

Staging Area Simulation Model for Seattle METRO Bus Subway

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Documented in this paper is the development of a staging area simulation model for the Municipality of Metropolitan Seattle Transit Department (Metro) bus subway. The bus subway, currently under construction, will use dual-powered buses that can operate on diesel engines above ground and from DC electric traction power from an overhead trolley wire in the tunnel. Before construction of the bus subway took place, Seattle's Metro planners wished to analyze the operation of staging areas at each end of the subway. These staging areas provide locations for changeover of traction power for the dual-powered buses and for dispatching buses into the subway in "platoons." It was believed that these areas could present capacity constraints and might introduce delay into the proposed subway operations. An interactive simulation model was developed for use on an IBM-PC. This simulation model operated in real time, featuring graphic displays of the proposed staging area. The model allowed planners to measure schedule delays and throughput at the proposed staging areas. The model also allowed planners to evaluate the performance of bus dispatchers and automatic dispatching at these locations.

Discussed in this paper are the development and structure of an interactive computer graphic model of a typical bus staging area for the Municipality of Metropolitan Seattle Transit Department (Metro) (Seattle METRO) bus subway. The objective of the model development was to create a tool that would analyze the staging area operations and could possibly be used later in training dispatchers.

Described in this paper are the system configuration to be modeled, the capabilities built into the model, the displays, and the overall model operation and structure.

SYSTEM MODELED

The Seattle METRO tunnel, shown in Figure 1, is under construction as a 1.3-mi transit subway serving five stations and running under Pine Street and Third Avenue in downtown Seattle. Three stations will be built in the subway and one station at each end will be constructed at grade outside the tunnel portals. These end stations were the focus of the simulation model. Each end or portal station will include a transition area for changeover of the dual-powered buses between diesel and electric operation, as well as for passenger boarding and alighting. Additional functions are described herein.

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Underground stations will have platforms approximately 380 ft long. Service will be provided by a fleet of dual-powered articulated buses, which receive DC electric traction power from overhead trolley wires in the tunnel. Some existing trolley bus routes will also be rerouted to use the tunnel. The tunnel is being designed for future conversion to light rail, and joint use of the tunnel by both light rail vehicles (LRVs) and trolley buses during the conversion period is being considered. The tunnel will have one bus lane/LRV trackway operating in each direction.

Because the underground station platforms are long and many bus lines will operate in the tunnel, buses will stop at prearranged locations along the platform to reduce boarding time and passenger crowding on platforms. In addition, the tunnel is currently configured as a single-lane operation in each direction with no passing lanes except at stations. These considerations have led to the concept of operating buses in platoons of two to three buses. Each bus route using the tunnel would be identified as belonging to one of two to three groups, and buses from the same group would always stop at the same platform location at each station.

For model design purposes, it was assumed that three groups of bus lines would be used: *A*, *B*, and *C*, although the model was designed to be capable of representing up to four groups with no program changes required. Group *A* buses would always stop at the head end of the platform, Group *B* buses would always stop at the middle of the platform, and Group *C* buses would always stop at the rear of the platform. Each platoon was to include three buses, one from each group in appropriate sequence (*A*, *B*, and *C*) to stop simultaneously in the required locations. Peak-hour bus service is expected to require a capacity of 180 buses/hr in each direction, or one three-bus platoon/min.

BUS PRIORITIES

Each bus in the simulation has a priority that is used to determine the sequence in which buses are dispatched at the staging area. The priority is automatically applied in the automatic dispatch mode of the simulation.

- **Deadhead buses:** Those buses that enter the tunnel with no passengers aboard and return to a METRO base (bus garage). They display a METRO BASE destination sign. There are many of these in the a.m. peak, few in the p.m. peak. They have the lowest priority and should be dispatched somewhat before the lead bus of a platoon. The model permits them to be dispatched between platoons or in an empty platoon slot. These

