AN ADVANCED COMPUTER PROGRAM FOR DETERMINING VEHICLE EMISSIONS AND FUEL ECONOMY WITHIN A SURFACE STREET NETWORK

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ABSTRACT

In recent years there has been increasing interest in surface street traffic simulation. The Aerospace Corporation, using techniques based upon extensive experience with freeway traffic simulation models, has developed a model that simulates surface street traffic for a wide variety of traffic conditions and a large number of street and highway configurations. The model can be used to predict vehicle and traffic parameters such as exhaust emissions, fuel economy, and light timing effects.

This surface street model is very flexible. The configurations that can be modeled are one-way streets, two-way streets, or combinations of the two. Intersections can have signal lights or boulevard stop signs controlling traffic flow.

The simulation is microscopic, i.e., each vehicle is completely followed on its route through the street configuration. Driver attributes are generated from probability distributions, the parameters of which can be varied via input. Vehicle behavior is constrained by the application of driving rules governing lane changing, headway distances, etc. Fuel economy, emissions, and traffic flow data are obtained by Monte Carlo techniques when steady state conditions are reached in the simulation. Results presented show the emissions, fuel economy, and light timing effects obtained from a simulation of a portion of the downtown Los Angeles street network. Comparison is made to data supplied by the Los Angeles Department of Traffic.

I. INTRODUCTION

The Aerospace Corporation has been actively involved in the investigation of automobile exhaust emission reduction and fuel economy improvement. Various tools have been developed for use in the analysis of these concepts.

This paper describes a computer model for determining automotive emissions and fuel economy effects under surface street traffic conditions. This surface street simulation model is a part of the VPT (Vehicle Performance in Traffic) system, discussed in Reference (1), which was developed to support a company financed study. The VPT system simulates both surface street and freeway traffic. A presentation of the freeway model (FREEWAY) is given in Reference (2). The surface street model is an extension of the FREEWAY model and will henceforth be referred to as VPSST (Vehicle Performance in Surface Street Traffic). It is designed not only to compute traffic flow rates, but in conjunction with an engine performance model to compute fuel economy and mass emissions of HC (Hydrocarbons), CO (Carbon Monoxide), and NOx (Oxides of Nitrogen) for a typical vehicle in a given surface street scenario. Using VPSST, the effect of various traffic light timing strategies on gasoline consumption and on pollutant production can be assessed and optimum strategies can be found.

The VPSST uses a microscopic simulation technique, i.e., each vehicle is followed on its entire route through the surface street network. This is done to take into account the entire distribution of driver attributes as well as vehicle maneuvers such as lane changes and gap closings which are critical if one desires to obtain realistic fuel consumption and pollutant emissions under traffic conditions. These traffic flow perturbations force some vehicles to accelerate and others to decelerate independently of the average flow speed, thereby changing the power demands on each vehicle considerably. This results in corresponding large variations in vehicle fuel consumption and exhaust emissions.

The traffic stream is composed of one or more types of vehicles, each representative of a class of vehicles. So far, a standard size automobile represented by a 1971 Chevrolet Impala with a 350 CID engine and automatic transmission (4600 lb), and a subcompact automobile represented by a 1970 Toyota with 115.8 CID engine and manual transmission (2500 lb) have been modeled. These vehicles can be mixed in various proportions as may be needed to simulate a desired vehicle distribution. Other vehicle types such as trucks and buses can easily be added.

It is possible to model a large number of orthogonal intersections interacting with each other with a mixture of signal lights and stop signs, and with a mixture of one-way or two-way streets. Figure 1 illustrates the surface street traffic flexibility of the program and Figure 5 represents a portion of downtown Los Angeles which has been simulated during the study.

II. VPSST MODEL DESCRIPTION

This section will describe the most significant parts of the VPSST model. The vehicles are created stochastically at each entry to the street system. The model approximates a Poisson distribution of arrival times at each entry with a mean determined from the specified input inflow rates. The route of each vehicle is determined by a sequence of input weighted uniform random variables, each term in the sequence giving the route to be followed by the vehicle at each intersection. The weighting values that are input for each intersection are percentages proportional to the probabilities that a given vehicle will go in each of the possible directions at the intersection.

