Development of an Automatic-Vehicle-Monitoring Simulation System

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The Automatic-Vehicle-Monitoring Simulation System (AVMSS) is described. AVMSS is an interactive bus-route simulation model designed to act as a test bed for the evaluation of automatic-vehicle-monitoring (AVM) strategies and tactics. The system is composed of three component programs: the Traffic Environment Generator (TEG), the Bus Schedule Generator (BSG), and the AVM Simulator (AVMS). The simulation system uses both macroscopic and microscopic simulation techniques. The macroscopic traffic-flow model used in the TEG program is based on the TRANSYT model. Buses are moved in the AVMS by using a microscopic time-scanning technique. The features of each component program are discussed, data requirements and the measures of effectiveness produced are presented, and AVM strategies embedded in the model are described.

Over the past 10 years, increasing concern with energy consumption, traffic congestion, and the environmental aspects of urban transportation systems has motivated the development of a wide range of techniques for improving urban bus operations. One method of improving service reliability is to give transit operators the capability of centralized and coordinated control of bus schedules and headways.

This paper presents the design of a software system to perform bus-route simulation. The system, the Automatic-Vehicle-Monitoring Simulation System (AVMSS), was designed as an engineering tool to aid in the development and evaluation of automatic-vehicle-monitoring (AVM) control tactics. These tactics would seek to improve the service reliability of bus systems.

BACKGROUND

The simulation of a bus transit system, with or without AVM control, is a description of dynamic processes operating within, and responding to, a dynamic environment. In this application, the dynamic processes pertain to the activities of each bus in the system. These activities include (a) accelerating, decelerating, and moving at free-flow speed; (b) responding to AVM control tactics; (c) responding to traffic control devices; and (d) servicing passengers at bus stations. Each of these activities is conditional on the following external factors, which, in aggregate, constitute the operating environment: (a) geometric constraints of the physical street system, (b) general traffic flow and signal conditions, (c) location and number of bus stations, (d) passenger demand and boarding and alighting, and (e) bus capacity, schedules, and transit rules.

Many of these factors vary with time. Since the intrinsic, potential instability of bus systems reflects both long- and short-term variability of the operating environment, it is essential that both components of variability be properly represented in any simulation program.

Three different classes of simulation models have been developed that meet these conditions: microscopic, macroscopic, and hybrid. A brief comparison of these classes of models is given below:

Class	Characteristics	Example
Microscopic	Explicit modeling of automobiles and buses, time scanning, complex code, costly to run, much detailed output	NETSIM (1)
Macroscopic	No discrete modeling of automobiles, modeling of bus travel time, event scanning, efficient computer memory, less detailed output	TRANSYT (2), TORG (3)
Hybrid	Macro treatment of automobiles, micro treatment of buses, event and time scanning	SUB (4), AVMSS (5)

Microscopic models tend to represent vehicles individually and their movements explicitly in great detail. Thus, they provide a high level of accuracy along with the ability to provide extremely detailed output. Macroscopic models sacrifice modeling detail to provide faster machine times and reduced computer-memory requirements. Hybrid models combine the features of both microscopic and macroscopic modeling techniques. One component of traffic can be treated with great detail while another is represented at a lower level of detail.

The choice of model classification during the design of a simulation program is dictated by the constraints placed on model performance. AVMSS had to be able to handle bus traffic and passenger transactions explicitly. No constraint was placed on the treatment of automobile traffic. Finally, the program had to be interactive and fit into a 32 000-word region of core. Hence, AVMSS was designed as a hybrid model; i.e., it models automobile traffic macroscopically and bus movements microscopically.

General Structure of AVMSS

On the basis of a functional analysis, AVMSS was designed as a system of three independent programs:

1. The stage 1 program, the Traffic Environment Generator (TEG), is a traffic simulation program to create a data base that defines the "traffic environment" and to store this data base on magnetic tape.
2. The stage 2 program, the Bus Schedule Generator (BSG), is a preprocessor program to create a data base that contains the schedules of all buses on the subject line, all passenger demand rates at all stations, and the scheduled times of arrival of buses on other lines. The data base is stored on magnetic tape.
3. The stage 3 program, the AVM Simulator (AVMS), is a microscopic bus-operations simulation program that includes the ability to interact with the operator (simulating the role of the dispatcher) so as to implement on-line AVM tactics and to simulate the consequences (i.e., system response).