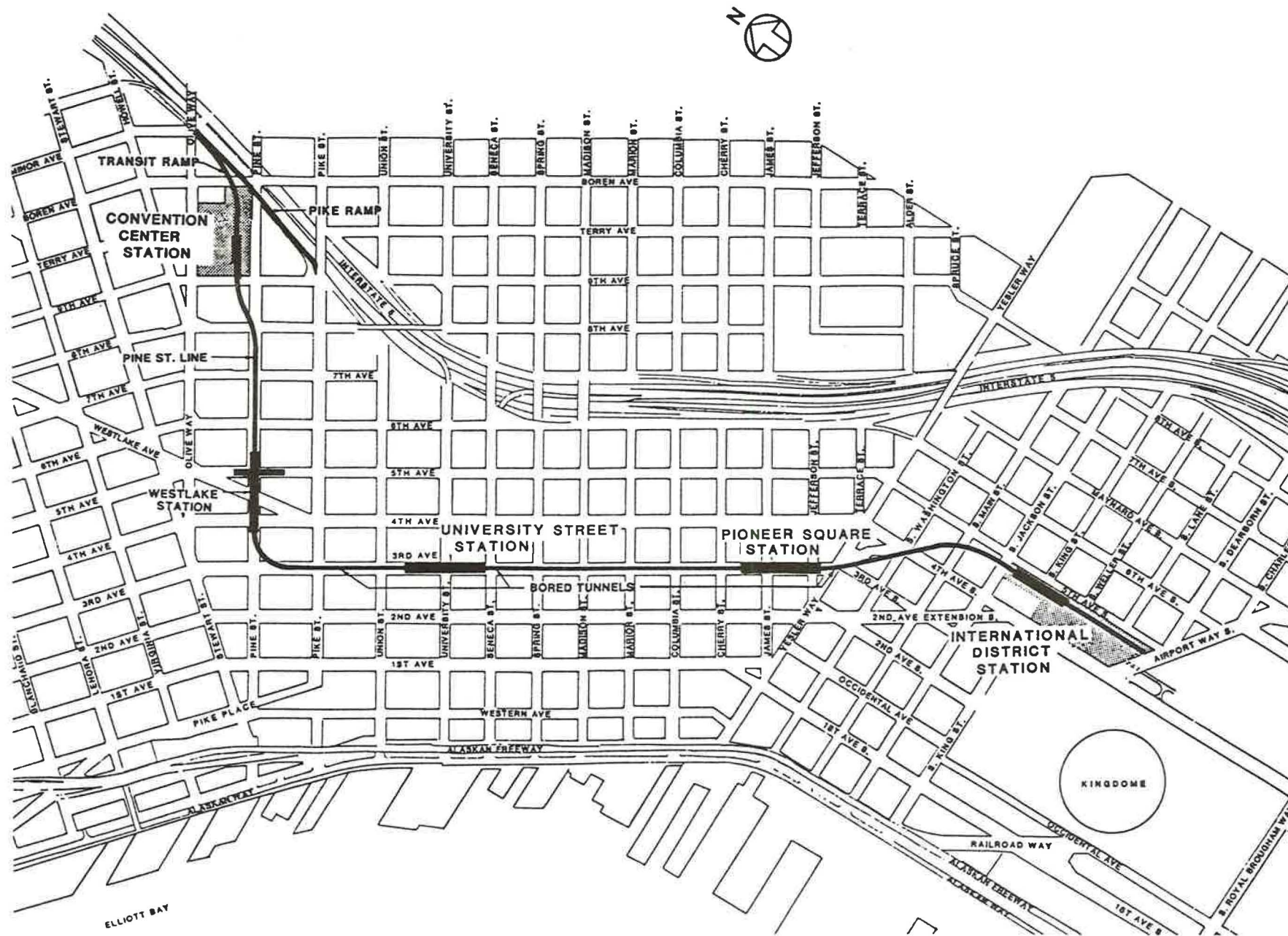


FIGURE 1 Seattle METRO tunnel plan.

buses bypass the loading platforms in the model and enter the tunnel directly from a deadhead queue lane.

- **Outbound entering service:** These buses have no passengers aboard and are coming from a METRO base. They display a route destination sign. They are, however, beginning their runs and need to maintain schedules. At the staging area they enter queues for each platoon group and enter the loading bays from these queues. They must enter the tunnel in correct platoon sequence. In the a.m. hours there will be few buses in this category; in the p.m. hours there will be many. These buses will have a "medium" priority.

- **Inbound terminating:** These buses arrive loaded from their runs and will terminate at the opposite portal station. Because they will not pick up passengers in the tunnel (except perhaps to shuttle passengers among the tunnel stations), they do not have to be in platoon sequence. Because they have passengers on board, they are assigned a "medium-high" priority. These buses can enter any of the loading bays without regard to platoon designation, and are routed to the shortest queue in the automatic mode of the simulation, especially in the a.m. hours. In the p.m. hours, however, they would probably be directed into the appropriate platoon group to avoid reducing capacity of other platoon groups.

- **Inbound through-routed:** These buses arrive from specific routes and will be continuing on through the downtown area to an outbound route. These buses have passengers aboard and must proceed to the correct platoon loading bay and into the tunnel in correct sequence. They would both pick up and discharge passengers in the tunnel stations. These buses would receive the highest priority at the staging areas.

STAGING AREAS

The formation of platoons and the change from diesel to electric power will take place at staging areas located at both the north and south tunnel portal stations. Although the design was subsequently revised, the staging-area concept model is shown in Figure 2. Each area has a set of parallel bus boarding areas into which buses would pull to change power and stop for passengers. Each bus group could use only the lanes specifically designated for that group. A dispatcher would be stationed at the staging area to dispatch platoons into the tunnel using traffic control signal lights.

