23.7%
CB RADIO DIRECT TO HP UNIT IN RANGE                     49.0%         29.2%

CB RADIO TO HP BASE                                      0.0%         13.2%
CB RADIO TO CB BASE, PHONE TO HP BASE                    0.0%          0.0%

                                CONTROL AREA

                                                  % OF ACCIDENTS FOR WHICH
                                                  LINK HAD MINIMUM TIME TO

           COMMUNICATION LINK                     NOTIFICATION     RESPONSE

HP ALONE                                                16.3%         37.3%
CITIZEN PHONE TO HP BASE                                83.7%         62.7%
CB RADIO TO CB BASE, PHONE TO HP BASE                    0.0%          0.0%
```

3. Apprehension Rate Table

This table is unique to moving, non-accident events. Based on the probabilities input and the dynamic situation created, this table presents the percentages of violators who were caught, who reduced their speed, or who escaped.

```
                                 APPREHENSION RATE
                                        CITIZENS BAND            CONTROL CASE
                                          PERCENT                  PERCENT
VIOLATORS CAUGHT                           99.4                     99.4
VIOLATORS SLOWED TO NORMAL SPEED            0.6                      0.6
VIOLATORS ESCAPED                           0.0                      0.0
```

In this case, the parameters were such that no violators escaped and less than 1 percent were able to slow down before being apprehended.

4. Distribution of Times

The next table is a distribution of times for the best of all possible times. This table has the same format as accidents and fixed, non-accident events.

```
                                         DISTRIBUTION OF TIMES
                            EXPERIMENTAL AREA                CONTROL AREA
                                TO             TO               TO             TO
       MINUTES             NOTIFICATION     RESPONSE       NOTIFICATION     RESPONSE
                                 %              %                %              %

FROM  0.0 TO  5.0              28.6            8.5              7.6            7.6
FROM  5.0 TO 10.0              23.2           12.2              7.4            7.4
FROM 10.0 TO 15.0              48.2           18.0             85.0            8.3
FROM 15.0 TO 20.0               0.0           23.1              0.0           21.3
FROM 20.0 TO 25.0               0.0           15.2              0.0           13.6
FROM 25.0                       0.0           23.0              0.0           40.3
```

5. Table of Parameters

The final option is to view the table of parameters used in the run. The user may elect to not see this table. The table of base parameters and a list of the eleven additional parameters for moving, non-accident events are presented.

```
DO YOU WANT TO SEE THE TABLE OF PARAMETERS USED IN THIS RUN?
Y
```

```
                              TABLE OF BASE PARAMETERS

     ROAD                                         CITIZEN

     LENGTH:    100.0 MILES                       PHONE TIME:    10.00 MINUTES
     SPEED:    55.00 MPH
     TRAFFIC VOLUME:     1000.00 VPH


     HIGHWAY PATROL UNITS                         HIGHWAY PATROL BASE STATION

     NO. OF HP UNITS:     4                       COORDINATES:    33.00,  0.0
     TRACKING TOLERANCE:    10.00 MILES           HP DISPATCH TIME:    0.50 MINUTES


     CITIZENS BAND MOBILE UNITS                   CITIZENS BAND BASE STATIONS

     PROBABILITY VEH. WITH CB:    0.10            NO. OF BASE STATIONS:     1
     CB DISPATCH TIME:    1.00 MINUTES            PHONE TIME:     1.00 MINUTES
                                                  COORDINATES (  1):    67.00,  1.00



     RANGES

     CB MOBILE UNIT RANGE:     4.0
     BASE STATION RANGE:    10.0
                ADDITIONAL PARAMETERS FOR MOVING,NON-ACCIDENT EVENTS

  PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON SAME SIDE:                 0.075
  PROBABILITY THAT A CITIZEN WILL REPORT AN EVENT ON OPPOSITE SIDE:             0.050


  DISTANCE PAST SCENE OF EVENT THAT CB UNIT WILL TRANSMIT:                      5.0
  PROBABILITY THAT CB UNIT WILL REPORT AN EVENT ON SAME SIDE:                   0.650
  PROBABILITY THAT CB UNIT WILL REPORT AN EVENT ON OPPOSITE SIDE:               0.300


  PROBABILITY THAT HP WILL SEE SPEEDER GOING IN OPPOSITE DIRECTION IS           0.400
  PROBABILITY THAT SPEEDER WILL SPEED BY HP OFFICER IS                          0.100
  SPEED OF SPEEDER IS                                                          70.0
  DISTANCE HP OFFICER MUST BE BEHIND SPEEDER IS                                 0.50
  DISTANCE HP OFFICER MUST BE AHEAD OF SPEEDER IS                               5.00
  EMERGENCY SPEED OF HIGHWAY PATROL IS                                         30.00


  NUMBER OF ACCIDENTS SIMULATED:    1000
```

I. Logoff Procedure

To terminate the session, the appropriate response to the request for a rerun code is a carriage return. This causes exit from the DEMON program. The user next responds by typing 'logoff'. The computer responds with charges.

```
RERUN CODES:
1 = CHANGE PARAMETERS
2 = CHANGE TYPE OF EVENT
3 = NUMBER OF ITERATIONS
4 = RETURN TO MAIN PROGRAM
CARRIAGE RETURN = END PROGRAM

ENTER RERUN CODE
. .