Traffic Environment Generator

TEG is a macroscopic traffic simulation program based on a model developed by KLD Associates, Inc., for the Federal Highway Administration (6), which, in turn, is an elaboration and refinement of the flow model embedded in the TRANSYT program (2). TEG models the traffic flow on a network represented by "nodes" (intersections) that are connected by unidirectional "links" (one-way roadways). The network to be modeled consists of that portion of the physical street system that contains all possible bus paths that are to be specified by BSG and simulated by AVMS.

TEG describes the general traffic conditions on the network in the form of lane-specific statistical SERVICE and QUEUE histograms. The SERVICE histogram represents the time history of available service provided by the control device at the downstream intersection at a macroscopic level of detail. The QUEUE histogram describes the time history of vehicle queueing at the stop line. These two sets of histograms provide all the necessary information at this macroscopic level of detail to estimate the impedances experienced by buses due to the presence of other traffic.

The output of TEG consists of a tape that contains the SERVICE and QUEUE histograms for all relevant lanes of each link in the bus analysis network. Each histogram is created for a period of time known as the "time interval" (approximately 50-200 s). Other link-specific properties are also present on the tape.

Bus Schedule Generator

BSG was designed to process user-specified input to describe bus and bus-station operations. BSG reads and diagnostically checks the input data. Error messages are generated if problems are located. If no errors are detected, BSG creates a data file that will be used by the AVMS (stage 3).

AVM Simulator

AVMS is the heart of AVMSS. It is this program that moves buses through the network. Buses respond to traffic control and volume conditions specified by the TEG program. Buses also respond to schedules and passenger information as generated by BSG. AVMS gives the user interactive control over buses through the implementation of various AVM control strategies.

Bus Movement

Each bus moving through the AVM network is treated as a separate entity. As buses move through the network, they respond to certain external stimuli, including (a) surrounding traffic conditions, (b) traffic signal control states, (c) bus-driver characteristics, (d) bus-station characteristics, and (e) passenger loading and unloading characteristics.

Buses in motion accelerate in accordance with bus performance criteria until either a free-flow speed is achieved or the bus must begin to decelerate. A bus will decelerate in order to join a queue, enter a bus station, enter a layover point, or fall in behind another bus if there is no room to pass. When a bus falls in behind another bus, that bus moves in accordance with car-following logic.

Passenger Traffic

New passengers arrive at bus stations in accordance with a Poisson distribution about a mean arrival rate for the specific station. The algorithm used is adequate for routes where buses arrive at headways of less than 10 min.

Passenger boarding and alighting transactions are modeled by using calibration data obtained in the field. One important factor in passenger boarding and alighting transactions is bus type. A standard bus has a single rear door to allow alighting. An articulated bus has two rear doors. Passengers are assigned to either one or two rear doors depending on bus type.

AVM Tactics

A total of nine AVM control strategies have been implemented. These strategies fall into two major categories: (a) universal strategies, which apply to all buses in the network, require no operator intervention, and are automatically implemented when threshold values are reached, and (b) strategies that require operator interface during the course of a run (these strategies operate on specified bus runs only). Each of the nine AVM control strategies implemented is described briefly below.

