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Program on Advanced Technology for the Highway
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA AT BERKELEY

BTS (Version 1.1) - Bottleneck Traffic Simulator User's Manual

**Wei Hua Lin
Randolph W. Hall**

**PATH Working Paper
UCB-ITS-PWP-91-6**

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**BTS (Version 1.1) - Bottleneck Traffic Simulator
User's Manual**

by

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Randolph W. Hall**

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**Program on Advanced Technology for the Highway
Institute of Transportation Studies
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CHAPTER 1

INTRODUCTION

BTS -- Bottleneck Traffic Simulator -- is a macroscopic tool for simulating the performance of freeway bottlenecks. BTS can be used to measure the travel time benefits of changes in roadway design through: (1) addition of capacity, (2) increase in travel speed, or (3) improvement in roadway reliability. The unique features of BTS include:

- Allows non-standard roadway characteristics, which might be created through highway automation.
- Evaluates lane stoppages or other incidents through random simulation.
- Determines both recurrent and non-recurrent traffic delay.
- Measures impact of growth in traffic level.
- Accounts for changes in traveler behavior, including changes in departure time and changes in route.
- Interfaces with Lotus 1-2-3 to provide graphs of cumulative arrivals and departure and to demonstrate queueing over time.

BTS Version 1.1 contains several enhancements over Version 1.0:

- Enhanced capabilities for input and output.
- Ability to randomly simulate weather effects on road capacity and daily variations in traffic volume.
- Allowance for time variable roadway tolls.
- Allowance for incident dependencies.
- Accounts for reduction in traffic due to large roadway delays through use of renegeing function.

BTS operates on an IBM PC or compatibles with three .EXE files, BTS.EXE, QM.EXE, and VIEW.EXE. A fully operative BTS, including output files, requires about 300K bytes of work disk space.

*To obtain a copy of BTS, contact Randolph Hall at the Department of Industrial Engineering & Operations Research, University of California at Berkeley, 94720.

CHAPTER 2

THEORY BEHIND BTS

BTS was developed to illustrate how a freeway bottleneck behaves over time as traffic levels and freeway performance change. By focusing on a single bottleneck, rather than an entire freeway corridor or network, BTS provides more details about roadway performance than previously possible. In particular, by randomly simulating the occurrence, duration and magnitude of freeway incidents, BTS calculates average recurrent delay and average non-recurrent delay. This information is especially valuable in evaluating the merits of incident management strategies.

To run BTS, the user must first specify an initial demand pattern, as well as highway characteristics. BTS uses this input to evaluate travel time performance by time slice. If desired, BTS can iteratively adjust the demand pattern in response to the travel time data. These adjustments can include a demand increment to account for a general increase in traffic from year to year, as well as changes in route, renegeing behavior and arrival time at the bottleneck. BTS can run up to 10 iterations, representing 10 years. Travel time performance is automatically stored after each iteration for later analysis.

The following two sections explain the key phases of BTS: the performance evaluation step and the demand assignment step.

A. Performance Evaluation

Each iteration of BTS simulates traffic conditions over a period of up to 200 days (Each day will be called a run. See Table 2.1). For each day, the time, duration and magnitude of freeway incidents

- Time Slice:** A time increment of five minutes during which arrival rates and capacities are assumed to stay constant.
- Run:** A single day comprising up to 45 consecutive time slices (3 3/4 hours).
- Iteration:** A set of runs during which arrival time and route assignments, as well as mean traffic volumes, do not change. An iteration might represent one year.

Table 2.1. Definitions

are randomly simulated according to user specified probability distributions. In addition, BTS randomly simulates weather patterns and daily traffic volume, according to user specified functions. The purpose of the simulation is to represent actual bottleneck capacity within each time slice on a given day, taking into account the conditions that occur on that day.

User specified probabilities determine the likelihood that an incident occurs in any time slice. If an incident occurs, the duration and magnitude are simulated, and the bottleneck capacity is decremented as appropriate. However, if one incident occurs soon after another, the incident with the largest magnitude defines the capacity, until it is cleared up. To illustrate these concepts,

consider the following example, pertaining to a 3-lane freeway with nominal capacity of 6000 vehicles/hour:

Time Slice	Incident	Duration (slices)	Capacity Loss	Current Capacity (veh/hr)
1	No	--	--	6000
2	No	--	--	6000
3	Yes	3	33%	4000
4	No	--	--	4000
5	Yes	4	20%	4000
6	No	--	--	4800
7	Yes	1	50%	3000
8	No	--	--	4800
9	No	--	--	6000
10	No	--	--	6000

As the example demonstrates, the current capacity is defined by the outstanding incident with the biggest capacity loss. In time slice 5, the first incident has the biggest loss, and the capacity is 4000/hour. However, the first incident is cleared at the end of slice 5, so the capacity in time slice 6 is 4800, as defined by the second incident.

BTS Version 1.1 also simulates daily weather patterns and traffic volume. Users can specify up to three alternative weather patterns. For each run, BTS randomly determines which weather pattern applies -- normal (full capacity) or one of three alternatives -- according to user specified probabilities. If an alternative pattern occurs, the capacity is decremented for the entire run by the appropriate percentage specified by the user. Similarly, at the start of each run, the daily traffic volume is randomly simulated. Then throughout the run, traffic volume by time slice is increased or decreased accordingly. BTS assumes that the daily volume is a normal random variable, with a user specified coefficient of variation.

The queue size at the end of a time slice is calculated in the following manner. Let:

- A_i = number of arrivals in slice i
- C_i = capacity in slice i (vehicles / hour)
- Q_i = queue size at the end of slice i
- n = number of time slices per hour
- N = number of time slices in simulation.

Then:

$$Q_i = \max \{ (A_i - C_i/n) + Q_{i-1}, 0 \}$$

The first part of the equation applies when the bottleneck operates at capacity and queues exist, while the second applies when the bottleneck operates below capacity.

On any day of the simulation, the total time spent waiting in queue, measured in hours, is found from a summation of the queue sizes:

$$\text{Total Time in Queue} = W = \sum_{i=1}^N Q_i (1/n)$$

The average system delay (i.e., wait) is found by averaging W over all of the days simulated.

Because the simulation includes incidents, the average system delay is the sum of the average recurrent delay and the average non-recurrent delay. To calculate average *recurrent* delay, BTS simulates one additional day in which no incidents occur, weather is normal and traffic volume is average. The output from BTS provides both this value and the average system delay on a per vehicle basis. The difference between the values is the non-recurrent delay. In addition, BTS provides the average free-flow travel time, which can vary when travelers shift between routes that have different travel times.

BTS has the capacity to analyze up to three parallel routes. Two of these routes are accessible to all travelers, while the third is designated as automated. The automated route is only accessible to a (user specified) portion of travelers that owns necessary equipment. BTS provides system delay, recurrent delay and free-flow travel time for each of the three routes. If desired, the third route might alternatively represent an HOV lane, accessible to a user specified portion of travelers.

As input to the traffic assignment phase, system delay per vehicle is also calculated by time slice, as a function of arrival time at the bottleneck. System delay per vehicle is found by dividing the queue size by the actual capacity for the given day and adding the free-flow time. BTS averages these waiting times among the days simulated to determine an average system delay by time slice. BTS also determines waiting time for a user specified percentile of the waiting time distribution.

A final feature is that BTS allows the user to specify a roadway capacity upstream from the bottleneck. For BTS to operate properly, this capacity must be larger than the nominal bottleneck capacity. In the output, BTS shows the recurrent delay upstream. This represents the minimum possible delay on the highway should the bottleneck be removed, without making ancillary improvements upstream.

B. Traffic Assignment

At the end of each iteration of BTS, waiting time data is used to revise the assignment of vehicles to arrival times and to routes and to determine renegeing. BTS allows for three types of traveler behavior:

- Fixed arrival time (Type 1)** These travelers always arrive at the same time, independent of queueing. However, they will shift between routes to select the fastest available, counting both queue time and free flow time.
- Fixed departure time (Type 2)** These travelers would like to depart from the bottleneck at a time that insures they will arrive at their destination at a fixed time with high probability. Travelers choose the route which allows them to leave home as late as possible, and still arrive at their destination on time with high probability.
- Cost minimizers (Type 3)** These travelers have a desired time to depart from the bottleneck, but are willing to depart either earlier or later if their personal cost is reduced. Travelers choose the route that offers the minimum *average* cost, which is the sum of an early cost, a late cost, a travel time cost, and a roadway toll (if applicable).

Based on the above criteria, as well as waiting time and free flow travel time data, BTS determines the optimal route and arrival time for each type of traveler. Travelers are automatically reassigned to their optimal *arrival time*. However, only a user specified proportion of travelers is allowed to shift between routes at any iteration. Reassignment only takes place at the end of an iteration.