READY
LOGOFF
CHARGE =
CPU TIME =
ELAPSED TIME =
I/O COUNT =
REGION =
```

IV MATHEMATICAL ASSUMPTIONS AND PROGRAM DESCRIPTIONS

The principal CB subroutines are CBSTAT, an overall control program, ACCSIM (for accidents), EVTSIM (for fixed, non-accident events) and SPDSIM (for speeders). The user selects the number of events to be simulated, η, and this number is passed to CBSTAT which calls ACCSIM (or EVTSIM or SPDSIM, as the case may be) η times. For a given η, only one type of event--accidents, fixed events, speeders--may be simulated. Each time ACCSIM (EVTSIM, SPDSIM) is called, it simulates one event on the road segment and computes detection, notification and response times for several different modes of reporting. CBSTAT takes these computed times and calculates means for the various links, and probabilities that various links will have minimum detection time, notification time, etc. This function of CBSTAT will be explained in greater detail, following a detailed description of ACCSIM, EVTSIM and SPDSIM.

A. Simulation of an Accident (Subroutine ACCSIM)

Each time it is called, subroutine ACCSIM simulates an accident occurrence and the response of Highway Patrol units to the accident. Initial conditions and accident locations are governed by random variables, so they vary for each accident simulated.

The first function of ACCSIM is to set up initial conditions. These include the accident location, the location of Highway Patrol (HP) units on the road segment at the time of accident occurrence, and the location of other vehicles on the road, whose drivers will report the accident in various ways.

1. The Roadway, Location of an Accident

A two way roadway is mathematically defined as being of length ℓ, and is modeled as a loop of total length 2ℓ. Locations along the roadway are denoted by X. At either end of the roadway, locations are $X=o$ $(=2\ell$, because of the loop) or $X=\ell$. HP units continually loop around the roadway, but other vehicles enter at either $X=o$ or $X=\ell$ and leave the roadway at the other end.

An accident is placed randomly on the roadway, visible from both sides of the road. Figure 2 shows the accident and vehicles in one position. X_a denotes the accident location.

2. Location of HP Units

The HP units are assumed to circulate around the loop at a constant traffic speed, v, in miles per hour. The assumption used in spacing the HP units is that they are approximately evenly spaced around the loop. To derive the actual placement, the number of HP units, h, and a ± tolerance s are used. The first HP unit is placed randomly in the interval

$o<X<\frac{2\ell}{h}$. The distance between this and the second HP unit is computed as

$$D_2 = \frac{2\ell}{h} + s(1-2R)$$

where R is a random number between 0 and 1. The distance between the kth and (k-1)st HP unit is

$$D_1 = R\left(\frac{2\ell}{h}\right)$$

$$D_k = \frac{2\ell}{h} + ,k=1\ s(1-2R),\ k=2,\ 3,\ \ldots$$

where R would represent a new random digit for D_k (i.e., distinct from that used for $D_1, \ldots, D_{k-1}$).

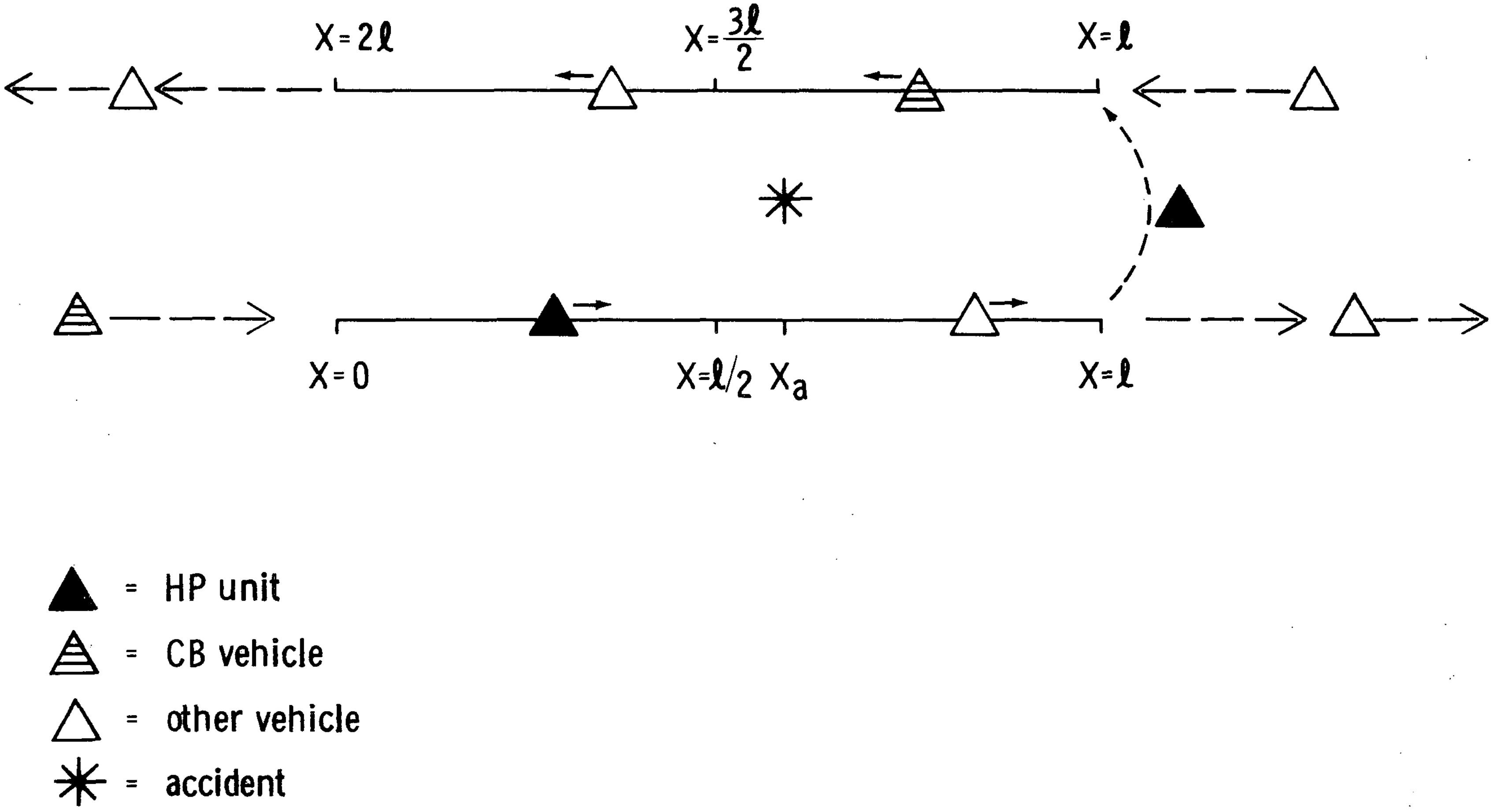


Figure 2 LOCATION OF ACCIDENT ON ROADWAY

3. Location of Other Vehicles

The roadway is assumed to have traffic volume m (vehicles per hour), with all vehicles traveling at constant speed v. The distance between the vehicles (excluding HP units) is assumed to be exponentially distributed. Vehicles are counted from the accident location point, and both directions along the roadway are counted separately.

In a given direction, the distance between any two vehicles, E, is computed according to

$$E = -\left(\frac{v}{m}\right) \ln(1-R),$$

where R is a random digit. This equation is derived from

$$R = 1-e^{-\left(\frac{m}{v}\right)E},$$

the uniform point on the cumulative exponential distribution.

A string of these distances in both directions are generated, each with a distinct value for R, denoted by $\overset{>}{E}_1$, $\overset{>}{E}_2$, ... and $\overset{<}{E}_1$, $\overset{<}{E}_2$, ... where

$\overset{>}{E}_1$ = distance from the accident to the first vehicle moving toward the accident from the left

$\overset{>}{E}_k$ = distance between the kth and (k-1)st vehicles moving toward the accident from the left k=2, 3,...

$\overset{<}{E}_1$ = distance from the accident to the first vehicle moving toward the accident from the right

$\overset{<}{E}_k$ = distance between the kth and (k-1)st vehicles moving toward the accident from the right, k=2, 3,...

The corresponding locations,

$\overset{>}{X}_1, \overset{>}{X}_2, \overset{>}{X}_3, \ldots$
$\overset{<}{X}_1, \overset{<}{X}_2, \overset{<}{X}_3, \ldots$

are computed as

$$\overset{>}{X}_1 = X_a - \overset{>}{E}_1$$
$$\overset{>}{X}_k = X_{k-1} - \overset{>}{E}_k,\ k-2,\ 3,\ldots$$
$$\overset{<}{X}_1 = 2\ell - X_a - \overset{<}{E}_1$$
$$\overset{<}{X}_k = X_{k-1} - \overset{<}{E}_k,\ k=2,\ 3,\ldots$$

These designations are assigned at the start of the simulation and are shown on Figure 3. Other vehicles shown are assumed to be incapable of acting so as to report the accident.

Similarly, computations may be made for the location of vehicles who have passed X_a before the accident occurred, but only one vehicle in each direction, the closest CB unit ahead of the accident, has usefulness for the model. These two CB units are potential relayers given that they are in range.

4. Identification of Reporting Vehicles

In each direction, four vehicles are identified as participants. Each vehicle has a probability of having a CB unit, p_c. As each of the vehicles in the string is assigned a distance from the previous one, a random number R is drawn. If this number is less than p_c, the vehicle is "tagged" as a CB unit. In ACCSIM, all CB units will respond to the event with probability one. This is not true in EVTSIM or SPDSIM.

In each direction the CB unit ahead of the accident and the two who will be approaching the accident are designated as participants. No other CB units will participate. If $R \geq p_c$, a vehicle has no CB unit, but these vehicles have a probability, p_r, of reporting the accident by phone. For these vehicles, another random number is generated. If this number is less than p_r, then the vehicle is designated as a reporting citizen, the fourth participant in each direction. No other vehicles will participate.

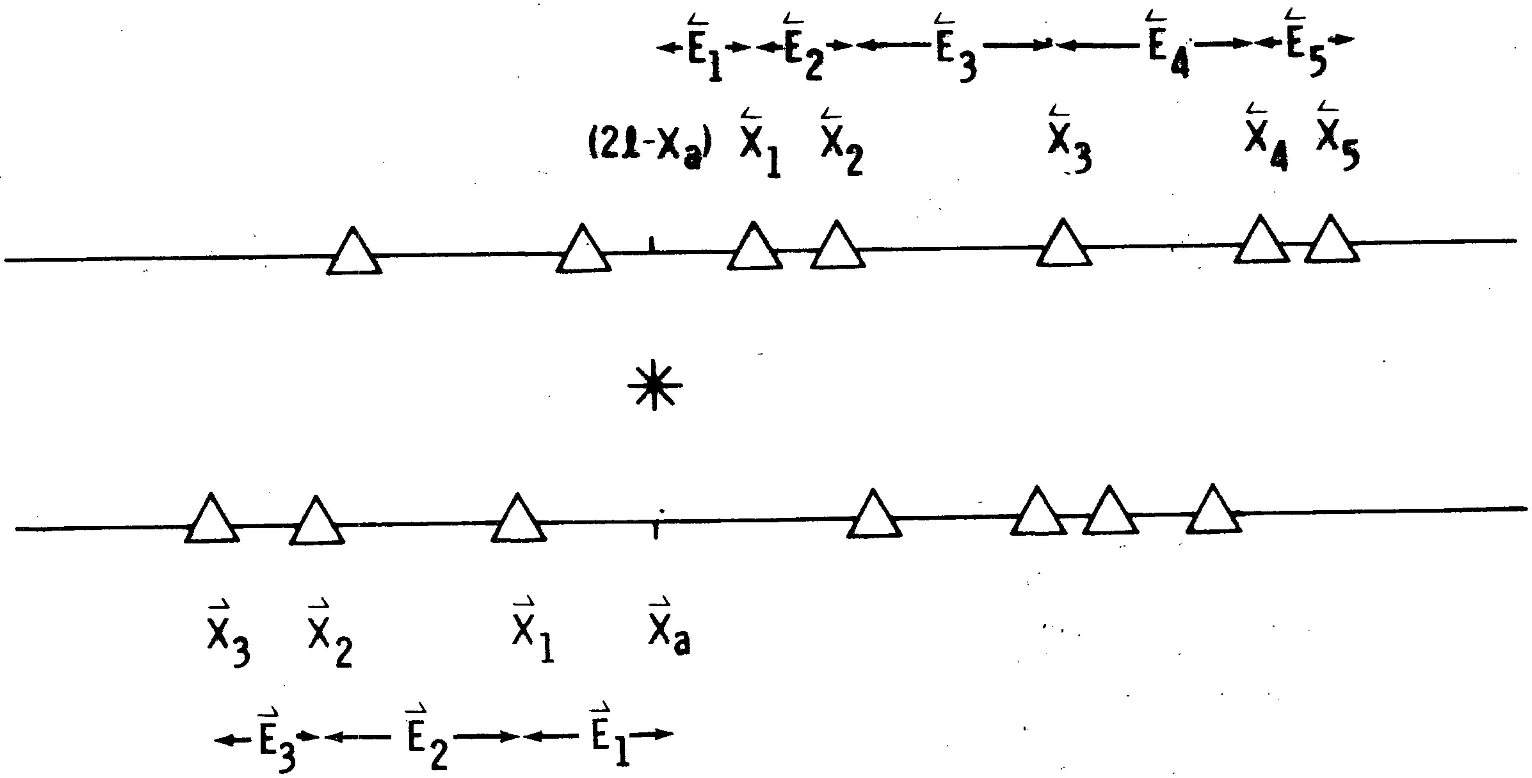


Figure 3 VEHICLES THAT MAY OBSERVE AN ACCIDENT

ACCSIM moves these eight vehicles along the road, along with all HP units, all at speed v. When notified, the HP units can increase speed to v_e, emergency speed. When the first CB unit approaches the accident in either direction, the driver will stop at the scene. Other CB units are relayers and will continue on with velocity v. The non-CB participant will continue at speed v and exit from the road at the next exit to phone the HP base station.

5. Communication Links

Given the CB and citizen vehicles and HP units described above, several links may occur. A link consists of a vehicle observing an event and notifying the authorities, and response to the event by the authorities. The links for accidents are:

- HP unit detects accident on patrol without the aid of others