In addition to buses arriving from each group at the staging area, other buses were expected to be merged into the traffic stream. Deadhead buses being placed in service (especially during the p.m. peak period) would be handled by the dispatcher and sent into the tunnel in proper sequence. Delays caused by traffic, bus breakdowns, operation of wheelchair lifts, and other factors were assumed to cause irregularities in the bus stream. The dispatcher could dispatch partially filled platoons when necessary.

Given these assumptions, the task was to design and develop a working interactive simulation model of the bus staging areas to evaluate the performance of the various elements.

MODEL CAPABILITIES

The following capabilities were provided in the model to

1. Simulate the physical parameters of a bus staging area in terms of the flow of buses in time through queue areas and

platforms; and typical event times for mode change, passenger stops, and bus movement. Record event-processing times and delays for each bus.

2. Perform simulation in real time, with keyboard signal inputs from a dispatcher, to allow training of dispatchers and evaluation of dispatch performance using prototype schemes.

3. Determine and evaluate ability of the dispatch function to maintain throughput capacity in peak periods, given the following: alternative staging area configurations, information displays, control signal configurations, bus priorities, and simulated delays.

4. Evaluate staging area configurations and platoon operation for number of platoon groups, assignment of bus lines to platoon groups, number of buses per platoon, number of bus bays, and required bus queue area.

5. Evaluate the effectiveness of various bus priority rules, traffic control signals, and information inputs to the dispatcher.

6. Evaluate loading time for variation in passenger demand.

EVALUATION MEASURES OUTPUT BY MODEL

The model was designed to be interactive and perform in real time, accumulate performance data, and, at the end of a simulation session, generate an output file of tabular data containing the information listed below. The performance data accumulated by the model consisted of a matrix in which each row represented a bus, and each column represented a characteristic of the bus, an event, or the time of starting or ending an event. Because buses can operate ahead of schedule, the model had to accommodate negative numbers in analysis of delay.

OUTPUT FILE INFORMATION

The model was designed to generate the following output file information:

1. Scenario description: Text containing date and time of run, configuration tested, dispatcher identification, run number, and special conditions modeled.

2. Simulation times: Simulated start time, simulated end time, and duration of simulation.

3. Throughput measures: Total number of buses input to staging area, total number of buses output to tunnel, total number of buses with passengers input to staging area, and total number of buses with passengers output to tunnel.

4. Platoon performance frequency distribution of number of platoons dispatched by size of platoon, number of platoon slots unfilled, and mean and standard deviation for time interval between platoons entering tunnel.

5. Bus delay performance: Total bus delay compared with bus schedule; total bus delay contributed by staging area; and mean and standard deviation for bus delay from schedule; mean and standard deviation for delay contributed by staging area; and frequency distributions of bus staging area delay by number of buses by delay time in appropriate intervals of seconds. Bus delay performance is reported for all buses and separately for each of the following four types of buses: deadhead buses, inbound through-routed buses, inbound terminating buses, and outbound entering-service buses.