In addition, BTS 1.1 contains a new renegeing feature, which accounts for loss in traffic volume as delays increase.

B.1 Arrival Time Assignment

As an illustration of the arrival time assignment, suppose that the following travel time data is available for a route. The travel time will represent the sum of the queue time and free-flow travel time. Assume that there are no roadway tolls.

Time Slice	Elapsed Time End of Slice	Mean Travel Time End of Slice	90% Travel Time End of Slice
1	5 min.	2 min.	3 min.
2	10 min.	3 min.	5 min.
3	15 min.	5 min.	10 min.
4	20 min.	8 min.	17 min.
5	25 min.	10 min.	21 min.

Because Type 1 travelers have fixed arrival times, only the arrival times for Type 2 and 3 travelers are influenced by the data. In order to arrive at work on time, suppose that a Type 2 traveler must depart from the bottleneck by the end of slice 5 with 90% probability. Then the traveler must arrive at the bottleneck by the end of slice 3.

Now suppose that a Type 3 traveler desires to depart at the end of slice 5, and that its earliness cost is \$5/hour, its queueing cost is \$10/hour, and its lateness cost is \$20/hour and that the road has no toll. Then the optimal arrival time is found by comparing alternatives:

Arrival Time	Earliness Cost	Lateness Cost	Travel Cost	Total Cost
5 min.	$(18/60) \cdot 5$	0	$(2/60) \cdot 10$	\$1.83
10 min.	$(12/60) \cdot 5$	0	$(3/60) \cdot 10$	\$1.50
15 min.	$(5/60) \cdot 5$	0	$(5/60) \cdot 10$	\$1.25 ***
20 min.	0	$(3/60) \cdot 2$	$(8/60) \cdot 10$	\$2.33
25 min.	0	$(10/60) \cdot 20$	$(10/60) \cdot 10$	\$5.00

For the example, an arrival time of 15 min, the end of slice 3, is preferred.

Had there been a toll, the appropriate toll value would have been added to the total cost and the Type 3 traveler would have selected the arrival time which minimizes the sum. Because BTS 1.1 allows tolls to vary among time slices, the optimal arrival time would not necessarily be the same as above. Type 1 and Type 2 travelers, on the other hand, are not influenced by tolls because their objective function is not cost based.

BTS assumes that only a portion of the travelers would own the required equipment to access the automated route. So each of the three classes is divided into two categories, designated automation equipped (AE) and not equipped (NE). The latter group chooses the optimal route among those that are accessible.

B.2 Route Assignment

To illustrate how vehicles are assigned to routes, suppose that 50% of vehicles fall in the class AE, and that 20% of vehicles are allowed to change routes at any iteration. Now, suppose that the following costs are available for Type 3 travelers:

Desired Time Slice	Cost			Current Assignment		
	Rte 1	Rte 2	Rte 3 (auto)	Rte 1	Rte 2	Rte 3 (auto)
9	7	6	5	140 NE 160 AE	60 NE 0 AE	0 NE 40 AE

For AE vehicles, Route 3 is optimal and for NE vehicles, Route 2 is optimal. Therefore, in the next iteration vehicles will be assigned as follows for the time slice:

Route 1:	Not automated:	$140 - .20 (140) = 112$	(20% shift to route 2)
	Automated:	$160 - .20 (160) = 128$	(20% shift to route 3)
Route 2:	Not automated:	$60 + .20 (140) = 88$	(20% come from route 1)
	Automated:	0	
Route 3:	Not automated:	0	
	Automated:	$40 + .20 (160) = 72$	(20% come from route 1)

The assignment to routes for Type 1 and 2 travelers is done in a similar fashion.

Running BTS over several iterations reveals how traveler behavior evolves over time. However, BTS does not guarantee that route and arrival time choices converge toward an equilibrium. Rather, BTS is designed to mimic different types of behavior, which may or may not converge.

After an iteration is completed, the number of arrivals within each class, for each time slice, is incremented by a user specified proportion representing annual growth in highway traffic. However, if desired, the number of arrivals can be held constant from iteration to iteration.

The user specifies how demand should be allocated to the different traveler types. If desired, all travelers can be allocated to the first type, in which case the distribution of arrivals among the time slices remains constant from iteration to iteration. Within each type, different travelers have different desired arrival or departure times, as specified by the user.

B.3 Reneging

BTS 1.1 allows users to specify a reneging function to account for lost traffic as delay increases. Because the reneging function is cost based, it only applies to Type 3 travelers.

For each of four levels, the user specifies a cost threshold and a percentage. When the cost to a class of travelers exceeds the threshold, the baselevel traffic volume is decreased by the corresponding percentage. Reductions apply to the iteration following the one for which costs are calculated. For example, suppose that you have input the following reneging function:

Cost	% loss
2.00	10
3.00	20
4.00	40
5.00	80

Then the renegeing function would adjust traffic volumes as follows for the example data:

Desired Arrival Time Slice	Minimum Cost	Baselevel Traffic Volume	Adjusted Traffic i+1
10	1.5	600	600
11	2.0	700	630
12	2.8	700	630
13	3.6	800	640
14	2.9	750	675
15	1.9	550	550

BTS stores the baselevel traffic volume at the end of each iteration, not the adjusted traffic volume. Therefore, allowances for renegeing in an iteration are independent of the number of travelers that renegeed in the previous iteration, except to the extent that renegees affect travel costs.

Allowing for renegees acts to reduce travel costs because there is less congestion. Allowing for renegees also reduces the total number of arrivals because people are discouraged from traveling. Therefore, renegeing has both positive and negative consequences.

CHAPTER 3
OPERATION OF BTS

The input data for BTS can be divided into five categories: route characteristics, system breakdown, driver choice behavior, traffic volume distribution, and the simulation control data. The data from the first four categories can be created as a new file, retrieved from an existing file, or saved into a file of the user's choice. The last category can be entered before simulation by choosing the selection "Run Simulation Program" in the main menu of BTS. When the simulation is done, the results, including a summary statistics report and a detailed arrival volume and delay list, will be stored on the files Report.prn and a user specified Lotus file.

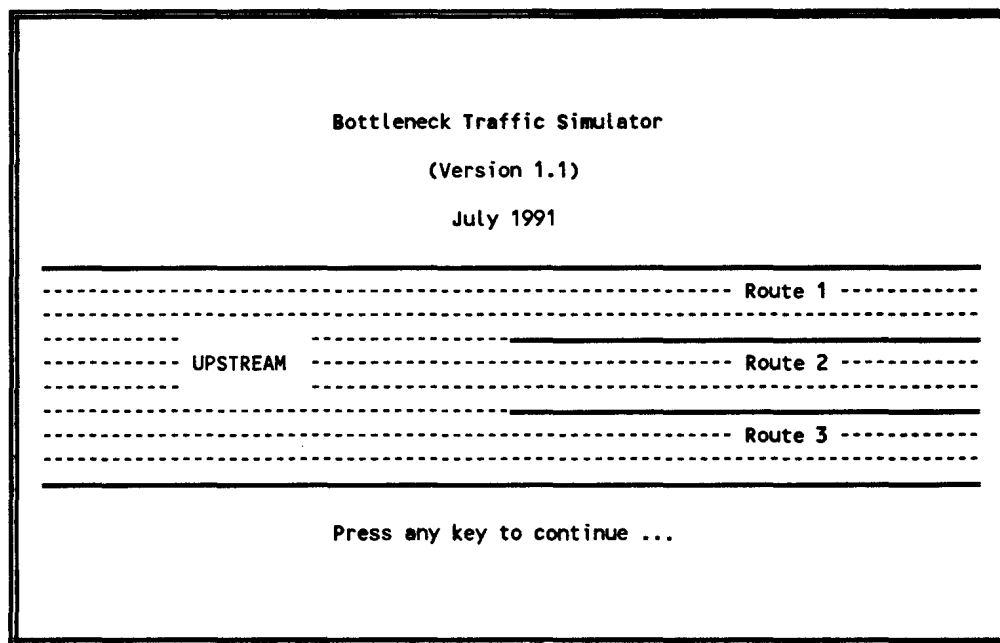


Figure 3.1 Bottleneck Traffic Simulator (Version 1.1)

To execute BTS, type BTS followed by ENTER. When BTS begins execution, the panel shown in Figure 3.1 will appear on the screen. Pressing any key twice brings up the main menu as shown in Figure 3.2.

The main menu consists of six parts. The following section examines these parts. A list of data descriptions is given in section B of this chapter.

A. Program Structure

- **Create New Data Set** When Selection 1 is chosen, you will see the screen shown in Figure 3.3. Initially, each data is assigned a minimum value. Figures 3.4 through 3.7 show a set of data after input.