- Citizen observes the accident, and reports to an HP base station
- CB vehicle reports accident to HP unit on patrol
- CB vehicle reports accident to HP base station
- CB vehicle relay to CB base station, relay to HP base station
- CB vehicle relay to another CB vehicle, relay to HP unit on patrol
- CB vehicle relay to another CB vehicle, relay to HP base station
- CB vehicle relay to another CB vehicle, relay to CB base station, relay to HP base station.

Each link ends with a patrol HP vehicle on scene, so either an HP unit was notified and proceeded to arrive on scene or radioed to a closer HP unit on patrol. The HP unit may have been notified by a CB unit or an HP base station.

a. HP Unit Detection Link (HP)

The location of all HP units approaching the accident from either direction is compared to the location of the accident. The closest HP unit is the one designated for computation of this link. Denote its distance from the accident as F^{o}_{HP}. The time of detection T_d, time from detection to notification, T_n, and time from notification to response, T_r are as follows:

$$T_d = \frac{F^{o}_{HP}}{v}$$

$$T_n = 0$$

$$T_r = 0$$

For this link, detection, notification and response occur simultaneously with the HP arrival on scene. The detection time is just the time it takes to approach the scene at regular speed and the additional time units are zero (notification and response instantaneously completed).

The time to notification is $T_d + T_n$ and the total time to complete the link is $T_d + T_n + T_r$. The model provides each time interval and the two cumulative times, for each link.

b. Citizen Phone to HP Base Station Link (CIT→HPBS→HP)

Let $\overrightarrow{F}^{o}_{CIT}$ denote the distance from the first non-CB equipped citizen vehicle approaching the accident from the left. Define $\overleftarrow{F}^{o}_{CIT}$ similarly, from the right. The detection time for this link will be the shorter of the two times to detect for each citizen, i.e., in each direction. The notification time for this link is a fixed input value, c, the time required to exit from the road, reach a phone and call the HP base station. Once notified, the HP base station has a fixed input time, d, to dispatch a unit to the scene. The dispatched unit is assumed to proceed to the scene at emergency speed and is the unit closest to the accident at the time of dispatch, t.$F_{HP}(t)$ is the distance from the accident to this nearest approaching HP unit at time t. (This differs from F_{HP}^{o}, the distance of the closest HP unit at the outset, prior to any link activity or movement of vehicles).

The detection, notification and response times for this link are:

$$T_d = \frac{\min\,(\overrightarrow{F}^{o}_{CIT}, \overleftarrow{F}^{o}_{CIT})}{v}$$

$$T_n = c$$

$$T_r = d + \frac{F_{HP}(t)}{v_e}$$

c. <u>CB unit to HP Unit Link (CB→HP)</u>

In this link the first CB unit approaching the accident from the left, $\overrightarrow{F}^{o}_{CB}$ and the one from the right, $\overleftarrow{F}^{o}_{CB}$ are considered. Whoever arrives first, is assumed to stop at the accident site and start transmitting the emergency message about the accident. It is assumed that a time, w, is required before actual transmittal occurs. The distance from the accident to the closest approaching HP unit at the time transmittal starts, t, is denoted by $F_{HP}(t)$ for this link. When this unit comes within range of the CB unit, the HP unit increased "instantaneously" to emergency speed. The range of the CB mobile unit is assumed to be a fixed value, y_m (one way).

The detection, notification and response times for this link are:

$$T_d = \frac{\min\,(\overrightarrow{F}^{o}_{CB}, \overleftarrow{F}^{o}_{CB})}{v}$$

$$T_n = \frac{\max\,(F_{HP}(t)-y_m,\ 0)}{v}$$

$$T_r = \frac{\min\,(F_{HP}(t),\ y_m)}{v_e}$$

If an HP unit can be on scene faster by the addition of a CB relaying vehicle, the link, described in f below, will be assumed to occur rather than the one described here.

d. CB Unit to HP Base Station Link (CB→HPBS→HP)

Since the first CB unit ($\overset{\geq}{F}{}^{o}_{CB}$ or $\overset{\leq}{F}{}^{o}_{CB}$) stops at the scene of the accident, there is a possibility for the HP base station to receive the stopped CB units' message, given that the accident was within the base station range (HP and CB base stations are assumed to have the same receiving range, y_b). Since the HP base station has a fixed input location, this possibility depends on the random location of the accident in each iteration. If the user does not wish to use this link, this may be achieved by setting the HP base station location to a specified value. If this link is desired, it may or may not occur for a given accident, depending on accident location. If it does not occur for an accident (i.e., the HP base station is not within range of the accident), then the corresponding relay link will occur. This is because a relaying CB vehicle will eventually reach the HP base station. The relay link is discussed in f, below.

Assuming that the accident is within range of the HP base station, the link mechanism is quite simple. As soon as the message is complete, taking time w, the HP base station is notified and selects the closest HP unit, to arrive on scene taking time, d, to dispatch. The distance from the closest one will, at time t, be $F_{HP}(t)$, where t is the time for the CB unit to arrive plus w. The time equations are:

$$T_d = \frac{\min\,(\overset{\geq}{F}{}^{o}_{CB}, \overset{\leq}{F}{}^{o}_{CB})}{v}$$

$$T_n = w$$

$$T_r = d + \frac{F_{HP}(t)}{v_e}$$

e. CB Unit to CB Base Station, Phone to HP Base Station Link (CB→CBBS→HPBS→HP)

Another link is one similar to d. except that the CB unit transmits to one of the CB base stations, which, in turn, phones the message to the HP base station; the time for the phone call is u. As in d, above, this link is possible only if the accident, and, thus, the first CB unit, is within the receiving range of the CB base station. If range constraints prohibit the execution of this link, the corresponding relay link will occur, in its place. If the user does not wish to use this link, this may be achieved by setting the number of CB base station locations to zero. Also, if the base station locations are outside of the receiving range from the highway, the link cannot occur.

Should this link occur, the equations for detection, notification and response time are:

$$T_d = \min(\overset{>}{F}{}^{o}_{CB}, \overset{<}{F}{}^{o}_{CB})$$

$$T_n = w + u$$

$$T_r = d + \frac{F_{HP}(t)}{v_e}$$

f. Links Involving CB Relay

The three remaining links considered are elaborations of c, d, and e. In these links, the accident message is transmitted by the CB unit on scene to two other secondary relaying CB units, located at $\overset{>}{S}_{CB}(t)$ and $\overset{<}{S}_{CB}(t)$, one traveling in each direction. $\overset{>}{S}_{CB}(t)$ specifically denotes the next CB unit approaching the accident from the left at time t, when the stopped CB unit has transmitted the first emergency message; $\overset{<}{S}_{CB}(t)$ is defined similarly. These two units continue moving and eventually transmit to an HP unit, HP base station (if in range) and a CB base station (if one is in range). If the corresponding links c, d, or e occurred without relay, then the corresponding relay link is <u>not</u> required, and thus, <u>not</u> computed.