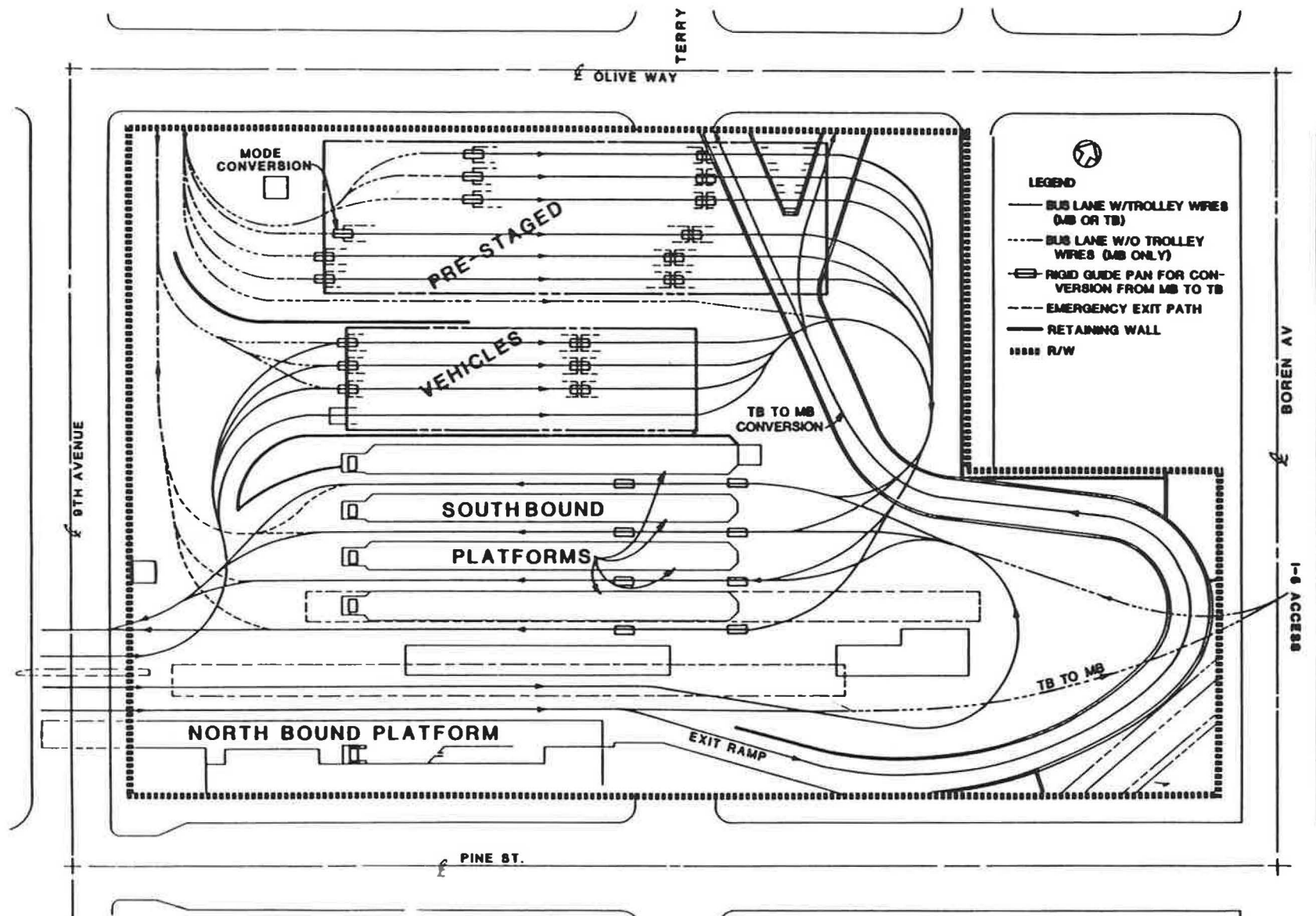


FIGURE 2 North staging area: Convention Center station.

6. Bus bay performance: Number of buses entering each queue and bus bay; number of buses leaving each bus bay; and maximum number of buses in queue at each queue and each bus bay, maximum number of buses in queue for entire staging area.

7. Individual bus performance schedule: The model can print this output file on request. Selected rows or columns can be printed as desired. A report print option is provided in the parameter setup for the model. Items included are

Record sequence number
 Bus route number (preloaded)
 Bus destination sign text (preloaded)
 Bus run number (preloaded)
 Platoon group alphanumeric symbol (preloaded)
 Whether there are passengers on board at arrival (preloaded)
 Scheduled arrival time (preloaded)
 Schedule variation (preloaded)
 Actual arrival time (calculated)
 Time of entry to platoon bay, scheduled dwell begins (from simulation)
 Time scheduled dwell ends (calculated from above plus scheduled dwell time)
 Time bus leaves platoon bay (from simulation)
 Time bus enters tunnel (from simulation)
 Special notations (handicapped aboard, bus type, and so on) (preloaded)

INFORMATION DISPLAY

The model displays simulation information to the dispatcher on an inexpensive color CRT in real time while the simulation is running. The model operation is sufficiently fast to update the screen at least once every second. An IBM PC with standard color display will be used to operate the simulation. The only graphic capabilities required are the ability to display the normal 24×80 character matrix and to define colored rectangles.

Shown in Figure 3 is an example of the information display format to be produced by the model, and in Figure 4 an annotated version of this format. A digital clock, which advances in real time, is located in the upper left-hand corner. In the lower right-hand corner is an indicator of whether the simulation is being run in manual (dispatcher-controlled) or automatic (computer-controlled) mode and the direction of flow. The lower left-hand corner contains an area for the text messages (e.g., "stalled bus in tunnel") which will be loaded in during preprocess to appear at certain times for a certain duration.

Each bus is represented by a rectangle that contains the route designation, platoon letter, and arrival time. The background color of the bus varies by platoon (i.e., Platoon A in red, B in green, and so on). The foreground color of the writing on each bus change in three states: normal (yellow): loading/unloading (flashing yellow), and trolley pole raised, ready to proceed from platform (white). The loading platforms are at the center