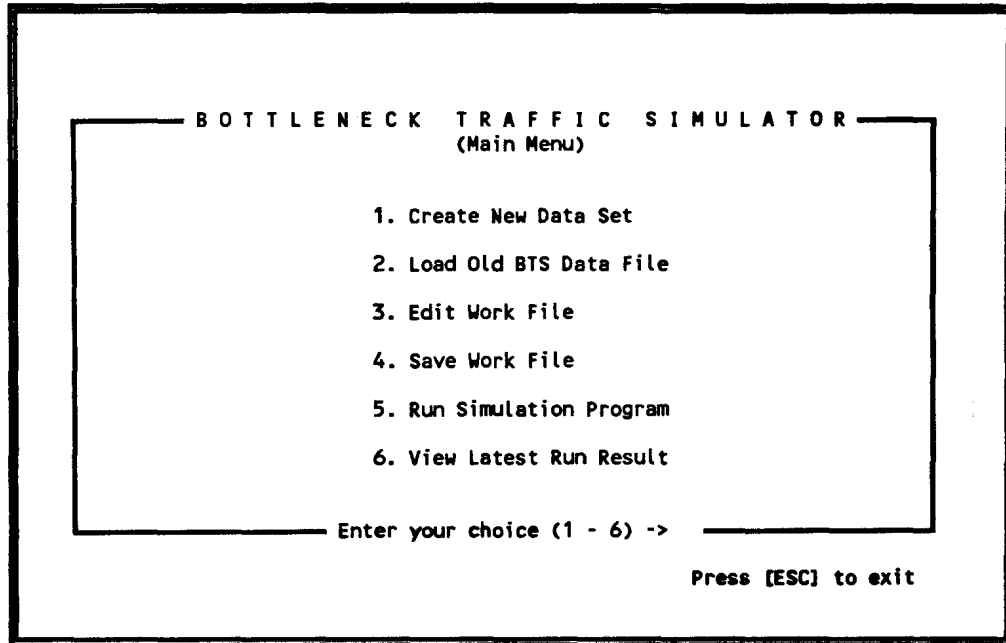


Figure 3.2 Main Menu for BTS

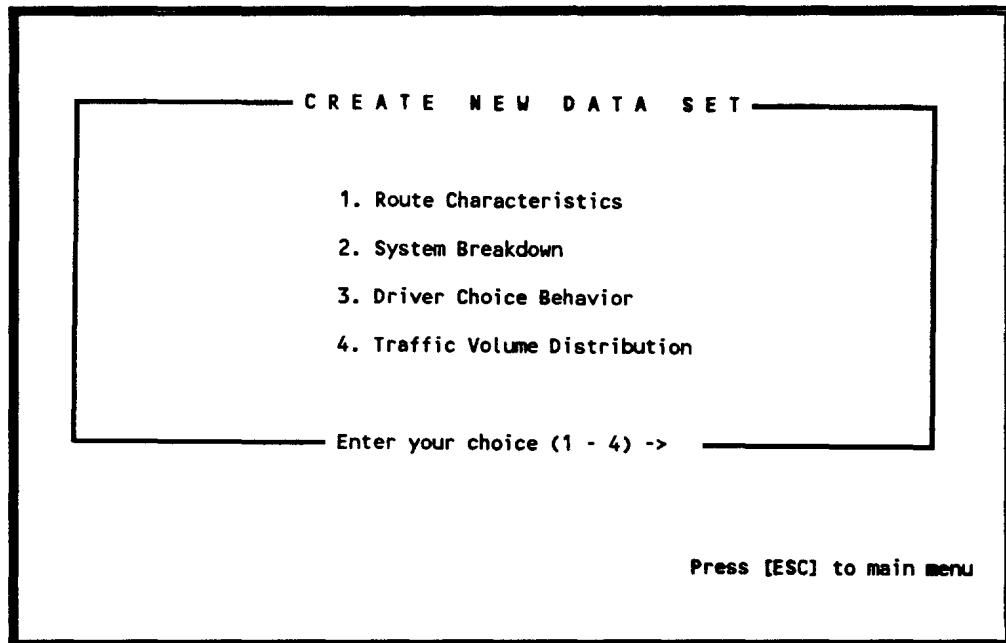


Figure 3.3 Selection 1: Create New Data Set

* ROUTE CHARACTERISTICS *				
	Rte 1	Bottleneck Rte 2	Rte 3	Upstream
Free flow travel time (min):	15.00	10.00	5.00	
Capacity (veh/hour):	3500	2500	2000	8800
Weather effects on route capacity:				
Weather Type	Probability	Rte 1	Rte 2	Rte 3
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
Time dependent toll (dollars/veh):				
Time Slice	Rte 1	Rte 2	Rte 3	
1 - 12	0.00	0.00	0.00	
13 - 24	0.00	0.00	0.00	
25 - 36	0.00	0.00	0.00	
37 - 45	0.00	0.00	0.00	
Press [ESC] to exit				

Figure 3.4 Route Characteristics

* SYSTEM BREAKDOWN *				
Prob(no incident occurs no current incident)	Rte 1	Rte 2	Rte 3	
	0.99	0.99	1.00	
Prob(no incident occurs current incident)	Rte 1	Rte 2	Rte 3	
	0.99	0.99	1.00	
Duration of breakdown (Time slices): Lower bound	1	1	1	
(Uniform distribution) Upper bound	12	12	12	
Capacity loss distribution:				
Level of capacity Loss	Rte 1	Rte 2	Rte 3	Probability
10%	0.45	0.45	0.45	
20%	0.35	0.35	0.35	
30%	0.05	0.05	0.05	
40%	0.05	0.05	0.05	
50%	0.05	0.05	0.05	
60%	0.05	0.05	0.05	
70%	0.00	0.00	0.00	
80%	0.00	0.00	0.00	
90%	0.00	0.00	0.00	
100%	0.00	0.00	0.00	
Press [ESC] to exit				