To visualize the selection of vehicles located at $\overset{>}{S}_{CB}(t)$ and $\overset{<}{S}_{CB}(t)$, the reader is referred back to Figure 3. On this figure, $\overset{<}{E}_1 < \overset{>}{E}_1$, therefore the first CB unit to arrive is located at $\overset{<}{X}_1$, $\overset{<}{F}{}^{o}_{CB} = \min \overset{>}{F}{}^{o}_{CB}, \overset{>}{F}{}^{o}_{CB})$ miles from the accident, approaching from the right. After time $t' = \frac{\overset{<}{E}_1}{v} + w$

the CB unit has reached the accident site, stopped and transmitted a message. The relaying vehicles are those which at the outset were located at $\overset{<}{X}_2$ and $\overset{>}{X}_1$ and we see that $\overset{<}{S}_{CB}(t') = \overset{<}{E}_2 - wv$ and $\overset{>}{S}_{CB}(t') = \overset{>}{E}_1 - \overset{<}{E}_1 - wv$. If $\overset{>}{E}_1$ had been less than $\overset{<}{E}_1$, the relationships would reverse. The locations at times, o, $\overset{<}{E}_1/_v$, and $\overset{<}{E}_1/_v + w$ are shown on Figure 4.

On Figure 4, neither relay vehicle is within range of the stopped CB unit, thus the distances required to be traversed to be within range are $\overset{>}{E}_2 - wv - y_m$ and $\overset{>}{E}_1 - \overset{<}{E}_1 - wv - y_m$ (or zero if they are in range). Once in range, the relay units receive the message and transmit while leaving the accident scene until the authorities are reached. The relay vehicles also require a time w to transmit the message.

For the relay links, the three vehicles located 0, $\overset{<}{E}_1 - wv$ and $\overset{>}{E}_1 - \overset{<}{E}_1 - wv$ miles from the accident are assumed to participate until an HP mobile unit is contacted, an HP base station is contacted and a CB base station is contacted. Conceptually, these are three separate, independent sequences of transmission, as clearly a CB vehicle would not continue to notify the other two contact points, after one had been contacted.

(1) CB Relay to HP Unit Link (CB → CB → HP)

The CB relay vehicles begin transmitting when they first receive the message. This occurs at the time of the first units' transmission or after a time required to move into range, depending on position. At the time the first relay transmission has been completed, t, the HP unit which can be notified by a relayer and is closest to the accident is tagged $F_{HP}(t)$. Once this HP unit is in range of a CB mobile unit, it proceeds at emergency speed to the accident. As previously mentioned, if an HP unit were to receive the message earlier from the first, stationary unit, the relay would not be necessary.

Detection occurs as in c. Notification occurs when the relay vehicles have moved to within range of the stopped CB vehicle and moved further to relay the message within range of an HP unit. Detection occurs when this HP unit arrives on scene.

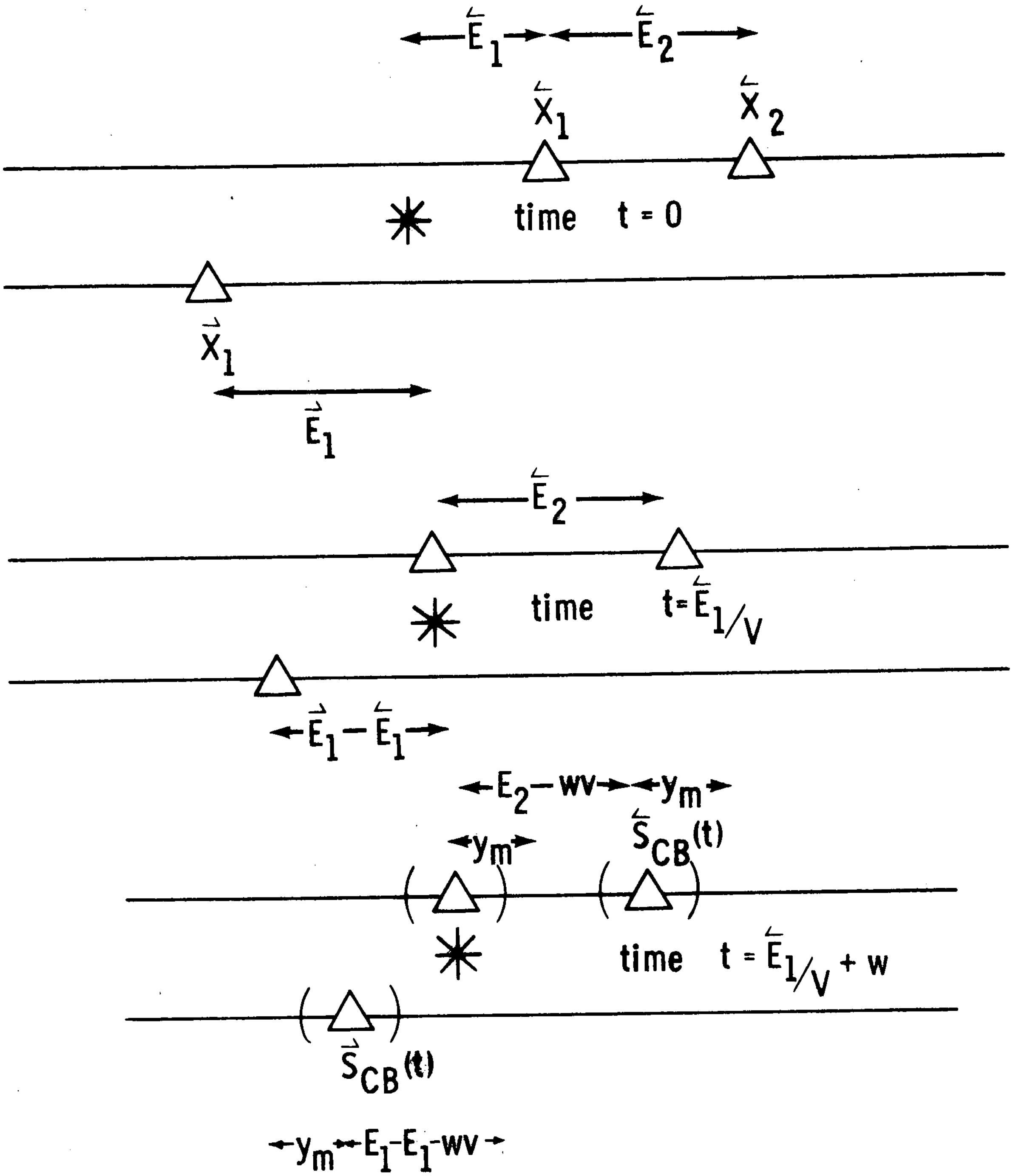


Figure 4 DERIVATION OF $\overrightarrow{S}_{CB}(t)$ $\overleftarrow{S}_{CB}(t)$

(2) CB Relay to HP Base Station Link (CB→CB→HPBS→HP)

In this link, the relayers continue past the accident until they are within range of an HP base station. The base station then dispatches the HP unit closest to the accident. The location of this HP unit, unlike the previous link, is not dependent on the location of relayers, only on the time that the HP base station contact occurred.

(3) CB Relay to CB Base Station Link (CB→CB→CBBS→HPBS→HP)

In this link, the relayers contact a CB base station, rather than HP base station. The CB base station closest to either of the relayers will be the one contacted. Following contact, the CB base station phones the HP base station which dispatches an HP unit as in the last link described.

B. Simulation of a Fixed Event (Subroutine EVTSIM)

The simulation of fixed (non-moving) non-accident events (roadway hazards, stalled vehicles, etc.) is similar to that for accidents. The basic differences involve the fact that the citizens and the authorities are assumed not to act with as much urgency as for accidents. Specifically, the differences are:

- CB units and HP mobile units have a probability assigned to whether or not they will act when observing a situation. (For accidents, this probability is 1.)
- CB units which will act do not stop at the scene, but will continue along the road, broadcasting the message for an assumed fixed number of miles. (For accidents, the first CB unit on scene stops and transmits as long as is required, until response is achieved.)
- No relay links are considered. (This reduces the total number of links from 8 to 5.)

- The direction of travel of the vehicle is given more consideration for fixed events; events are designated as occurring on one side of the road, in particular, and citizens without CB, CB units and HP units have probabilities of observing and acting on an observed event, depending on direction of travel. (Accidents are visible from both directions and have no designated side of the road).
- HP units do not use emergency speed when notified of a fixed event (They do for accidents).

1. The Roadway, Location of a Fixed Event

The procedure for fixed events is the same as for accidents, and its location is denoted by X_f, $o \leq X_f \leq \ell$. For fixed events, the side of the road has greater importance than for accidents and while the events are always located on one side of the road, reporting can occur on the same or opposite side of the road. Since the situation is symmetric, there is no need to consider events with $\ell \leq X_f \leq 2\ell$.

2. Location of HP Units

The location of HP units for fixed events is precisely the same as for accidents.

3. Location of Other Vehicles

As for accidents, vehicles have exponentially distributed distances between, measured from the fixed event site. Once this string of vehicles is generated, the identifications are more complex than for accidents because of the probabilities introduced for fixed event activities.

4. Identification of Reporting Vehicles

Five probabilities are required as input to determine the identifications for reporting vehicles. These are:

p_c = probability that a vehicle has a CB radio

$\overset{>}{p}_c$ = probability that a CB unit will see and attempt to report an event on the same side of the road

$\overset{<}{p}_c$ = probability that a CB unit will see and attempt to report an event on the opposite side of the road

$\overset{>}{p}_r$ = probability that a citizen will see and report an event by phone when the event occurred on the same side of the road

$\overset{>}{p}_r$ = probability that a citizen will see and report an even by phone when the event occurred on the opposite side of the road

In the string of vehicles approaching the event from either direction, a random number, R, is drawn for each vehicle to identify it. The first vehicles is either direction for which

$$R < \overset{>}{p}_r\ (1-p_c) \text{ or}$$

$$R < \overset{<}{p}_r\ (1-p_c)$$