1. Strategy 1, coordinated skip stop--Strategy 1 is initiated interactively by the operator when two buses are running close together. Bus A stops to pick up passengers at stations 1, 3, 5, 7, etc. Bus B stops to pick up passengers at stations 2, 4, 6, 8, etc. Buses A and B are allowed to leapfrog each other.
2. Strategy 2, discharge only--In strategy 2, passengers are allowed to get off at scheduled stops, and no passengers are allowed to board the bus. The bus will skip a stop if no one wishes to disembark.
3. Strategy 3, holding back a bus--Strategy 3 is a universal strategy that is not subject to operator intervention. Whenever a bus arrives at a stop earlier than a given schedule threshold, it waits.
4. Strategy 4, controlling trip start time--Strategy 4 allows a bus to leave a layover point or a terminal at a different time than its original schedule dictates. The schedule at each bus stop is modified accordingly.
5. Strategy 5, turning short--Strategy 5, an interactive strategy, allows the user to alter the route of a bus as it moves through the network. The bus proceeds to its next scheduled stop, where it discharges all its passengers. When all passengers have been removed from the bus, the bus then disappears from the network until it is scheduled to reappear somewhere else. When the bus reappears, it proceeds on the remainder of its route in a normal manner.
6. Strategy 6, gap filling--Interactive strategy 6 allows the operator to insert a new, unscheduled bus midroute in order to fill a long gap between buses. The user specifies the route, the insertion point, and the insertion time, and a new bus is generated and placed on the network.
7. Strategy 7, nonstop--A bus operating under interactive strategy 7 stops at the next scheduled stop, where any passengers who wish to get off do so. When the bus exits this station, it proceeds nonstop until the end point of the strategy is reached, at which time the bus begins to stop normally and will proceed along its schedule route.
8. Strategy 8, adjust schedule--The purpose of strategy 8 is to modify the scheduled time of arrival of a bus at its intermediate destinations along the route.
9. Strategy 9, in-vehicle display--Strategy 9, a universal strategy, is used to simulate the schedule performance meter developed for the AVM system.

This strategy applies to all buses on the network. When any bus exceeds one or more of the schedule deviation thresholds, driver aggressiveness is modified. As a bus becomes later and later, the driver becomes increasingly aggressive. Alternatively, a bus that is early will force the driver to become more lethargic.

Interactive Capabilities

The AVMS program is an interactive simulation model. Thus, the user has the ability to perform certain command and control functions. Among these are (a) creating a checkpoint, (b) generating system snapshots, (c) initiating or canceling AVM strategies, (d) ending interactive communication, and (e) terminating a run.

Input Requirements

Input for the TEG program has two functions:

1. The physical geometry of the traffic network must be described.
2. Information about traffic operations on the network is required.

The physical geometry of the network is described in terms of links and nodes. The information required includes link lengths, number of lanes, grade, lane channelization, and the number of adjoining nodes. Traffic operations are a combination of traffic-volume information and complete descriptions of the traffic control signal at the downstream end of a link.

Input for BSG is used to describe bus operations on the network being simulated. The paths buses must follow are input as a sequence of node numbers, bus-station numbers, and layover points, beginning at a terminal and ending at a terminal. Bus stations are described by their position and capacity, passenger arrival rates, and the proportion of the bus load alighting at that station. Bus schedules are input as the scheduled time of arrival at each bus station and the scheduled time of departure of a bus from a terminal or a layover point.

Input to AVMS is used to define threshold values for certain types of output and information on the universal AVM strategies to be implemented, if any. In addition, the user may input time-period adjustment factors that are used to vary traffic-flow information in order to model peaking characteristics.

Output

Each of the programs that make up the AVMSS has its own set of output. TEG and BSG output information concerning their respective functions so that the user has a complete description of the network, traffic flow, and bus operations.

The primary output describing system performance is produced by AVMS. This output falls into three categories: exception messages, system snapshots, and cumulative statistical reports.

Exception Messages

Whenever certain bus or bus-station measures of effectiveness exceed threshold values, one of the following exception messages is generated:

1. Late arrival--A bus arrives at a station at least X min late,
2. Early arrival--A bus arrives at a station at least Y min early,
3. Upper load factor--A bus leaves a station with at least X percent of passenger capacity filled,
4. Lower load factor--A bus leaves a station with less than Y percent of passenger capacity filled,
5. Upper headway--A bus arrives at a station more than X min later than the previous bus arrived at the same station,
6. Lower headway--A bus arrives at a station more than Y min later than the previous bus arrived at the same station, and
7. Passenger queue--A bus station has more than X passengers waiting to be served.

System Snapshots

System snapshots are interactively triggered reports that give a picture of the status of system elements at a given point in time. The following measures of effectiveness are output by system snapshots:

1. Bus status--run number, driver type, bus type, current link number, position (feet), status code, station-layover number, acceleration, speed, passenger load, destination, schedule deviation of last station, actual headway, nominal headway, load-factor variation, last station number, passengers on at last station, passengers off at last station, schedule deviation imposed by AVM command, and AVM strategies in force;
2. Station status--number of passengers waiting for a bus, number of buses in dwell, and number of buses on queue waiting to enter station; and
3. Link status--number of buses on the link, current queue length at the downstream node, and current service rate at the downstream node.