The model determines driver personality attributes. These attributes are assumed to be normally distributed random variables, with mean and standard deviation entered as input for each attribute. All of the driver personality attributes are functions of the same uniformly distributed aggressive-conservative factor. They are formed by transforming the aggressive-conservative factor from the uniformly distributed random variable to the appropriate normally distributed random variable with proper mean and standard deviation. Some of these attributes are desired velocity, slow leader toleration, gap acceptance, and lane preference (uniformly distributed). Reference (2) gives a more detailed description of these attributes.

The model is capable of certain vehicle maneuvers that will be described in the following paragraphs; however, other maneuvers could be implemented with little difficulty.

Turns from one road to another are the only type of turn maneuver allowed. Turns can only be executed at intersections. All intersections must either be controlled by a signal light or by a two-way stop sign. The signal lights have red, yellow and green cycles in each direction at the intersection. The signal lights are set so that the time duration of the red cycle in one direction is equal to the time of the green cycle plus the time of the yellow cycle in the orthogonal direction. The duration of each color at each intersection, together with the initial light setting, is input and fixed for each signal. Two-way stop signs are such that the traffic stops only in one direction; the orthogonal direction traffic does not stop (see Figure 1 for an illustration). The only turn that can cross oncoming traffic is a left turn at a signalized intersection. All turns at signalized intersections must be made when the light is green in the direction the vehicle is traveling before executing the turn. Right turns must begin in the right lane and end in the right lane. Left turns must begin in the left lane and end in the left lane. All other turns specified for a signalized intersection are allowed for both directions of traffic flow at a stop sign intersection. Before turning left across traffic, the vehicle checks to see if the turning maneuver can be executed in front of the oncoming traffic without collision. Then, and only then, is the turn made. Similarly, the other type turns are made only when the turning vehicle can safely take a position on the road to which he is turning.

When a vehicle desires to cross orthogonal traffic at a stop sign intersection, the vehicle first determines when the orthogonal cross traffic can be crossed safely. Figure 1 gives a schematic of the turning and crossing maneuvers presently available with VPSST.

When approaching a stop sign or a red (or yellow) signal light, a vehicle begins to slow down in anticipation of stopping. This slowing-stopping maneuver provides a slight deceleration at long distances (between 144 ft and 288 ft from the intersection), moderate deceleration at medium distance (between 72 ft and 144 ft from the intersection), and heavy deceleration at short distances (between 0 ft and 72 ft from the intersection). The deceleration function varies stepwise between 0 and -11.1 mph/sec. If the vehicle cannot stop safely, it will proceed through the intersection at maximum acceleration; this occurs typically if the signal changes to yellow when a vehicle is a few feet away from the intersection. This set of rules givesa realistic braking profile for a stopping vehicle. Reference (3) gives more detail of vehicle turning, vehicle crossing, and vehicle stopping dynamics.

When a vehicle accelerates from rest (e.g., at a stop sign or signal light), it uses the maximum acceleration available consistent with the actual vehicle performance model used decreased by the driver attribute (aggressive-conservative factor). Thus, a conservative driver will employ a lower acceleration than an aggressive driver.

When a simulation run is initiated, the surface street network is gradually filled with vehicles, each behaving according to its set of attributes. The vehicles interact with one another as they attempt to reach their destination. For example, a vehicle desiring to turn right at the next intersection must move into the right lane of the road it is traveling on. In doing this, its desired velocity and gap acceptance attributes are considered. Also, the vehicle might have to modify its velocity in order to avoid a collision with another vehicle. Figure 2 gives an overall schematic of the VPSST logic, and Reference (2) gives more details of the intervehicle effects.

When total network traffic inflow is approximately equal to the total traffic outflow, a steady state condition is obtained. Then a Monte Carlo method is used to calculate parameters of interest, e.g., fuel economy, exhaust emission, mean travel time through the network, and average velocity. For example, the convergence of fuel economy and CO exhaust emission to a constant as the steady state condition is approached is shown in Figures 3 and 4.