are citizens who will report an event. (The value of R will be different for the left approaching and right approaching vehicle.) Their distances from the accident at the outset, $\overset{>}{F}{}^{o}_{CIT}$ $\overset{<}{F}{}^{o}_{CIT}$, are required to compute times for one of the links. Second, third, etc. such vehicles do not participate, since the vehicle that is closest,

$$\min\ (\overset{>}{F}{}^{o}_{CIT}, \overset{<}{F}{}^{o}_{CIT})$$

will complete the sequence to notification, by calling the HP base station.

Similarly, a vehicle is a reporting CB unit if $R < \overset{>}{p}_c\ p_c$ or $R < \overset{<}{p}_c\ p_c$, depending on locations. Because the CB reporting units only transmit for a specified distance and then stop, it is possible for this effort not to yield notification, when no HP unit or base station (CB or HP) is in range during transmission. Therefore, new reporting CB vehicles are generated until all links have been completed. A special routine in EVTSIM then computes the required separation and delineates those which will make contact from those that will not.

Although no identifiers are used for HP vehicles with accidents, this is required for fixed events. HP units will stop on scene if they were notified by the HP base station or a CB unit but may or may not stop if they observe the event on their own. Two probabilities are required:

$\overset{>}{p}_h$ = probability that an HP unit will stop for an event on the same side of the road

$\overset{<}{p}_h$ = probability that an HP unit will stop for an event on the opposite side of the road

For each HP unit a random number R is drawn. If $R < \overset{>}{p}_h$, or $R < \overset{<}{p}_h$, as the case may be, then the vehicle will stop if it passes by the event. This computation is made in both directions from the event until the closest such vehicle is found.

In all links, it is possible to set any of these probabilities to zero or to one, to either remove the link option or to show greater urgency.

5. Communication Links

The links for fixed events are:

- HP unit detects the event and stops at the scene without the aid of others
- Citizen observes the event and reports to an HP base station
- CB vehicle successfully reports accident to HP unit on patrol
- CB vehicle successfully reports accident to HP base station
- CB vehicle successfully reports accident to CB base station, relay to HP base station.

Each link ends with an HP unit dispatched to the scene, except for the first link shown above, where the unit is already on scene at detection. Each link is discussed further.

a. HP Unit Detection Link (HP)

Let F_{HP}^{o} denote the HP unit closest to the event which will stop (that is, achieved $R < \overset{>}{p}_h$ or $R < \overset{<}{p}_h$). The times are as for accidents:

$$T_d = F_{HP}^{o}$$

$$T_n = o$$

$$T_r = o$$

b. Citizen Phone to HP Base Station Link (CTI→HPBS→HP)

Although the parameter values for this link, reporting probabilities, c, citizen reporting time, d, HP dispatch time, would normally be different for fixed events than for accidents, the basic computational procedures are identical, except that the HP unit dispatched does not use emergency speed:

$$T_d = \frac{\min (\overset{\geq}{F}{}_{CIT}^{o}, \overset{\leq}{F}{}_{CIT}^{o})}{v}$$

$$T_n = c$$

$$T_r = d + \frac{F_{HP}(t)}{v}$$

Note that in the computation of $\overset{\geq}{F}{}_{CIT}^{o}$, $\overset{\leq}{F}{}_{CIT}^{o}$ the side of the roadway on which the fixed event occurred is considered, i.e., the probabilities of reporting vary according to the side of the road.

c. CB Unit to HP Unit Link (CB→HP)

For this link, several possible CB vehicles and HP units are considered. Since both are moving and the CB vehicles have a finite range and transmit for a finite distance, the first HP units approaching a reporting CB vehicle may be too late to receive the message. When the first such reception which will occur is obtained for both directions of travel, these CB vehicles are designated by their locations, $\overset{\geq}{F}{}^{o}_{CB}$ and $\overset{\leq}{F}{}^{o}_{CB}$. Here, $\overset{\geq}{F}{}^{o}_{CB}$ and $\overset{\geq}{F}{}^{o}_{CB}$ denote the distance from the event of the first reporting vehicles in either direction which will complete the link to an HP unit. If t is a function of time that $\overset{\geq}{F}{}^{o}_{CB}$ or $\overset{\leq}{F}{}^{o}_{CB}$ detected the event, this HP unit will be a distance $F_{HP}(t)$ from the event at time t. The first CB unit which will achieve minimum total time is selected. Letting [ ] denote the appropriate distances between for the variations on direction of travel, the CB unit, HP unit pair that will achieve minimum total time is selected according to:

$$T^* = \min\ (T:T = \frac{F^{o}_{CB}}{v} + w + \frac{[F^{o}_{CB} - F_{HP}(t)]}{v},$$

where $F^{o}_{CB} = \overset{\geq}{F}{}^{o}_{CB}$ or $\overset{\leq}{F}{}^{o}_{CB}$ and $F_{HP}(t)$ corresponds to one or the other of these and a pair $(F^{o}_{CB}, F_{HP}(t))$ will achieve the link.

Denote by $(F^{o*}_{CB}, F_{HP}(t)^{*})$ the pair which achieves this minimum.

The time equations for this link are, then,

$$T_d = \frac{F^{o*}_{CB}}{v}$$

$$T_n = w + \max\ \frac{(F_{HP}(t)^{*} - y_m, o)}{v}$$

$$T_r = \min\ \frac{(F_{HP}(t)^{*}, y_m)}{v}$$

d. <u>CB Unit to HP Base Station Link (CB→HPBS→HP)</u>

This link proceeds in a manner very similar to the CB unit <u>relay</u> to HP base station link for accidents. As in the last link, several sequences may have to be attempted before a CB vehicle is transmitting while passing a base station. The basic difference between this link and the relay mode for accidents is that the first arriving CB unit which will transmit past a base station is also the relayer for fixed events, rather than stopping. Also, HP units travel at normal speeds when dispatched to fixed events.

e. CB Unit to CB Base Station, Phone to HP Base Station Link (CB → CBBS → HPBS → HP)

As in the last link, this link proceeds as the corresponding relay mode for accidents.

C. Simulation of a Moving Event (Subroutine SPDSIM)

Subroutine SPDSIM simulates a speeder or reckless driver moving at a speed greater than the average speed of traffic on the highway. The speeder can be observed and reported by citizens, CB vehicles or HP units and the HP units attempt to pursue and apprehend the speeder. Detection, notification and response times are calculated as in ACCSIM and EVTSIM, and the program also determines whether the speeder is apprehended, slows to normal speed when an HP unit is observed, or escapes without being caught.

The simulation is similar to EVTSIM in that the speeder may be observed from both sides of the road by citizens and CB units with different probabilities for each side of the road. Also the CB unit continues driving after having observed the speeder and transmits only for a fixed distance past the point of observation. There are no relay modes.

1. The Roadway, Location of a Speeder

The speeder is assumed to enter the road segment at X=o, proceeding to the right at speed $v_s > v$. The location of the speeder is denoted by $X_s(t)$, $o \leq X_s(t) \leq \ell$. If the speeder achieves $X_s(t)=\ell$ without being apprehended, the speeder escapes. The location is calculated as $X_s(t)=v_{\frac{s}{t}}$ unless the speeder observes an HP unit at time t' and slows to normal speed.