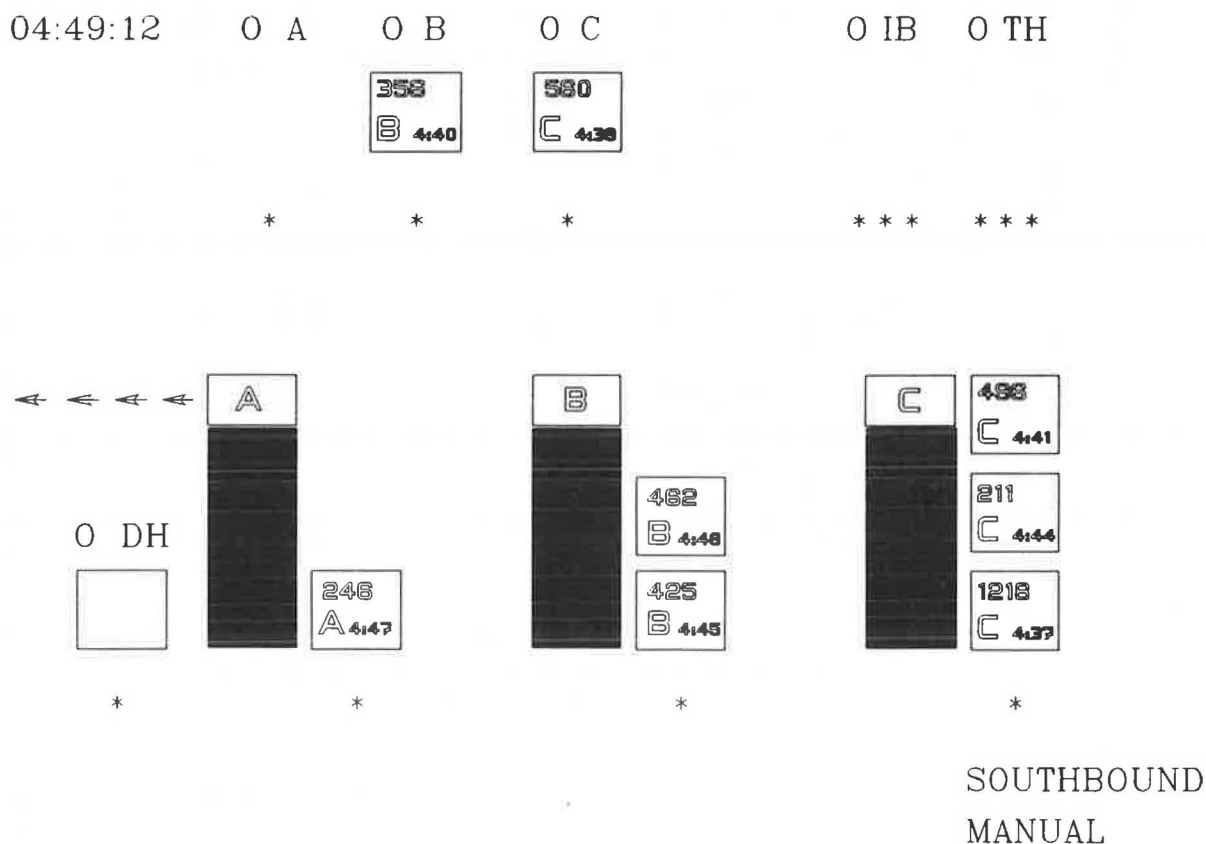


FIGURE 3 CRT display format.