Figure 3.5 System Breakdown

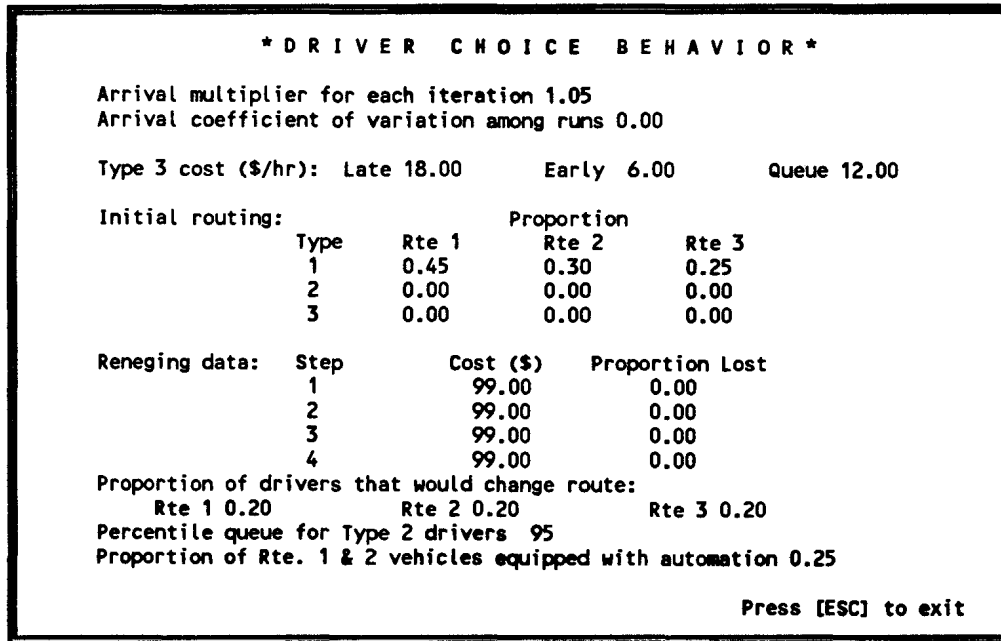


Figure 3.6 Driver Choice Behavior

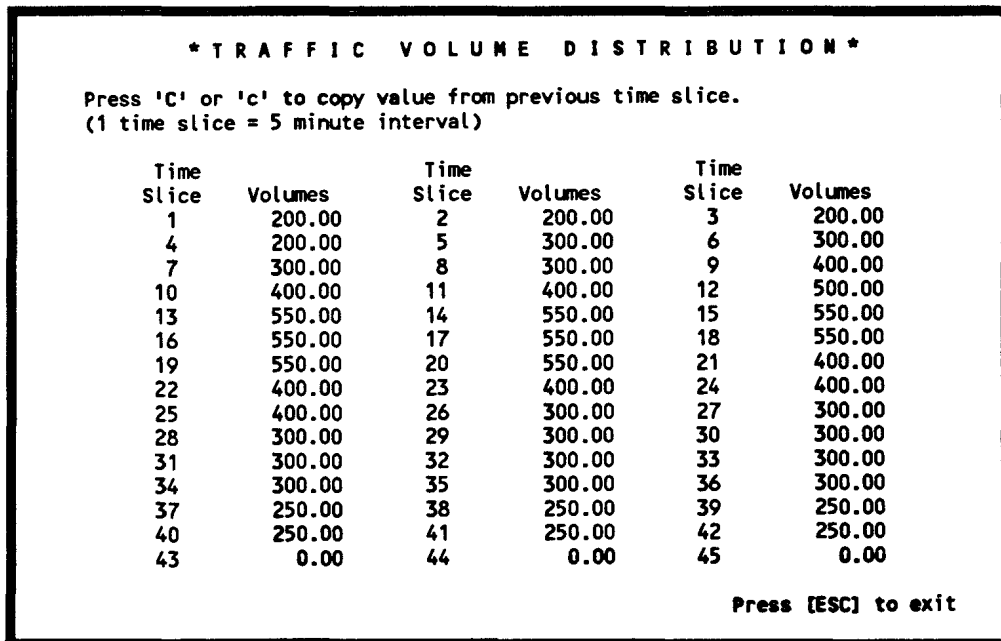


Figure 3.7 Traffic Volume Distribution

Inside the editor, the cursor movement is controlled by the four arrow keys and the ENTER key. Pressing ENTER moves the cursor to the next entry. As you move through the screen, the range of each entry is displayed at the lower left corner. The editor automatically checks your data to insure that it falls in the given range. Data inconsistencies (for example, a sum of probabilities that does not equal one) are not checked until the simulation is executed. In Selection 4, Traffic Volume Distribution, consecutive identical traffic volumes can be duplicated by typing "C" or "c."

A newly created file becomes a work file once the user chooses to exit to the main menu.

- **Load Old BTS Data File** When Selection 2 is chosen, you will see the screen shown in Figure 3.8. At this point, you are required to provide the name of an existing BTS file. *BTS only reads files written by BTS.* Should you wish to locate a data file in one of your directories, you may temporarily exit to DOS by typing 'd' followed by ENTER. (This option should not be used to exit BTS.) Once an existing BTS data file is successfully loaded, the file assumes the status of a work file. At this point you can either modify the data or run the simulation program from the file.

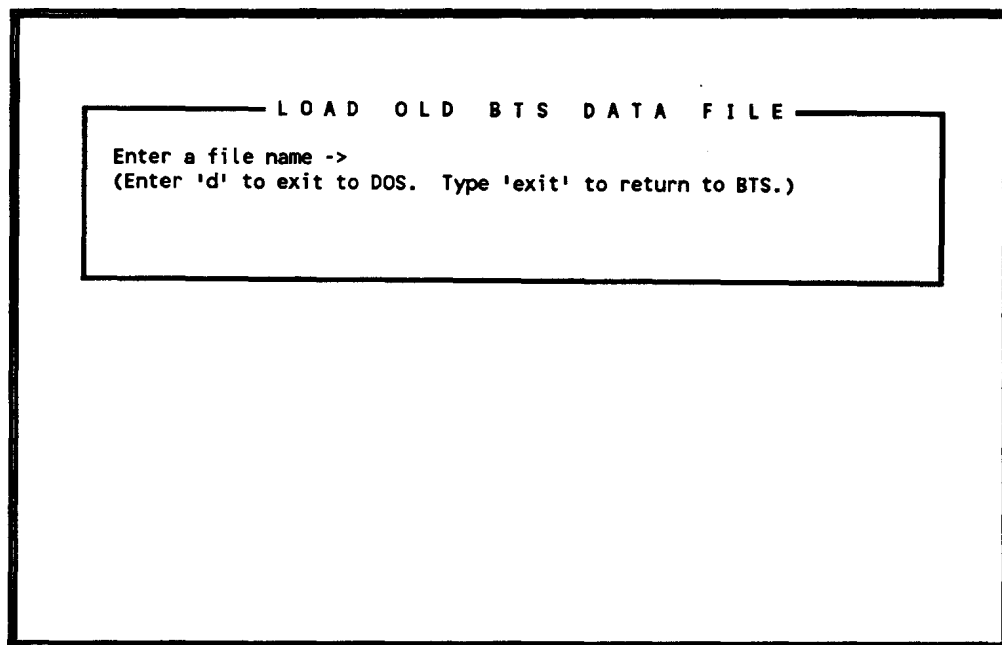


Figure 3.8 Selection 2: Load Old BTS Data File

- **Edit Work File** You can modify any data in a work file from Selection 3. A work file can either be a newly created BTS file or an old BTS file. This selection must be preceded by either Selection 1 or 2. The editor is identical to the editor in Selection 1.
- **Save Work File** When Selection 4 is chosen, you will see the screen shown in Figure 3.9. If the current work file is newly created, you must provide BTS with a name. If the current work file is an existing file, you can either overwrite it or save it under a different name.

- **Run Simulation Program** When Selection 5 is chosen, the panel shown in Figure 3.10 will appear on the screen. The simulation control data must be specified by the user. The number of time slices must be less than or equal to the number of slices for which traffic volume data was assigned. Before execution, BTS checks your data for inconsistencies. If you receive an error message, return to the editor to make necessary corrections.

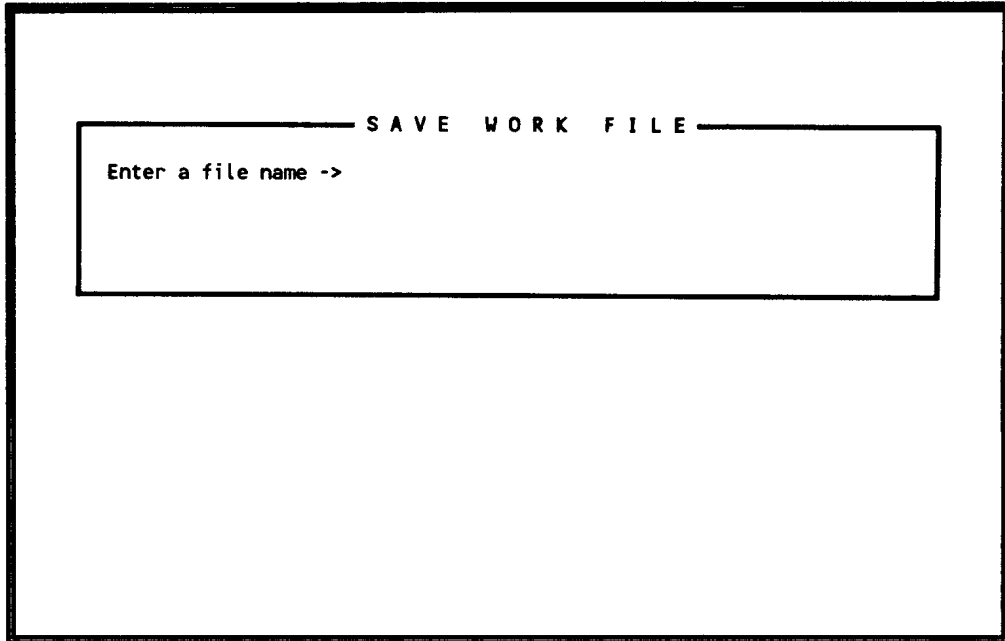


Figure 3.9 Selection 4: Save Work File

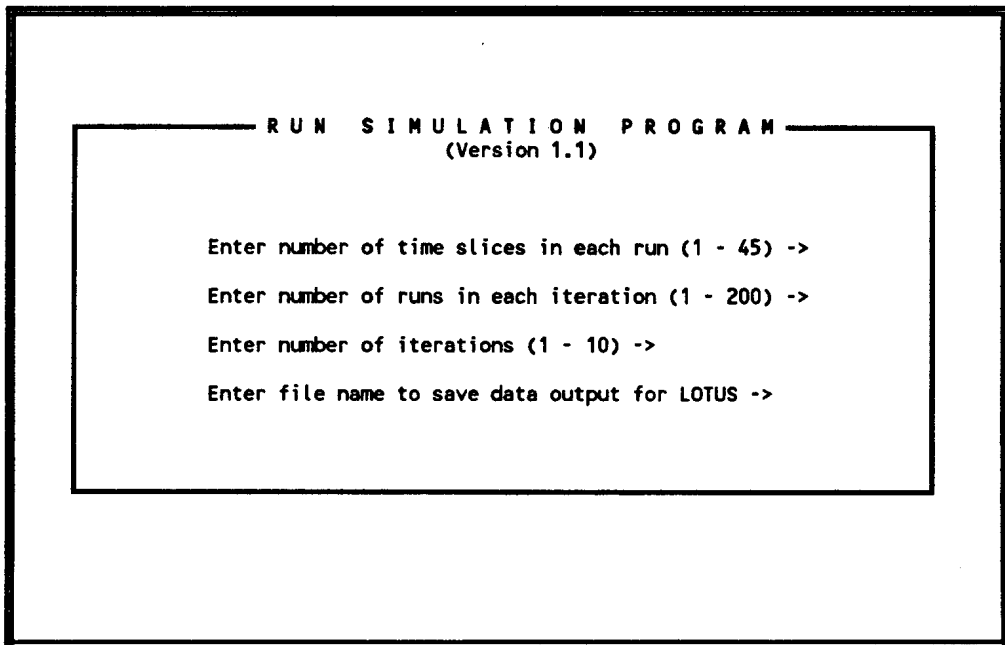


Figure 3.10 Selection 5: Run Simulation Program

- View Latest Run Result** When Selection 6 is chosen, you will see a simulation report with all the input data and a summary statistics report from the most recent simulation run. The report is stored in the file REPORT.PRN.