The velocity and acceleration at any instant of time can be used by an engine performance model to calculate fuel economy and mass emissions. The velocity and acceleration of each vehicle are used to compute engine performance demands. The vehicle model is detailed in Reference (1) and includes the effect of manual or automatic transmission characteristics. The fuel consumption is obtained by entering a map of specific fuel consumption with engine speed and power requirements. Similarly, exhaust mass emissions of HC, CO, and NOx are obtained from specific HC, CO, and NOx emission maps.

The VPSST model has been programmed for the CDC 7600 computer at The Aerospace Corporation.

III. VALIDATION

Since VPSST is an extension of the freeway model used in VPT, and this model has been extensively validated as shown in Reference (2), only those aspects of VPSST that are different from the freeway model needed validation. However, a large surface street network was needed to insure proper interfacing of the surface street modifications with the established freeway capabilities. The case chosen is shown in Figure 5. It is a subset of downtown Los Angeles between 2nd and 4th Streets in the north-south direction and between Hill and Main Streets in the east-west direction, as shown in Reference (5). The data was obtained for a peak afternoon rush hour period from the City of Los Angeles Department of Traffic [see References (5) and (6)].

The input required, in addition to the street configuration, is the total traffic inflow (in vehicle/hour) at each street entrance to the system, the light timing at each intersection, and the turn percentages at each intersection. The driver attributes were based upon those in Reference (4).

A comparison of the VPSST results with the Los Angeles Department of Traffic data is given in Figure 6. It can be seen that the results in general show good agreement. The percent error for the total outflow for this case was 8 percent.

IV. APPLICATIONS

The VPSST program was used to study the effect of light timing on average traffic velocity, average traffic throughput time, average fuel economy, and average pollutant emissions for the downtown Los Angeles street subsystem described in the previous section. Three cases were run: (1) optimum signal timing (as given by the City of Los Angeles), (2) optimum timing only on the two streets with the highest inflow rate (Main and Spring) and uniformly distributed random timing on the others with a minimum red cycle of 20 seconds, and (3) all streets randomly timed with a minimum red cycle of 20 seconds. The results are shown in Figure 7. It can be seen that poorly timed signals not only decrease the average system velocity $\overline{v}$, and increase the average traffic throughput time $\overline{t}$, but also decrease fuel economy and increase pollutant emissions.

V. CONCLUSION

A brief description of the VPSST model has been given. In addition to the application given here, many other uses can be made of the model. Some of these are: better street configuration planning, traffic flow effect on vehicle emissions and fuel economy, traffic parameter studies for urban development planning programs, and engine design for fuel economy and low emissions.

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BIOGRAPHY

H. Sylvia Porjes attended New York University, where she received a Bachelor's degree in Mathematics. Ms. Porjes has been a Member of the Technical Staff at Aerospace for the last 14 years, where her main field of work has been computer simulation of traffic problems, and computer graphics.

After completing most of his studies in Paris (France), Camille Speisman received a Master of Science degree from the Department of Mechanics at the University of Wisconsin in 1956. He has been a Member of the Technical Staff at The Aerospace Corporation since 1962. In the last three years he has been involved in a number of studies on automobile fuel consumption and gas exhaust emissions. Mr. C. Speisman has been a member of the ASME since 1956.

Philip H. Young attended California State College at Los Angeles where he received his Bachelor's and Master's degrees in Mathematics. He has been a Member of the Technical Staff at The Aerospace Corporation for over 14 years where he has worked on a wide variety of computer problems with special emphasis on probability models, stochastic processes and numerical analysis. Mr. Young has been a member of the Mathematical Association of America for many years.