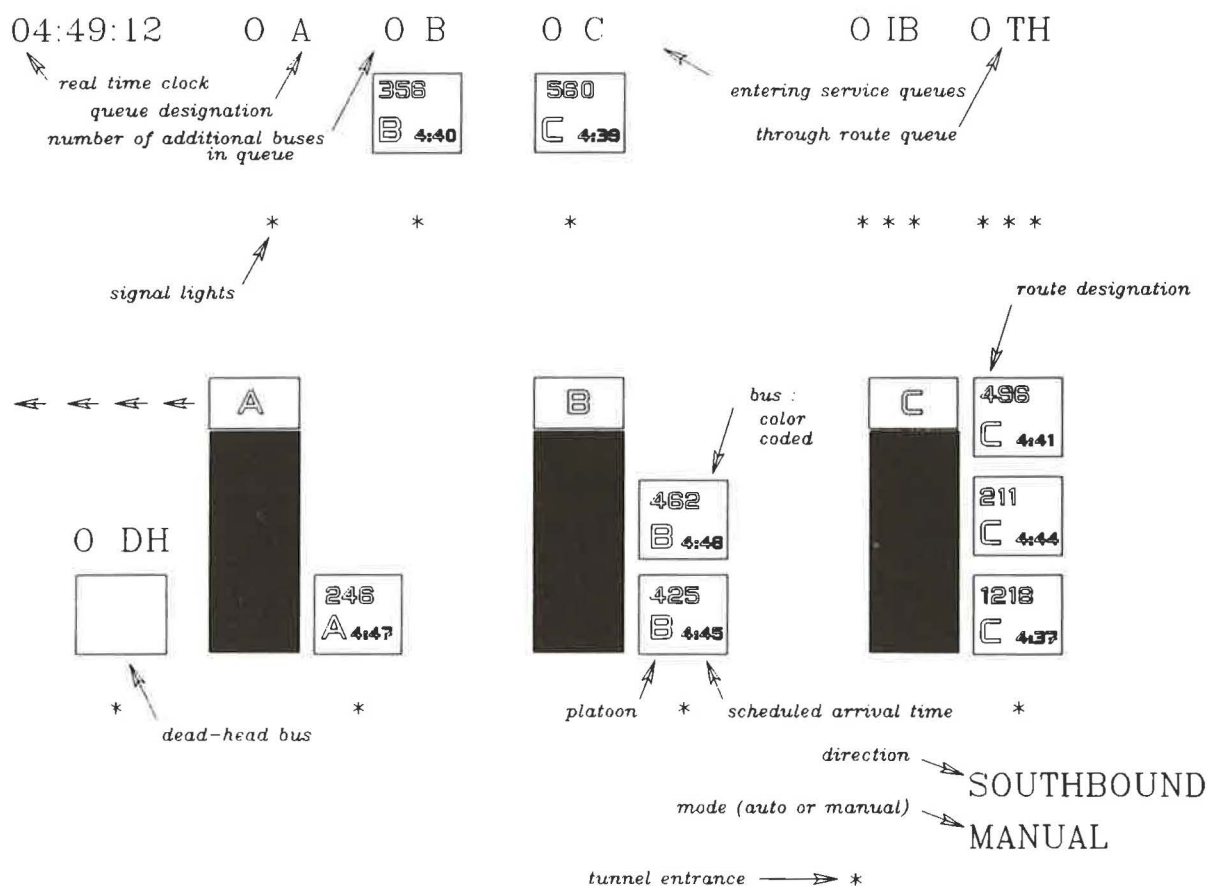


FIGURE 4 Annotated CRT display format.

of the screen and remain statically displayed throughout the simulation.

Bus symbols will first appear at the top of the screen in one of the arrival queues and leave the screen at the bottom at the tunnel portal. The various arrival queues (through bus, inbound unloading, and the entering service queues) are arrayed along the top of the screen, and the deadhead queue is at the left side. In each of these queues, only the first bus is shown. A number above the symbol for the first bus indicates the number of additional buses in the queue. The loading queues are next to the platform, with all buses shown up to the maximum of three per queue. At the bottom of the screen is the tunnel entrance queue. The display advances the bus symbols as the simulation advances in time. Bus symbols will not overlap one another. The exit from each queue is controlled by a signal, shown as an asterisk, located below that queue. The background color of the signals is red for stop and green for go.

INPUT DATA REQUIREMENTS

The input data in Items 1 through 6 in the following list are required to run the model. For data Items 1, 5, and 6, input data formats, test data sets, and interactive methods were provided to allow the user to input data from the keyboard without modifying the programs.

1. Bus schedule (variable),
2. Station configuration shown as a queueing network,

3. Control signal displays,
4. Rules to advance buses in the simulation,
5. Time period for the simulation (variable), and
6. Message text file (variable).

The bus schedule is a matrix in which each bus and its attributes are represented as a row. The items indicated as being preloaded in the discussion of the individual bus performance output file are input here. These are

- Record sequence number;
- Bus route number;
- Bus run number;
- Bus destination sign text (optional);
- Platoon group alphanumeric symbol;
- Passengers on board at arrival (logical code);
- Scheduled arrival time at staging area;
- Bus priority code (inbound through, inbound terminating, outbound entering service, deadhead); and
- Scheduled departure time from staging area.

An editing program is provided for the input schedule file. The file need not be in chronological order during the edit phase. The model is designed to sort it later.

The program provides an option to print out the input bus schedule before the interactive simulation run.

STAGING AREA MODEL

The staging area is represented as a queueing network composed of links and nodes in the program in a format that can be modified without modifying other parts of the simulator. Modifications include the ability to add, delete, and change the characteristics of queues. Preloaded queue characteristics include queue length in number of bus spaces (each bus space equals 75 ft), events that take place in the queue, queue gradient, platoon designation bus service type of designation, and condition logic codes to permit buses to enter or exit the queue. During the simulation, the queue characteristics change as the simulation progresses. These characteristics are number of buses in queue, available queue space (defined as total queue length in bus lengths minus the sum of all buses in the queue), time for a bus to transit the queue, and signal logic for queue entry and exit.

A diagram of the staging area network model is shown in Figure 5.