In this case, the location would be:

$$X_s(t) = \frac{v_s}{t'} + \frac{v}{t-t'}, \quad t > t'$$

Denote by X_{app} the location between o and ℓ that apprehension occurs and by X_{det}, the location where detection occurred.

For speeders only, the event has an identifier denoted by p_p, the probability that the speeder will pass the HP unit while speeding. For each iteration in the simulation a random number is drawn, R, and if $R < p_p$ then the speeder in that iteration will speed past an HP unit if one is encountered between $X=o$ and $X=\ell$.

2. Location of HP Units

The location of HP units for speeders is precisely the same as for accidents and for fixed events.

3. Location of Other Vehicles

Vehicles are assumed to have exponentially distributed distances between, as before, and are measured from $X=o$, the location of the speeder at time zero. A string is set up from $X=o$ to $X=\ell$, denoted $\overset{>}{X}_1$, $\overset{>}{X}_2$, ..., and, from $X-2\ell$ to $X=\ell$, $\overset{<}{X}_1$, $\overset{<}{X}_2$, ... Probabilities of citizen and CB vehicle reporting determine those who will report from these sequences in the same manner as for fixed events.

For a speeder proceeding in the same direction, the HP unit will observe the speeder and always attempt to apprehend. For a speeder passing in the opposite direction, there is a probability equal to $\overset{<}{p}_h$ of observing the speeder. For speeders, then, $\overset{>}{p}_h = 1$ and $\overset{<}{p}_h \leq 1$. For each HP unit located, a random number, R, is drawn, and if $R < \overset{<}{p}_h$ then that HP unit is designated as an "apprehender". All HP units will attempt apprehension if dispatched or notified by CB.

4. Communication Links

The links escape and correction possibilities are:

- HP unit detects the speeder and apprehends
- Citizen observes the speeder, reports to an HP base station, dispatches HP unit which apprehends
- CB vehicle reports speeder to HP unit on patrol which apprehends
- CB vehicle reports speeder to HP base station, dispatches HP unit which apprehends
- CB vehicle reports speeder to CB base station, phone HP base station, dispatches HP unit which apprehends
- Speeder escapes at the end of the roadway
- Speeder reduces speed to normal, after observing HP unit.

These possibilities are discussed below.

a. HP Unit Detection Link (HP)

First, in order to simulate the situation where an HP unit has pulled off the road and detects the speeding vehicle as it passes, speeders are assumed to be detected and apprehended in this manner if at $t = 0$ there is an HP unit within 0.5 mile of $X = 0$. If this is the case, detection and apprehension points are

$$X_{det} = 0$$

$$X_{app} = 1$$

If the situation described above does not occur, the point at which the speeder will pass the first HP unit is determined by $\overset{\geq}{F}{}^{o}_{hp}$. If this point is past the end of the road segment, $X = \ell$, it is possible for the speeder to escape. If the passing point, $\overset{\geq}{F}{}^{o}_{hp}$ is less than ℓ then a speeder designated as a "passer" will pass the HP unit and is immediately apprehended, $X_{det} = X_{app} = \overset{>}{F}{}_{hp}^{o}$. A "non-passer" will spot the HP unit and slow down.

Another possibility is that a speeder proceeds along the road passing an HP unit going in the opposite direction. These HP units have probability $\overset{<}{p}_h$ of observing the speeder and calling other HP units to apprehend the speeder. They do not turn around and chase the speeder themselves. If the first HP unit to pass in the opposite direction does not observe the speeder, then further vehicles are checked, until one is found or the speeder escapes.

To derive the apprehension point when $X_{det} = \overset{<}{F}{}_{hp}^{o}$ (an HP unit in the opposite direction detects the speeder and radios for apprehension), HP units are located in appropriate "capture zones" at the moment of notification. If there is an HP unit in a capture zone, an apprehension point is calculated and used for X_{app}.

Two distances define the capture zones:

k_b = distance behind a speeder within which an HP unit will attempt to close

K_a = distance ahead of a speeder beyond which an HP unit will pull off the side of the road and wait for speeder

At the time that HP mobile units receive the message, t, HP units are examined to determine the HP units closest to the speeder such that

$$X_s(t) - \overset{>}{F}_{HP}(t) \leq k_b, \text{ or}$$
$$\overset{>}{F}_{HP}(t) - X_s(t) \geq k_a$$

Denote by $\overset{>}{F}{}_{HP}^{b}(t)$ the distance from the speeder at time t to an HP unit that meets the first requirement and $\overset{>}{F}{}_{HP}^{a}$ one that meets the second, if any.

If apprehension is possible, we have that

$$X_{app} = \min\left[\frac{X_s(t)\cdot v_e - \overset{\geq}{F}{}^{b}_{HP}(t)\cdot v_s}{v_e - v_s},\ \overset{\geq}{F}{}^{a}_{HP}(t)\right]$$

if both $\overset{\geq}{F}{}^{b}_{HP}(t)$ and $\overset{\geq}{F}{}^{a}_{HP}(t)$ are determined. If only one is determined the location X_{app} is that one and if neither is determined there can be no apprehension. Further, if this will occur after location ℓ, then the speeder escapes and there is no apprehension.

The time equations are

$$\left.\begin{aligned} T_d &= \frac{X_{det}}{v_s} \\ T_n &= 0 \\ T_r &= 0 \end{aligned}\right\} \quad \begin{aligned} &\text{if } X_{det} \text{ and } X_{app} \text{ are determined} \\ &\text{and } X_{det} \leq \ell,\ X_{app} \leq \ell. \end{aligned}$$

Otherwise, the speeder slows or escapes.

b. <u>Citizen Phone to HP Base Station Link (CIT→HPBS→HP)</u>

Let $\overset{\geq}{F}{}^{o}_{CIT}$ and $\overset{\leq}{F}{}^{o}_{CIT}$ denote the closest reporting citizens to the speeder's location at the outset. The detection location for this mode is

$$X_{det} = \min\left[v_s\,\frac{\overset{\geq}{F}{}^{o}_{CIT}}{v_s - v},\ v_s\,\frac{\overset{\leq}{F}{}^{o}_{CIT}}{v_s + v}\right].$$

Notification time is fixed as c and response occurs precisely as in the link described above except that the time to dispatch, HP base station to HP unit, d, is required.

The time equations are

$$\left.\begin{aligned} T_d &= \frac{X_{det}}{v_s} \\ T_n &= c \\ T_r &= \frac{X_{app} - X_{det} - c\,v_s}{v_s} \end{aligned}\right\} \quad \begin{aligned} &\text{if } X_{det} \text{ and } X_{app} \text{ are determined} \\ &\text{and } X_{det} \leq \ell,\ X_{app} \leq \ell \end{aligned}$$

Otherwise, the speeder slows or escapes. Note that for this mode, there is a dispatch time d, therefore X_{app} would be computed starting from time T_n+d.

c. CB Unit to HP Unit Link (CB→HP)

This link is simulated in a manner similar to the preceeding one. CB vehicles who will report detect the speeder, transmit directly to HP units (no dispatch time is required) and the HP units attempt to apprehend as in all cases.

d. CB Unit to HP Base Station Link (CB→HPBS→HP)

This link proceeds as the last one except that a dispatch time must be awaited before the apprehension procedure can start.

e. CB Unit to CB Base Station, Phone to HP Base Station Link (CB→CBBS→HPBS→HP)

In this link, both the dispatch time and the CB base station, phone to HP base station, time must be awaited.