B. Data Definitions

The following is a full description of the data in each category, including the ranges and units. Each entry also shows whether the data element is specific to route, driver type and/or time slice.

B.1 Route Characteristics

- Free flow Travel Time**
Range: 0.00 .. 20.00 Specific: Route Unit: Minutes

Time required to travel through route *i* with *no wait in queue*.

- Bottleneck capacity**
Range: 0 .. 12000 Specific: Route Unit: Vehicles/hour

Nominal capacity by route under regular weather conditions in the absence of incidents.

- Upstream capacity**
Range: 0 .. 12000 Unit: Vehicles/hour

Total upstream capacity among all routes. Program assumes that no incidents occur upstream and that the weather is always normal. The upstream capacity must exceed the combined capacity of the bottleneck routes.

- Weather type distribution**
Range: 0.00 .. 1.00 Specific: Route Unit: Probability

Probability that Weather Type 1, 2, or 3 occurs in a run. These probabilities must sum to a value less than or equal to one. One minus the sum of these probabilities is the probability of normal (full capacity) weather.

- Weather effects on capacity**
Range: 0.00 .. 1.00 Specific: Route, Weather Type Unit: Proportion

The loss in route capacity due to the associated weather type, expressed as a proportion.

- Time dependent toll cost**
Range: 0.00..9.99 Specific: Route, Time Slice Unit: Dollars

The toll is the charge paid by drivers to use each route at a specific time of day. This toll is added to the lateness, earliness and travel cost for Type 3 drivers (cost minimizers), and influences their arrival time, route and renegeing. Tolls do not affect the choices for Type 1 and Type 2 drivers.

B.2 System Breakdown

- Probability that no incident occurs given the system is working
Range: 0.00 .. 1.00 Specific: Route Unit: Probability

Probability that *no new* incident occurs in a time slice in the absence of outstanding incidents.

- Probability that no incident occurs given the system is not working
Range: 0.00 .. 1.00 Specific: Route Unit: Probability

Probability that *no new* incident occurs in a time slice in the presence of outstanding incidents. This may be somewhat smaller than the working probability because outstanding incidents may lead to new accidents.

- Duration of breakdown
Range: 1 .. 12 Specific: Route Unit: Time Slices

Two parameters provide lower and upper bounds of a uniform probability distribution used to simulate incident duration.

- Capacity loss distribution
Range: 0.00 .. 1.00 Specific: Route Unit: Proportion

The level of the capacity loss expressed as a proportion, in 10% increments. *The sum of the proportions must equal one.*

B.3 Driver Choice Behavior

- Arrival multiplier per iteration
Range: 0.80 .. 1.50 Specific: None Unit: None

The multiplier by which baseline traffic is changed after each iteration. The value is applied identically to each driver type and each route at the end of each iteration, *after accounting for all shifts in arrival time and route*. For example, suppose that 400 Type 2 drivers are assigned to time slice 5 and Route 2, and that the multiplier is set to 1.1. Then the multiplier will increase the number of drivers to 440 at the start of the next iteration. The renegeing function is applied after the increment is calculated.

- Arrival coefficient of variation
Range: 0.00 .. 0.10 Specific: None Unit: None

The ratio of the standard deviation to the mean, used to randomly simulate traffic volume by run according to a normal probability distribution.

- Type 3 driver costs
Range: 0.00 .. 99.00 Specific: Type 3 Drivers Unit: Dollars/hour

Three parameters account for personal cost with respect to earliness, lateness, and queueing time, for Type 3 drivers (cost minimizers). Queueing cost also applies to free-flow time.

- Initial routing**
Range: 0.00 .. 1.00 Specific: Route, Driver Type Unit: Proportion

Nine parameters determine the initial proportional assignment of drivers to route, and type. Let

$$R_{i,j} = \text{proportion of drivers that are type } i \text{ and choose route } j;$$

$R_{i,j}$ is multiplied by the total traffic volume, specified earlier, to obtain the drivers by type and route. As an example, suppose that 400 drivers are assigned to time slice 6. With $R_{1,1} = 0.2$, $R_{1,2} = 0.2$, and $R_{2,3} = 0.6$, 160 are Type 1 drivers and 240 are Type 2 drivers. All Type 2 drivers initially choose Route 3, whereas half of the Type 1 drivers choose Route 1 and the other half choose Route 2. *The sum of the proportions must equal one.*

As the simulation progresses, drivers are allowed to change route. However, driver type stays the same in all iterations.

- Reneging data (travel cost level)**
Range: 0 .. 99.99 Specific: Type 3 Drivers Unit: Dollars

Specifies 4 thresholds of travel cost that determine when Type 3 drivers choose not to travel. Traffic volume is decreased by the percentage corresponding to the highest threshold exceeded by the travel cost (sum of earliness, lateness, queueing and toll). *This parameter only affects Type 3 drivers.*

- Reneging data (Proportion of Type 3 drivers that renege)**
Range: 0.00 .. 1.00 Specific: Type 3 Drivers, Cost Threshold Unit: Proportion

Specifies the proportion of Type 3 drivers that renege corresponding to each travel cost level. The travel cost for Type 3 drivers is calculated at the end of each iteration. The loss percentage is applied to the baseline traffic volume in the following iteration.

- Proportion of the vehicles that would change route**
Range: 0.00 .. 1.00 Specific: None Unit: Proportion

For each route, a parameter specifies the proportion of drivers that will shift to an alternate route after an iteration, if a lower cost route is available. The same proportion is used for all driver types.

- Percentile queue for Type 2 Drivers**
Range: 0.00 .. 100 Specific: Type 2 Drivers Unit: Percentile

The percentile of the waiting time distribution used by Type 2 drivers in selecting arrival time and route (The probability that Type 2 drivers depart on time). The parameter is also used to format output.

- Proportion of vehicles on Route 1 and 2 equipped with automation**
Range: 0.00 .. 1.00 Specific: Route, Driver Type Unit: Proportion

The proportion of the vehicles initially assigned to Route 1 and 2 that own the required equipment to access Route 3, the automated route. 100% of the vehicles initially assigned to Route 3 are automated.

B.4 Traffic Volume Distribution

- Number of vehicles in time slice i
Range: 0.00 .. 2000.00 Specific: Time Slice Unit: Vehicles

Initial assignment of vehicles to time slices. The volume is the sum among all vehicle types and routes, and does not distinguish between a desired arrival time and a desired departure time. Let A_i = volume in time slice i . Then if A_6 is set to 500, a total of 500 vehicles desire to depart or arrive from the bottleneck at time slice 6. *Each time slice represents a five minute interval.*

B.5 Simulation Control Data

- Number of time slices to be simulated
Range: 0 .. 45 Specific: None Unit: None

Specifies the number of time slices to be simulated in each run. Each time slice is equivalent to a five minute time interval. *To use the preset graph settings in Lotus 1-2-3, the number of time slices must equal 42.*

- Number of runs per iteration
Range: 0 .. 200 Specific: None Unit: None

Specifies the number of runs in each iteration. Each run is equivalent to a single day of up to 45 5-minute time slices, or a maximum period of 3 hours and 45 minutes.

- Number of iterations
Range: 0 .. 10 Specific: None Unit: None

Specifies the number of iterations per simulation. Each iteration represents a block of time (e.g., a year) over which route and arrival time choices do not change.

- Name of the output file
Range: N/A Specific: None Unit: None

Specifies a valid file name that stores output to be used in Lotus 1-2-3.

CHAPTER 4

EXAMPLE RUNS

Before running BTS, the files **BTS.EXE**, **QM.EXE** and **VIEW.EXE** must be on the run-time disk. BTS provides a demo file, **BTS.DAT**, with the same set of data as displayed in Figures 3.4 through 3.7 in Chapter 3. The steps to run the simulation on **BTS.DAT** follow.