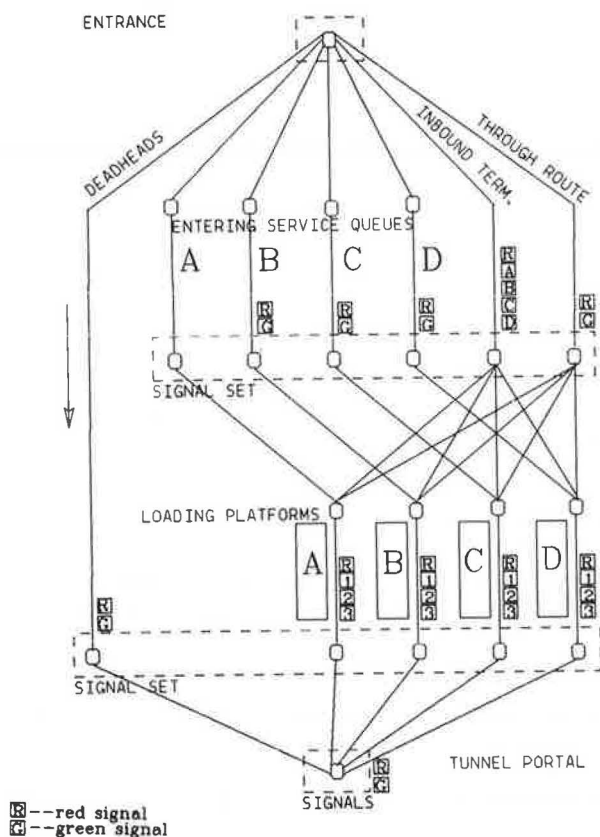


FIGURE 5 Staging area network model.

The program is capable of modifying the staging area at run time to any configuration that falls within the range of the model without changes to the program. One to four platforms may be used with one to four bus bays each. From one to four entering service queues can be specified to feed the bays, with the priority and group of each vehicle indicating the queue to be used. Queues can be set for automatic or flexible routing. Under the former, buses would always proceed to the bay corresponding to their platoon letter. With flexible routings,

queues have multiple signal lights for each loading bay. Under manual control and flexible routing, the dispatcher can press a button that causes the signal to direct the bus into the corresponding platoon bay. Under automatic control and flexible routing, the buses are directed by the simulation to the shortest queue. Flexible routing is available at user option for the inbound terminating queue and the through-routed queue. The time to proceed from queue to bay is changeable without modification to the program, as are loading times and power-conversion times.

SIGNAL SYSTEM AND RULES TO ADVANCE BUSES

The signal system is represented by a set of logical condition codes controlled by function keys, which are polled in real time, and for which a change in state results in appropriate simulated bus maneuvers and signal displays. Codes are reset automatically by the program to simulate treadle and timer activation of traffic signals. The signals may also be set automatically by giving instructions on which buses should receive priority in the parameter setup. The signal system displays and positions are shown in Figures 3 and 4. The tunnel portal signal is controlled by the dispatcher. It is set in the parameter setup phase of the model operation.

Rules to advance buses are incorporated into the model and include specifying the appropriate route codes to govern the sequence of events encountered by each bus. A bus will proceed from the entry point to the approach queue and then to the loading bay designated for its platoon. For the bus to advance into the approach queue and loading bay, there must be a slot available. For the bus to advance from the loading bay to the departure queue, the following conditions must exist:

1. All passenger loading and unloading complete,
2. Mode change complete,
3. Proceed signal from the dispatcher, and
4. Slot available in the departure queue.

For the bus to proceed from the departure queue into the tunnel, it must have a proceed signal displayed. The model includes a dwell time variable to simulate conditions 1 and 2.

Preloaded into the model by the user are a start and an end time for the simulation period that may be at any point within the bus schedule chronology provided to the simulation.

The message text file contains the text of user-input preloaded messages to appear on the screen. The time the message is to appear and the duration of the message display are contained in the file.

MODEL OPERATION AND STRUCTURE

The model is used in the following sequence: input schedule editing, parameter setup, schedule variance input, interactive simulation, and output editing.

Input schedule editing: The input bus schedule is modified as needed. The editing function can be used by a trained analyst and does not require reprogramming.

Parameter setup: A list of parameters and variables is displayed at the time the simulation program is to be loaded. The

simulation start and end times are input as variables. A text message describing the conditions of the run can be input by the user. This text is printed at the head of the output statistics file. All bus performance characteristics, such as acceleration and deceleration rates, speeds, link travel times and dwell times are represented by variables that can be changed if necessary. The number and size of the bus queues is changeable in the parameter setting.

The parameter setup includes an option to select automatic or manual operation of the model. Under the automatic mode, buses advance in the simulation without keyboard signal inputs from a dispatcher. Under the manual dispatch mode, the model advances buses from the queues only on keyboard input of appropriate signal commands by the dispatcher as the simulation is running. Default values are provided for each parameter. The default values can be overridden by user command.

The parameter setup includes an option to disable the signals shown in Figure 4 as controlling movement of buses from the entering service queues to the loading platforms. This permits operation of the model under the manual mode with dispatcher control only at the signals controlling the advance of buses from the loading bays to the tunnel portal.