D. Computation of Results (Subroutine CBSTAT)

Subroutine CBSTAT computes the results to be used for output tables. These computations are based on n iterations using either ACCSIM, EVTSIM or SPDSIM. Each iteration produces detection, notification and response time intervals and cumulative times which are used by CBSTAT.

There are 5-8 links depending on type of event, accidents, fixed events or speeders.

For each of the n iterations of an event, and for each link, the following is computed:

- minimum detection time
- minimum notification time
- minimum detection plus notification time

- minimum response time
- minimum total time.

Next, an Experimental Area configuration of links is devised, using all links. The Control Area links are only those links which do not involve use of CB by the HP base station and patrol units. For the Experimental Area links, the percentage of iterations in which each link had minimum detection plus notification time and minimum total time are computed, as well as the distribution of all times. The minimum time over all links, or best of all possible times, is computed for the Experimental Area. The same is done for Control Area links.

For further calculations the link structure is slightly revised to compute means. Since some links will not occur in ACCSIM and SPDSIM, these revisions are necessary for computations. In ACCSIM, the CB relay links are combined with their corresponding non-relay links, since either one or the other will occur. In SPDSIM, the links all have a chance of not occurring, so each link is "split" into three categories--speeder apprehended, escaped or slowed. If, in an iteration, a speeder slowed or escaped in all links, then apprehension did not occur. Output tables provide the means and standard deviations for these revised "completed" link definitions and, for speeders, escape and slowed ratios, also.

V CONVERGENCE PROPERTIES OF THE SIMULATION

The method used to determine the number of iterations required is a common one.[1] We desire to bound the mean total time (detection plus notification plus response) for all of the five main links studied to within a certain range with some given confidence. To do this, the simulation is run for various numbers of iterations to obtain a sample estimate of the standard deviations for each link (s_i, i= 1, ..., 5). We also select a confidence interval d, i.e., the simulated mean total time should be within ± d/2 of the true mean, x% of the time. The number of iterations required, N, is thus

$$N = \max\ (n_i : i = 1, \ldots, 5)$$

where

$$n_i = \frac{t_x^{\,2}\ s_i^{\,2}}{(d/2)^2}, \quad i = 1, \ldots, 5$$

and t_x is the tabulated value for the number of iterations in the sample run for which s_i was computed at the x% level.

Nine accident runs were made for each of the following number of iterations: 200, 500, 1000, 2000, 3000. Table 9 shows the mean total time and s_i for each run. For each of the nine runs for a given number of iterations, the highest mean, lowest mean and median mean are shown, along with the range, high minus low. The parameters used were very similar to those shown on Table 5.

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[1] "Systems Simulation, the Art and Science," R.E. Shannon, Prentice-Hall, Inc., p. 189.

TABLE 9

MEAN TOTAL TIMES

(Min)

Number of Iterations	200		500		1000		2000		3000	
i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i
HP	19.20	14.3	19.35	13.1	19.40	13.3	18.28	13.0	17.92	13.0
	19.10	13.0	18.36	12.2	19.04	13.3	18.23	13.2	18.00	13.2
	18.95	13.2	17.94	13.1	18.95	13.5	18.23	13.1	18.05	13.0
	18.63	12.3	17.89	13.3	18.63	13.2	18.14	12.8	18.05	13.1
	18.53	14.0	17.88	13.2	18.57	12.7	18.07	12.9	18.05	13.2
	17.99	12.3	17.85	13.1	18.31	12.8	17.96	13.0	18.15	12.9
	17.74	13.6	17.79	13.2	18.23	13.1	17.64	12.7	18.29	13.2
	17.54	13.6	17.39	12.5	18.01	13.6	17.61	13.2	18.30	13.2
	16.19	12.3	17.35	13.0	17.94	12.8	17.52	12.7	18.34	13.3
Median	18.53		17.88		18.57		18.07		18.05	
High	19.20		19.35		19.40		18.28		18.34	
Low	16.19		17.35		18.01		17.52		17.92	
Range	3.01		2.00		1.39		.76		.42	
CIT→ HPBS→ HP	17.26	5.0	17.12	4.6	17.26	4.6	17.04	4.6	16.95	4.4
	17.08	4.7	16.98	4.6	17.11	4.6	16.87	4.5	16.94	4.5
	17.03	4.5	16.91	4.7	17.05	4.6	16.86	4.5	16.94	4.5
	16.93	4.6	16.86	4.6	17.03	4.6	16.82	4.4	16.92	4.5
	16.83	4.6	16.84	4.7	16.94	4.4	16.82	4.3	16.89	4.5
	16.75	4.5	16.83	4.4	16.88	4.6	16.78	4.5	16.85	4.5
	16.57	4.4	16.82	4.5	16.82	4.5	16.77	4.4	16.85	4.5
	16.45	4.3	16.65	4.4	16.80	4.4	16.73	4.5	16.84	4.5
	16.25	4.3	16.61	4.5	16.80	4.4	16.58	4.4	16.81	4.5
Median	16.83		16.84		16.94		16.82		16.89	
High	17.26		17.12		17.26		17.04		16.95	
Low	16.25		16.61		16.80		16.58		16.81	
Range	1.01		.51		.46		.56		.14	

TABLE 9 (cont.)

MEAN TOTAL TIMES

(Min)

Number of Iterations	200		500		1000		2000		3000	
i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i
CB→ HPBS→ HP	29.46	19.0	29.90	20.2	29.12	19.9	28.61	19.8	28.57	19.6
	28.78	18.5	28.70	19.7	28.86	19.5	28.05	19.0	28.36	19.4
	28.68	19.1	27.95	19.3	28.25	19.4	27.89	19.3	28.02	19.3
	28.51	18.3	27.75	19.6	27.80	19.1	27.89	19.2	27.92	19.6
	28.29	19.0	27.75	19.4	27.47	19.3	27.70	19.0	27.82	19.3
	27.91	18.7	27.55	19.4	27.44	19.2	27.58	19.3	27.82	19.1
	27.76	20.0	27.50	19.7	27.37	18.9	27.52	19.1	27.79	18.8
	27.25	18.9	27.09	18.9	27.23	19.2	27.51	19.1	27.70	19.1
	26.27	18.7	27.06	19.1	26.77	19.2	27.43	19.4	27.59	19.2
Median	28.29		27.75		27.47		27.70		27.82	
High	29.46		29.90		29.12		28.61		28.57	
Low	26.27		27.06		26.77		27.43		27.59	
Range	3.19		2.84		2.45		1.18		.98	
CB→ CBBS→ HPBS→ HP	29.93	19.1	30.16	19.7	30.51	19.8	29.29	19.4	29.77	19.4
	29.70	18.0	29.67	19.1	30.02	19.4	29.01	19.4	29.40	19.5
	29.69	19.6	29.37	19.4	29.81	19.8	28.90	18.9	29.36	19.7
	28.91	20.0	29.32	19.9	29.72	19.6	28.88	19.2	29.27	19.6
	28.90	19.6	28.92	19.3	29.59	19.8	28.75	19.2	29.10	19.5
	28.60	18.3	28.68	19.0	29.59	19.8	28.74	19.0	28.80	19.4
	28.11	19.5	28.56	19.3	29.51	19.8	28.71	19.2	28.68	19.2
	28.05	18.9	27.85	18.6	29.14	19.2	28.66	19.4	28.44	18.8
	27.65	19.4	27.62	18.1	28.49	19.0	28.28	18.4	27.96	19.0
Median	28.90		28.92		29.59		28.75		29.10	
High	29.93		30.16		30.51		29.29		29.77	
Low	27.65		27.62		28.49		28.28		27.96	
Range	2.28		2.54		2.02		1.01		1.81	

TABLE 9 (cont.)

MEAN TOTAL TIMES

(Min)

Number of Iterations	200		500		1000		2000		3000	
i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i	Mean	s_i
CB→ HP	13.69	10.2	13.42	10.4	13.44	10.6	13.09	10.3	12.81	10.3
	13.49	10.9	13.05	9.9	13.19	10.8	12.77	10.1	12.75	10.2
	13.22	9.8	12.49	10.1	13.09	10.4	12.66	10.1	12.73	10.3
	13.13	10.4	12.46	10.2	12.98	10.2	12.61	10.0	12.68	10.2
	12.85	9.6	12.30	9.5	12.88	10.0	12.56	10.1	12.63	10.1
	12.60	10.8	12.29	10.2	12.67	10.1	12.54	10.1	12.61	9.9
	12.02	10.2	12.28	10.0	12.64	10.5	12.36	9.9	12.50	10.2
	11.99	9.7	12.16	9.8	12.53	10.2	12.27	9.9	12.48	10.2
	11.69	10.1	12.14	10.1	12.16	9.7	12.08	10.1	12.48	10.1
Median	12.85		12.30		12.88		12.56		12.63	
High	13.69		13.42		13.44		13.09		12.81	
Low	11.69		12.14		12.16		12.08		12.48	
Range	2.00		1.28		1.28		1.01		.33	