Cumulative Statistical Reports

Cumulative statistical reports are produced at the completion of a run. They include bus-run statistics and bus-station summaries. Schedule and headway performance reports are also produced. The type of data produced is outlined below:

1. Bus run completion summary, including run number, bus type, driver type, run time, schedule deviation, number of stops, travel time (person minutes), vehicle miles, number of passengers boarding, average passenger waiting time, root-mean-square excess load, and mean passenger trip delay;
2. Bus run schedule performance summary;
3. Bus run headway performance summary;
4. Bus run passenger performance summary;
5. Bus station summary, including station number, section number, link number, aggregate time station has no passengers, aggregate time buses wait to enter full stations, number of overloaded buses leaving the station, number of buses serviced, average dwell time, average number of loadings, and average number of alightings;
6. Bus station schedule performance summary; and
7. Bus station passenger performance summary.

CONCLUSIONS

The set of simulation programs described in this paper represents a powerful tool for the study of techniques to improve urban bus operations. As such it has a number of potential applications:

1. It may be used as a test bed to develop new strategies and tactics in a laboratory environment where traffic flow and passenger conditions are reproducible to form the basis for clear comparisons.
2. It can be used as a training device to allow dispatchers to recognize and correct problems with

bus operations before system service deteriorates significantly.

It is hoped that the use of the model will lead to a fulfillment of its potentials.

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Abridgment

Analytic and Simulation Studies of Factors That Influence Bus-Signal-Priority Strategies

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Research intended to identify conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy is described. Two techniques are presented for studying the problem. An analytic model was developed to compare the performance of bus systems operating with and without bus signal preemption. Studies were undertaken to examine the effects and interrelations of several factors in terms of bus operations. These factors include signal density, traffic volume, maximum signal-preemption length, passenger volume, bus headways, signal split and cycle length, station location, and exclusive right-of-way for buses. Insights from the study pertaining to each of these factors are described. In addition, the Federal Highway Administration's network flow simulation (NETSIM) model was modified to incorporate a bus-signal-preemption strategy. Simulation studies produced results that confirmed some of the insights provided by the analytical model and yielded additional insights.

The application of a bus-signal-priority strategy must be part of an overall systems approach to bus operations. Signal strategies do not operate in a vacuum but in a total environment that consists of all other factors that constitute a bus mass transit system.

Although studies have been conducted on bus signal control (1-3), it has not yet been determined which factors are most important to the success of a bus-signal-preemption strategy. The objective of this study was to identify those conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy.

Two techniques were used in studying this problem. An analytic model was developed to study the behavior of a bus system operating with and without bus signal preemption. Parametric studies were then undertaken with the analytic model to examine the influence of many factors on the operational performance of a bus system. Because of the extensive interrelations among the effects of various factors on bus system performance, graphical representations of the results were prepared. These were carefully examined to determine the significant consequences of the factor interrelations. The most significant combinations of factors affecting system performance could then be identified.

In addition, the network flow simulation (NETSIM) model of the Federal Highway Administration (FHWA) was modified to incorporate provisions for a conditional signal-preemption strategy. Simulation studies were undertaken both to confirm some of the insights obtained by applying the analytic model and to study the effects of additional factors that were outside the scope of the analytic model. Measures of effectiveness (MOEs) generated by the models were used to determine the impact of bus signal preemption under various conditions.

ANALYTIC STUDY

An analytic study (4) was conducted to quantify the sensitivity of various bus operating characteristics of a transit system (stops per mile, travel-time reduction, and percentage of travel-time reduction) to many of the factors that influence bus operations. These factors include signal density (intersections per mile), cycle split, bus headway, cycle length, traffic volume, bus passenger demand, maximum phase extension and truncation time, buses in exclusive right-of-way or in mixed traffic, preemption strategies of green extension only and green extension or red truncation, and station location [such as near side every block, far side every block, and near side every third block (express service)].

This study consisted of the following steps:

1. Developing analytic expressions that relate bus operating characteristics to these contributing factors,
2. Applying these expressions to specified bus environments,
3. Organizing the results in a manner that exhibits the underlying relations, and