Schedule variance input: For each simulation run, the model presents to the user the option to add schedule delay. Schedule delay is chosen from an empirical distribution of Seattle bus delay using a random number generator to select the amount of delay. The delay is added to (or subtracted from) the scheduled arrival time for each bus to determine the actual arrival time. The bus schedule file is then used in chronological order by

actual arrival time. A test distribution was obtained from Seattle METRO and used in the model.

Interactive simulation: After the steps already listed have been accomplished, the simulation program is loaded. Loading initializes all arrays and temporary variables. Pressing a start key initiates bus arrivals and generates the screen display. Pressing signal control keys advances buses under the manual mode. An internal clock inputs buses according to the schedule and provides time recording for each event. The bus performance schedule is continually updated. The simulation runs and terminates normally when (a) the scheduled stop time is reached, (b) the end of the bus schedule is reached, or (c) the stop key is pressed. Pressing the stop key stops the simulation clock and keeps all variables and data arrays intact. Pressing the start key restarts the simulation from the point at which it terminated. All other keys are disabled during the simulation.

Output editing: After the simulation is stopped, a command can be input to read the bus performance file, calculate the evaluation measures, and route the formatted output to the terminal for scanning. The program contains an option to route the output file to a printer or other hard copy device.

Shown in Figure 6 is a block diagram of the overall model structure. In this figure, the central portion indicates the interactive part of the simulation. The simulation contains three basic components: the clock, simulation, and display formatter.

The clock controls the operation of the simulation model. It is started and stopped by the user. The clock advances every second and performs the following functions: updates the clock display, determines the execution of the next event, updates the monitor display, checks to maintain the real-time simulation, and updates the bus performance matrix.

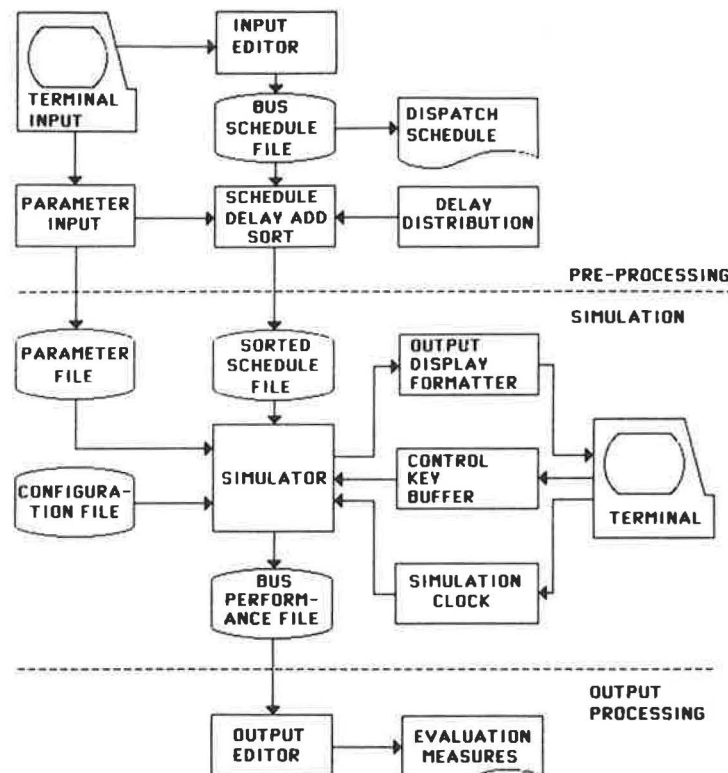


FIGURE 6 Program block diagram.

The simulator starts and stops the clock, enters buses into the approach queue, checks the queue capacity, advances buses into the loading bays, simulates load/unload functions, raises the trolley poles, and advances buses on command.

The display formatter accepts data, refreshes the static graphic display elements from the simulator, and updates the following information on the screen: clock, bus positions, passenger movements, bus symbol destination sign display changes, trolley pole up/down, signal displays, and text messages.

IMPLEMENTATION MODE

The program runs on an IBM PC with programming in the STSC APL language. An IBM PC/XT, with 256K memory, a 10-megabyte hard disk, floppy drive, 8087 math coprocessor, and a 384K extra memory card, was used. A standard IBM or IBM compatible color monitor displaying 24 rows of 80 characters is sufficient for the simulation display.

CONCLUSION

The model was turned over to the Seattle METRO and was used extensively in analyzing the operation of the staging areas. Use of the model led to increased confidence in the unique transit concept to be employed in the tunnel.

One significant result was that the Transit Department decided to use an *A-B* platoon configuration rather than an *A-B-C* configuration to begin operations. This decision was based on the expectation that overall platoon formation time would be shortened. A platoon would be dispatched with a maximum of two *As* and two *Bs* and could pick up a delayed bus at a tunnel station and grow to a five-bus platoon.

The team of programmers working on the project developed a speeded up version of the model that ran well over 10 times faster than the simulation version. Speeding up of the simulation was used for testing and debugging purposes.

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