Several things are notable in these tables. First, as one would expect, the range of means decreases as the number of iterations increases. Secondly, the sample standard deviations are quite consistent for all numbers of iterations considered. And third, we see that different links have markedly different ranges for a given number of iterations. This implies that some links, such as HP alone and CB→HPBS→HP, will require many more iterations to bound the mean time within specified minutes, than others. Since the model computes all links at once, the most difficult to bound will have to guide the number of iterations used.

The equation

$$n_i = \frac{t_x^2 \; s_i^2}{(d/2)^2}$$

was computed for two t_x values, $t_{.95}$ and $t_{.99}$, for 95 and 99 percent confidence levels, respectively. These apply to all numbers of iterations used since all sample runs are fairly large. The sample standard deviations vary from 4 to 20 among the links, so values of 4, 10, 15 and 20 were used for s values. Table 10 shows the number of iterations required for a confidence interval of 1, 2 or 3 minutes. The table is used as follows. If one desired to have a run's mean total time within 1/2 minute (plus or minus), approximately 173 iterations are required for CIT→HPBS→HP ($S \sim 4$); 1083 for CB→HP ($S \sim 10$); 2435 for HP alone ($S \sim 15$); and 4328 for CB→HPBS→HP→and CB→CBBS→HPBS→HP ($S \sim 20$). This correspondence is made using the standard deviation on Table 9. Since we are using the largest n_i required for any link, the approximations of 4, 10, 15, and 20 for standard deviations are adequate. The N = maximum n_i selected for this would be around 4000.

The final decision about recommending an N value was made based on cost of the runs and tolerable variations. Runs of 2000 iterations or more were judged to be costly and a one-minute error in either direction

TABLE 10

NUMBER OF ITERATIONS
REQUIRED TO ACHIEVE DESIRED CONFIDENCE

	Width of Confidence Interval About Mean		
Sample Standard Deviation	1 Minute	2 Minutes	3 Minutes
95% Confidence Level:			
s = 4	173	43	19
s = 10	1082	271	120
s = 15	2435	609	270
s = 20	4328	1084	480
99% Confidence Level:			
s = 4	346	86	38
s = 10	2164	541	240
s = 15	4869	1217	540
s = 20	8656	2164	960

was the largest acceptable at the 95 percent level. Consulting Table 10, with N = 1000, 95 percent of the time, the run means are less than one minute different from the true means (± 1 min., length 2 min.) and 99 percent of the time the run is only less than one and one-half minute off (± 1 1/2 min., length 3 min.). This holds for links with s_i near 20. Other links have smaller error, e.g., CB→HP ($s_i \sim 10$) is ± 1/2 min., length 1 min., at 95 percent and within ± 1 min., length 2 min., at 99 percent. N=1000 is therefore suggested for sensitivity runs.

List of Symbols

ACCSIM = subroutine that simulates response to one accident

c = time required to exit roadway and call HP base station (minutes)

CB = vehicle with CB radio

CBBS = CB base station

CBSTAT = control subroutine for computation of statistics

CIT = vehicle without CB radio

d = time required to dispatch an HP unit (minutes)

D_k = distance between the kth and (k=1)st HP unit (miles)

E = distance between successive vehicles (miles)

$\overrightarrow{E}_k$ = distance between the kth and (k-1) st vehicles moving toward the accident from the left (miles)

$\overleftarrow{E}_k$ = distance between the kth and (k-1) st vehicles moving toward the accident from the right (miles)

EVTSIM = subroutine that simulates response to one fixed non-accident event

$\overrightarrow{F}^{\circ}_{CB}$ = distance from the accident to the closest CB vehicle capable of completing the link, approaching from the left (miles)

$\overleftarrow{F}^{\circ}_{CB}$ = distance from the accident to the closest CB vehicle capable of completing the link, approaching from the right (miles)

$\overrightarrow{F}^{\circ}_{CIT}$ = distance from the event to the closest non CB citizen vehicle who will act and is approaching from the left (miles)

$\overleftarrow{F}^{\circ}_{CIT}$ = distance from the event to the closest non CB citizen vehicle who will act and is approaching from the right (miles)

F°_{hp} = distance of closest HP unit that will stop (either direction) approaching event (miles)

$\overrightarrow{F}^{\circ}_{HP}$ = distance along the roadway to the first HP unit between X=0 and X=1

$\overleftarrow{F}^{\circ}_{HP}$ = distance along the roadway to the first HP unit that observes an event between X=21 and X=1

$\overrightarrow{F}_{HP}(t)$ = distance along the roadway of HP units within a capture zone

$\overrightarrow{F}^{a}_{HP}(t)$ = distance along the roadway of the closest HP unit ahead of the speeder in a capture zone

$F_{HP}(t)$ = distance of the closest HP unit (either direction) approaching accident at time t (miles)

$\overrightarrow{F}_{HP}^{b}(t)$ = distance along the roadway of the closest HP unit behind the speeder in a capture zone

h = number of HP units

HP = highway patrol vehicle

HPBS = HP base station

k_a = capture distance ahead of speeder

k_b = capture distance behind speeder

l = length of roadway (miles)

m = traffic volume (vehicles per hour)

n = number of times that an event is simulated

pc = probability of having a CB unit

$\overrightarrow{pc}$ = probability of transmitting a CB message on same side of the road

$\overleftarrow{pc}$ = probability of transmitting a CB message on opposite side of the road

$\overrightarrow{ph}$ = probability that an HP unit will stop for an event on the same side of the road

$\overleftarrow{ph}$ = probability that an HP unit will stop for an event on the opposite side of the road

pr = probability of reporting by phone

$\overrightarrow{pr}$ = probability of seeing and reporting by phone on same side of the road

$\overleftarrow{pr}$ = probability of seeing and reporting by phone on opposite side of the road

R = random number between 0 and 1

S = spacing tolerance for HP units (miles)

$\overrightarrow{S}_{CB}(t)$ = distance from the accident location to the nearest secondary relaying vehicle approaching from the left (miles)

$\overleftarrow{S}_{CB}(t)$ = distance from the accident location to the nearest secondary relaying vehicle approaching from the right (miles)

SPDSIM = subroutine that simulates response to one speeder

Td = time of detection (minutes)

T_n = time from detection to notification (minutes)

T_r = time from notification to response (minutes)

u = time required for a CB base station operator to phone a message to the HP base station (minutes)

v = constant traffic speed (m.p.h.)

Ve = highway patrol emergency speed (m.p.h.)

Vs = speed of the speeder

w = time required for a CB vehicle to transmit a message (minutes)

X = location along the roadway (miles)

X_a = location of accident along the roadway (miles)

$Xapp$ = location where apprehension occurred

$Xdet$ = location where detection occurred

X_f = location of fixed event along the roadway (miles)

$\overrightarrow{X}_k$ = location of the kth vehicle moving toward the event from the left (miles)

$\overleftarrow{X}_k$ = location of the kth vehicle moving toward the event from the right (miles)

$X_s(t)$ = location of the speeder at time t

Y_b = receiving range (one-way or radius) of the base stations (miles)

Ym = receiving range (one-way or radius) of a CB mobile unit (miles)