Example 1: Base Case

- 1) Type command **BTS** at DOS prompt. Press **ENTER** twice to bring up the main menu.
- 2) Select choice 2. Type **BTS.DAT** and press **ENTER** to load the demo file. After the file is successfully loaded, press **ENTER** again to exit to the main menu.
- 3) Select choice 5. Type **42**, **50**, **10**, and **LOTUS.PRN** for the prompts and then press any key to start the simulation. As the simulation is in progress, you may press **ESC** to terminate the simulation. At the end of the current run, you will see a message "OK to quit? (y/n)." At this prompt, you may choose to exit to the main menu or continue the simulation. *If you exit, the summary statistics report and the output data file will be lost.*
- 4) When the simulation is done, the screen will provide a summary of performance statistics as shown in Figure 4.1.

```
Number of periods simulated: 42
Number of runs in each simulation: 50

-- Summary Statistics --
```

Iteration	Total Arrivals (vehicles)	Free Flow Travel Time Per Veh (minutes)	System Recurrent Per Veh (min)	Queue Time Per Veh		Upstream Recurrent Per Veh (min)
				Total Average (min)	Total 95% (min)	
1	14900	11.00	0.00	0.03	0.00	0.00
2	15645	10.36	0.00	0.07	0.32	0.00
3	16427	9.85	1.14	1.18	1.31	0.00
4	17249	9.50	3.06	3.31	4.87	0.00
5	18111	9.62	2.74	3.00	4.27	0.00
6	19017	9.69	2.84	3.03	4.28	0.00
7	19967	9.72	4.56	5.14	8.40	0.03
8	20966	9.93	4.60	5.07	8.20	0.40
9	22014	9.94	7.07	7.25	8.44	0.94
10	23115	10.01	9.68	10.53	15.38	1.81

Figure 4.1 Simulation Result for Example 1

5) Press any key to generate a summary report file. The simulation summary statistics and all the input data will be stored in the file REPORT.PRN. If REPORT.PRN does not exist, a new file is created. **If REPORT.PRN already contains the output from a previous simulation, it will be replaced by the output from the current simulation.** You can display the file REPORT.PRN by choosing Selection 6 in the main menu.

A more detailed output is provided in the file LOTUS.PRN. It contains the recurrent delay, nonrecurrent delay, and percentile delay by time slice and route, cumulative traffic volume by time slice and by route, upstream delay by time slice, and total cumulative traffic volume by time slice. This file can be examined in Lotus 1-2-3, as discussed in Chapter 5.

The above example only employs basic features of BTS. Some of the extended features of BTS are demonstrated in the following two additional examples.

Example 2: Weather Effect, Incident Dependency, and Arrival Variation

This example demonstrates the weather effect, incident dependency, and arrival variation. To run the example, use the cursor to move between entries and modify your input data as shown in Figure 4.2, keeping all other data the same as in the previous example. The summary statistics of the simulation are shown in Figure 4.3. Compared to the previous example, the added factors of Example 2 lead to greater variation in travel time, as indicated by the percentile data. Mean queue time is also larger because there is less capacity on average.

* ROUTE CHARACTERISTICS *					
Weather effects on route capacity:					
Weather Type	Probability	Capacity Loss			
		Rte 1	Rte 2	Rte 3	
1	0.10	0.05	0.05	0.05	
2	0.05	0.10	0.10	0.10	
3	0.02	0.15	0.15	0.15	
* SYSTEM BREAKDOWN *					
		Rte 1	Rte 2	Rte 3	
Prob(no incident occurs	no current incident)	0.99	0.99	1.00	
Prob(no incident occurs	current incident)	0.98	0.98	1.00	
* DRIVER CHOICE BEHAVIOR *					
Arrival multiplier for each iteration 1.05					
Arrival coefficient of variation among runs 0.10					

Figure 4.2 Modified Data for Example 2

Number of periods simulated: 42
Number of runs in each simulation: 50

-- Summary Statistics --

Iteration	Total Arrivals (vehicles)	Free Flow Travel Time Per Veh (minutes)	System Recurrent Per Veh (min)	Queue Time Per Veh		Upstream Recurrent Per Veh (min)
				Total Average (min)	Total 95% (min)	
1	14900	11.00	0.00	0.46	1.71	0.00
2	15645	10.36	0.00	1.0	3.12	0.00
3	16427	9.85	1.14	6.50	13.60	0.00
4	17249	9.95	2.44	6.59	13.06	0.00
5	18111	9.94	1.97	8.04	15.29	0.00
6	19017	10.44	2.15	4.44	11.54	0.00
7	19967	10.10	3.31	9.91	20.63	0.03
8	20966	10.48	5.01	10.35	19.94	0.40
9	22014	10.71	8.41	9.71	17.89	0.94
10	23115	10.73	10.47	10.72	23.06	1.81

Figure 4.3 Simulation Result for Example 2

Example 3: Type 3 Behavior and Tolls

To shift all drivers to Type 3, the initial routing is modified as shown in Figure 4.4. Data is also provided to define a reneging function. When travel cost exceeds \$4.00, 10% or more of the drivers choose to renege. Finally, the example pertains to a toll road, with a \$2.00 charge.

* ROUTE CHARACTERISTICS *

Time dependent toll (dollars/veh):

Time Slice	Rte 1	Rte 2	Rte 3
1 - 12	2.00	2.00	2.00
13 - 24	2.00	2.00	2.00
25 - 36	2.00	2.00	2.00
37 - 45	2.00	2.00	2.00

* DRIVER CHOICE BEHAVIOR *

Initial routing:

Type	Rte 1	Rte 2	Rte 3
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.45	0.30	0.25

Reneging data:

Step	Cost (\$)	Proportion Lost
1	4.00	0.10
2	5.00	0.20
3	6.00	0.30
4	7.00	0.40

Figure 4.4 Modified Data for Example 3

Number of periods simulated: 42
Number of runs in each simulation: 50

-- Summary Statistics --

Iteration	Total Arrivals (vehicles)	Free Flow Travel Time Per Veh (minutes)	System Recurrent Per Veh (min)	Queue Time Per Veh		Upstream Recurrent Per Veh (min)
				Total Average (min)	Total 95% (min)	
1	14460	10.95	0.00	0.04	0.00	0.00
2	15210	10.32	0.00	0.12	0.78	0.00
3	15993	9.81	1.17	1.21	1.33	0.00
4	16655	9.45	4.79	4.99	6.25	0.22
5	16744	9.67	6.66	6.82	7.27	1.87
6	17709	9.78	9.65	9.77	10.49	3.51
7	18351	9.73	8.62	8.86	10.41	2.54
8	19588	9.72	12.87	13.24	16.11	2.34
9	19829	9.85	15.38	15.53	16.72	2.65
10	21642	9.86	27.10	27.75	31.17	7.41

Figure 4.5 Simulation Result for Example 3 (With Reneging)

Number of periods simulated: 42
Number of runs in each simulation: 50

-- Summary Statistics --

Iteration	Total Arrivals (vehicles)	Free Flow Travel Time Per Veh (minutes)	System Recurrent Per Veh (min)	Queue Time Per Veh		Upstream Recurrent Per Veh (min)
				Total Average (min)	Total 95% (min)	
1	14460	10.95	0.00	0.04	0.00	0.00
2	15210	10.32	0.00	0.12	0.78	0.00
3	15993	9.81	1.17	1.21	1.33	0.00
4	16811	9.46	5.14	5.36	6.74	0.24
5	17668	9.73	8.46	8.69	9.70	2.78
6	18564	9.95	15.21	15.39	16.40	6.38
7	19504	10.03	15.14	15.44	17.09	5.46
8	20488	10.04	21.77	22.31	25.79	8.34
9	21521	9.98	30.46	30.73	32.42	10.00
10	22603	9.94	36.97	37.76	42.40	11.50

Figure 4.6 Simulation Result for Example 3 (Without Reneging)

The simulation is performed twice, once with reneging and once without reneging. The results are shown in Figures 4.5 and 4.6.

Even when drivers renege, average queue time is larger than the examples with Type 1 drivers. This is because Type 3 behavior, with the cost functions indicated, creates larger peaks in the arrival curve. In the examples, you can also see that allowance for renegeing reduces both the average queue time and the total number of arrivals.

CHAPTER 5

EVALUATION OF BOTTLENECK PERFORMANCE WITH LOTUS 1-2-3

After the simulation is complete, system performance can be evaluated in greater detail using Lotus 1-2-3. This can be done in the following steps.

- 1) Return to DOS and enter your LOTUS 1-2-3 program.
- 2) Select the /File/Retrieve option, and select Lotshell.wk1 from the drive that contains your BTS program.
- 3) Move the cursor to the cell that states "Import Lotus.prn here."
- 4) Select the /File/Import/Numbers option, and select Lotus.prn from the drive that contains your BTS program.

You will now have access to graphs and data that provide arrivals and queueing time by route, time slice and iteration. Each column is formatted as follows:

Column A:	Time Slice	
Column B:	Cumulative Arrivals	(Route 1)
Column C:	Percentile Wait per Vehicle	
Column D:	Average Wait per Vehicle	
Column E:	Recurrent Wait per Vehicle	
Column F:	Cumulative Arrivals	(Route 2)
Column G:	Percentile Wait per Vehicle	
Column H:	Average Wait per Vehicle	
Column I:	Recurrent Wait per Vehicle	
Column J:	Cumulative Arrivals	(Route 3)
Column K:	Percentile Wait per Vehicle	
Column L:	Average Wait per Vehicle	
Column M:	Recurrent Wait per Vehicle	
Column N:	Recurrent Wait per Vehicle	(Upstream)
Column O:	Cumulative Arrivals	(Sum of Route 1, 2, 3)
Column P:	Percentile Wait per Vehicle	
Column Q:	Average Wait per Vehicle	
Column R:	Recurrent Wait per Vehicle	

The data can be analyzed through any of the regular Lotus 1-2-3 features, or through the following predefined graphs. To display a graph, enter the commands:

/Graph/Name/Use

followed by the graph name. To print a graph, first save it by entering the commands /Graph/Save, followed by a graph name. The graph can later be printed from the Printgraph option of Lotus 1-2-3. The following are the preset graphs contained in the Lotshell.wk1 file:

Name	Function
CUMRT1	Cumulative arrival curve, Route 1, Iterations 2,4,6,8,10
CUMRT2	Cumulative arrival curve, Route 2, Iterations 2,4,6,8,10
CUMRT3	Cumulative arrival curve, Route 3, Iterations 2,4,6,8,10

CUMTOT Cumulative arrival curve, Total all routes, Iterations 2,4,6,8,10

AWTTRT1 Average system wait, Route 1, Iterations 2,4,6,8,10

AWTTRT2 Average system wait, Route 2, Iterations 2,4,6,8,10

AWTTRT3 Average system wait, Route 3, Iterations 2,4,6,8,10

AWTTOT Average system wait, Total, Iterations 2,4,6,8,10

PWTRT1 Percentile system wait, Route 1, Iterations 2,4,6,8,10

PWTRT2 Percentile system wait, Route 2, Iterations 2,4,6,8,10

PWTRT3 Percentile system wait, Route 3, Iterations 2,4,6,8,10

PWTTOT Percentile system wait, Total, Iterations 2,4,6,8,10

RWTRT1 Recurrent system wait, Route 1, Iterations 2,4,6,8,10

RWTRT2 Recurrent system wait, Route 2, Iterations 2,4,6,8,10

RWTRT3 Recurrent system wait, Route 3, Iterations 2,4,6,8,10

RWTTOT Recurrent system wait, Total, Iterations 2,4,6,8,10

RWTUPS Recurrent system wait, Upstream, Iterations 2,4,6,8,10

Figures 5.1 - 5.5 show five preset graphs: CUMTOT, AWTTOT, RWTTOT, PWTTOT, and RWTUPS, for Example 1. Notice that the graphs show how the queues evolve over time, both from iteration to iteration and time slice to time slice. By comparing AWTTOT to RWTTOT the extent to which incidents affect delay can also be assessed. For instance, note that incidents have a much larger impact at the end of the rush hour than at the start.

In addition to the preset graphs, users may choose to create individualized graphs. These can be saved in the Lotshell.wk1 file for reuse on different data sets. **However, to reduce memory required for future simulations, do not save your simulation output under the file name Lotshell.wk1.**

Cumulative Arrivals: Total

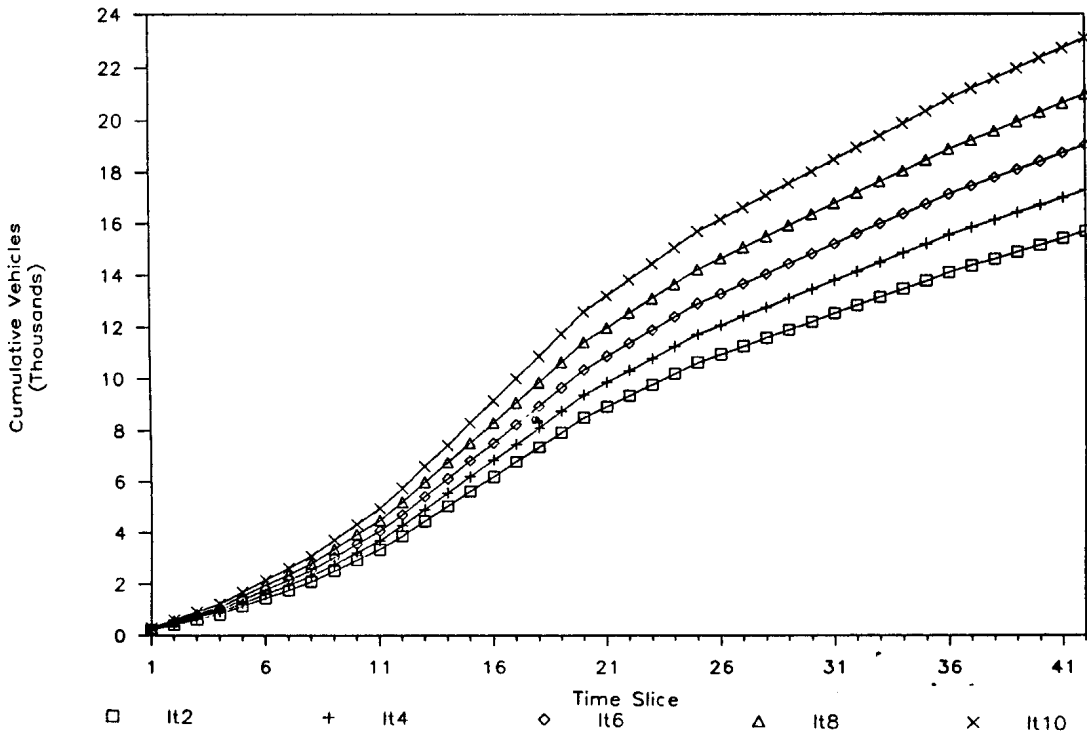


Figure 5.1 Cumulative Arrivals: Total

Average Waiting Time: Total

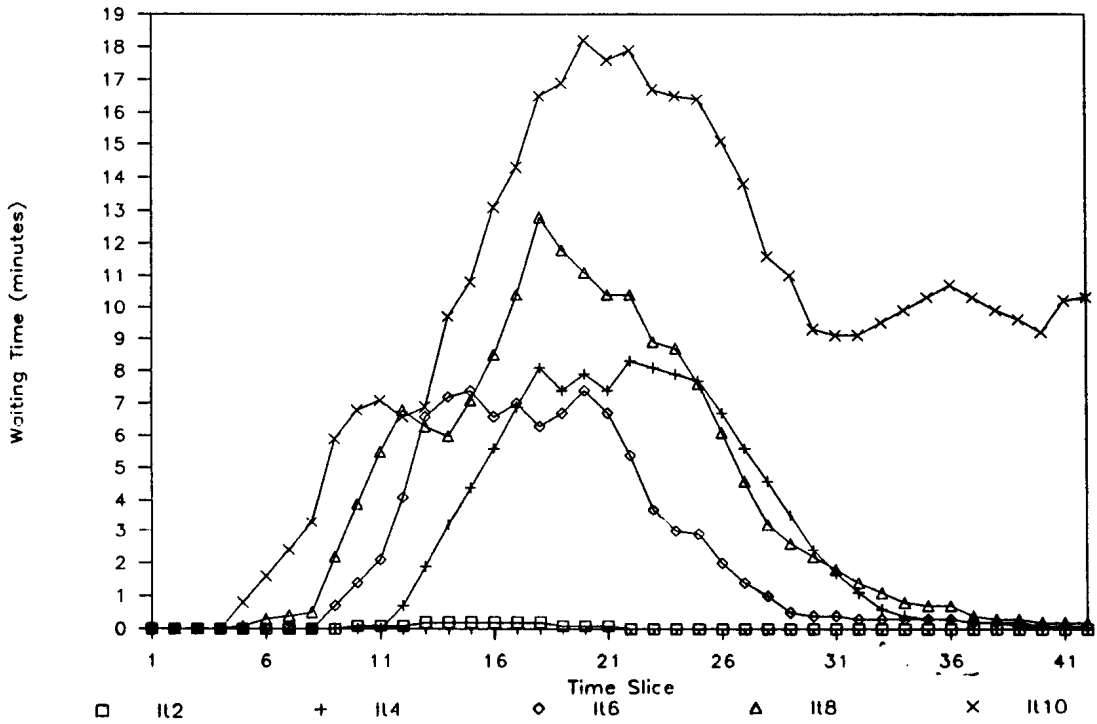


Figure 5.2 Average Waiting Time: Total

Recurrent Waiting Time: Total

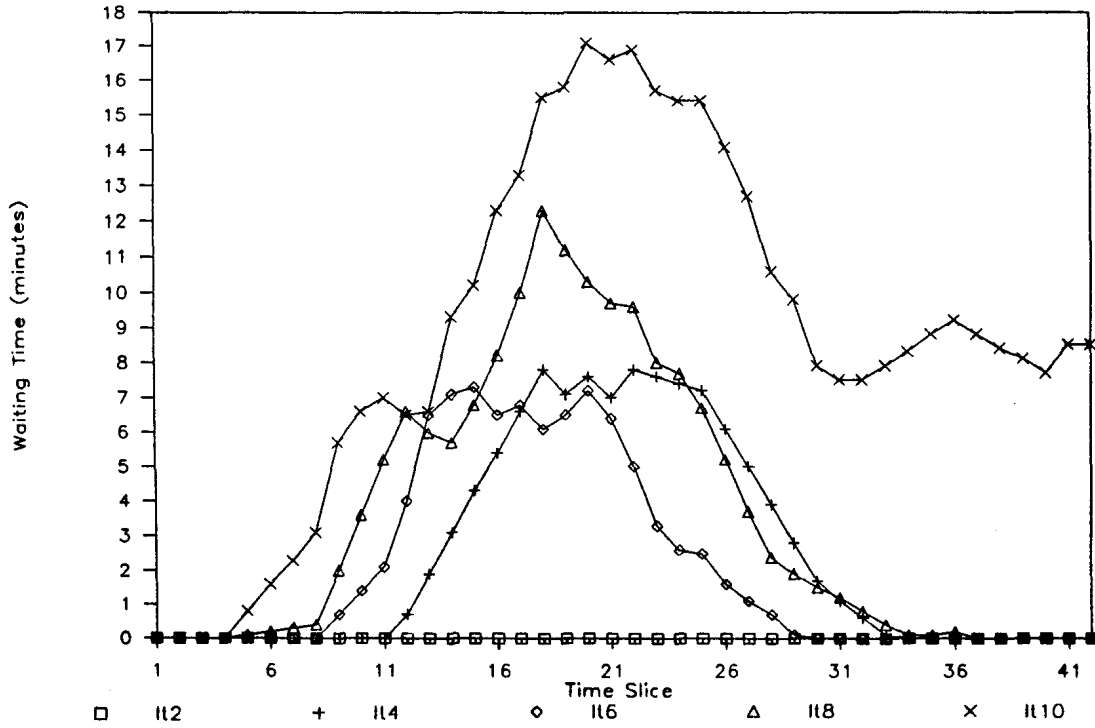


Figure 5.3 Recurrent Waiting Time: Total

Percentile Waiting Time: Total

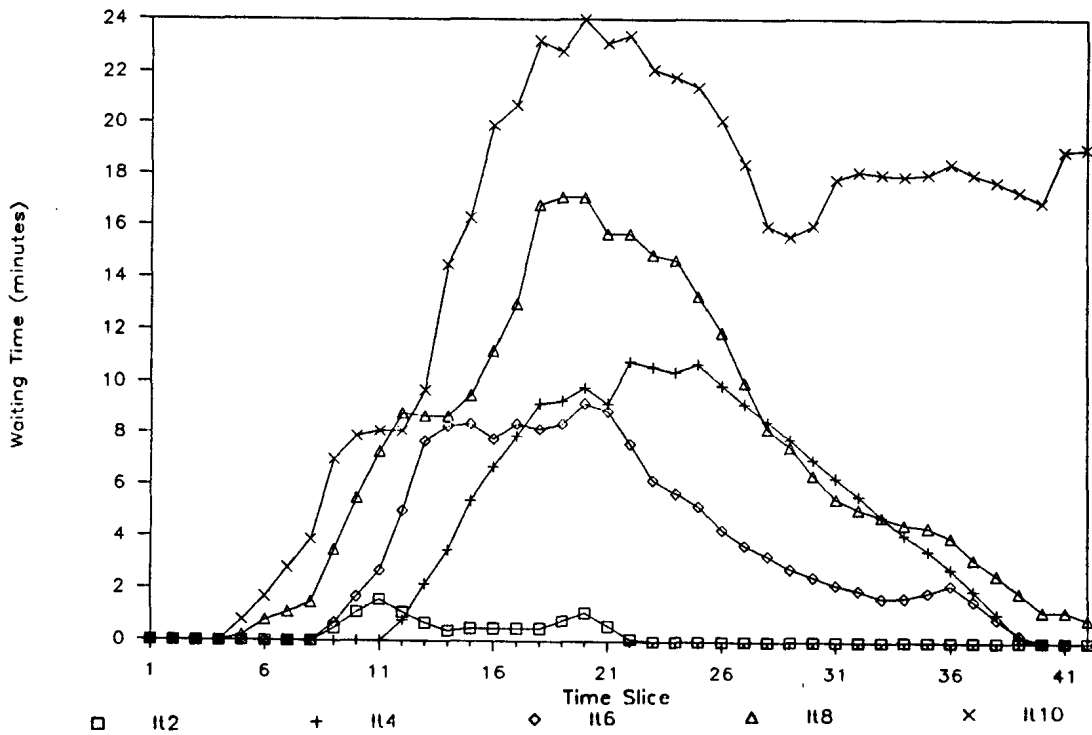


Figure 5.4 Percentile Waiting Time: Total

Recurrent Waiting Time: Upstream

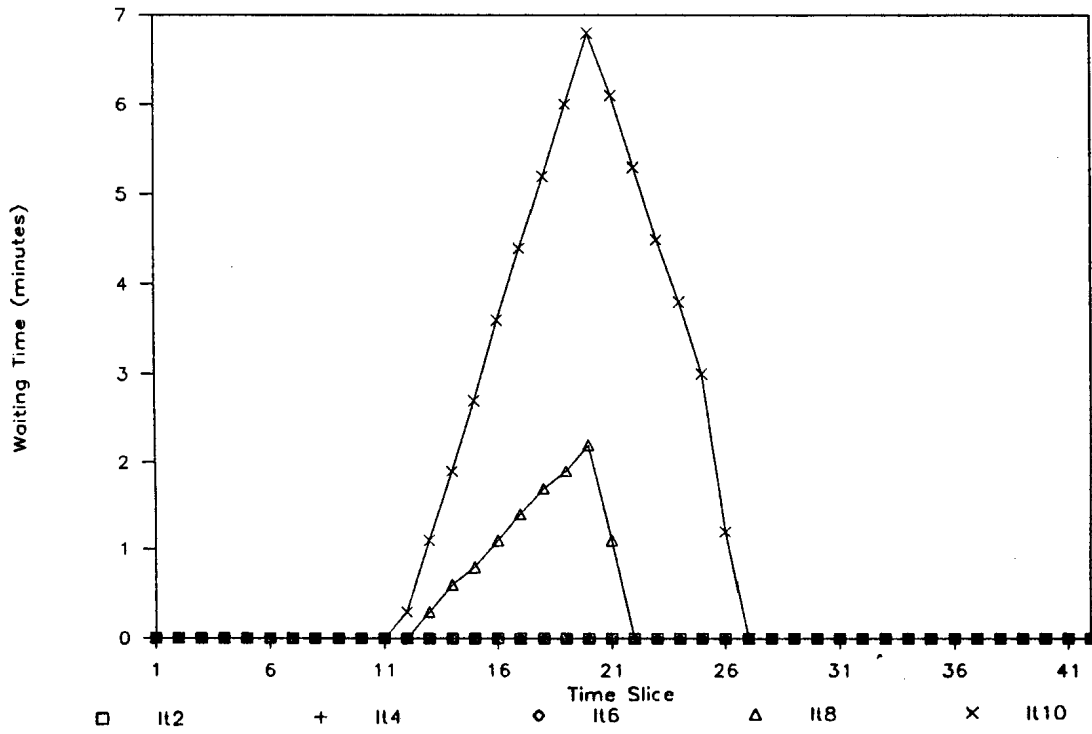


Figure 5.5 Recurrent Waiting Time: Upstream

CHAPTER 6

CONCLUSIONS

BTS can be used to evaluate a variety of changes in highway design to improve bottlenecks, such as: (1) addition of highway lanes, (2) addition of automated or HOV lanes, or (3) incident management strategies to reduce the frequency, duration and magnitude of incidents. BTS can also be used to project future highway conditions as baselevel traffic grows or driver behavior changes.

The new version of BTS was enhanced to include incident dependencies, variable weather conditions, renegeing, and randomly varying traffic volumes. As of yet, BTS is not capable of analyzing highway performance on a network basis. However, even in large networks delays are often dominated by a few key bottlenecks. BTS can be used to study the performance of these key locations.