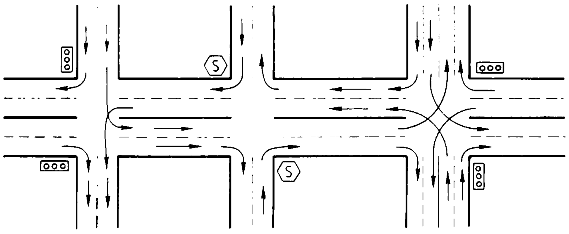

Figure 1. VPSST Turning and Crossing Maneuvers

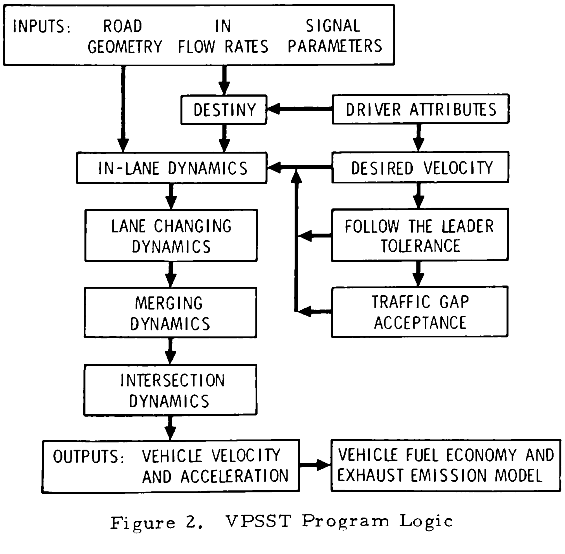

Figure 2. VPSST Program Logic

ACKNOWLEDGMENTS

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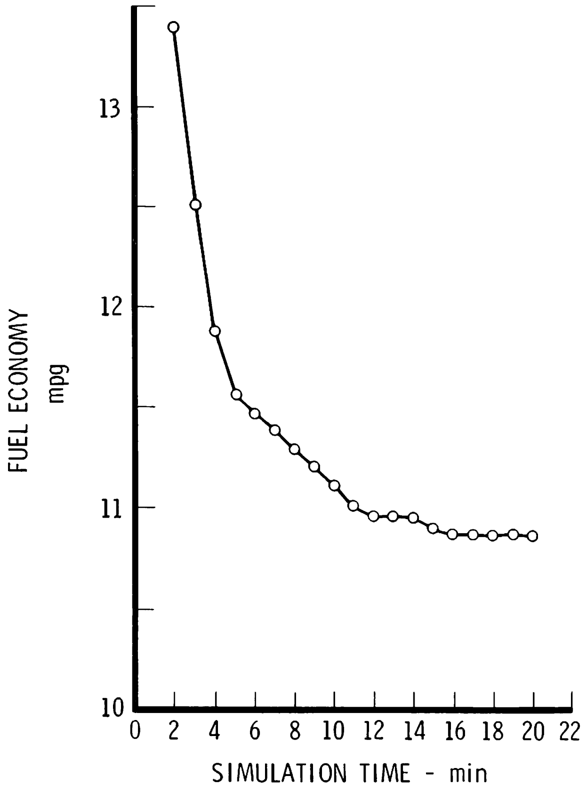

Figure 3. Downtown Los Angeles Street Subsystem VPSST Solution Convergence Impala Fuel Economy

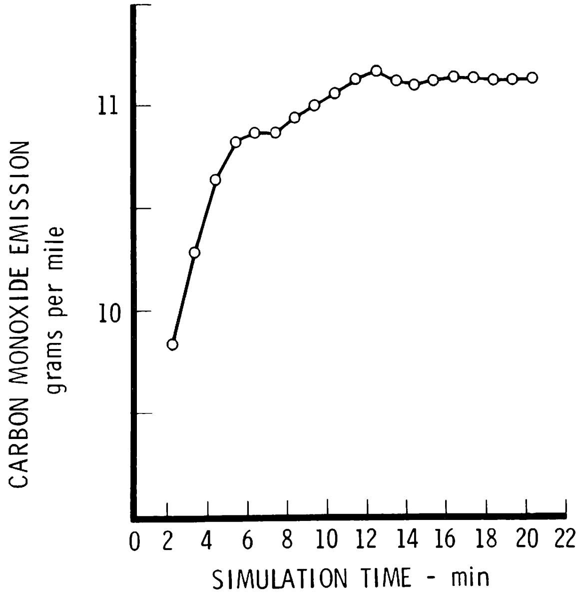

Figure 4. Downtown Los Angeles Street Subsystem VPSST Solution Convergence Impala Carbon Monoxide Emission

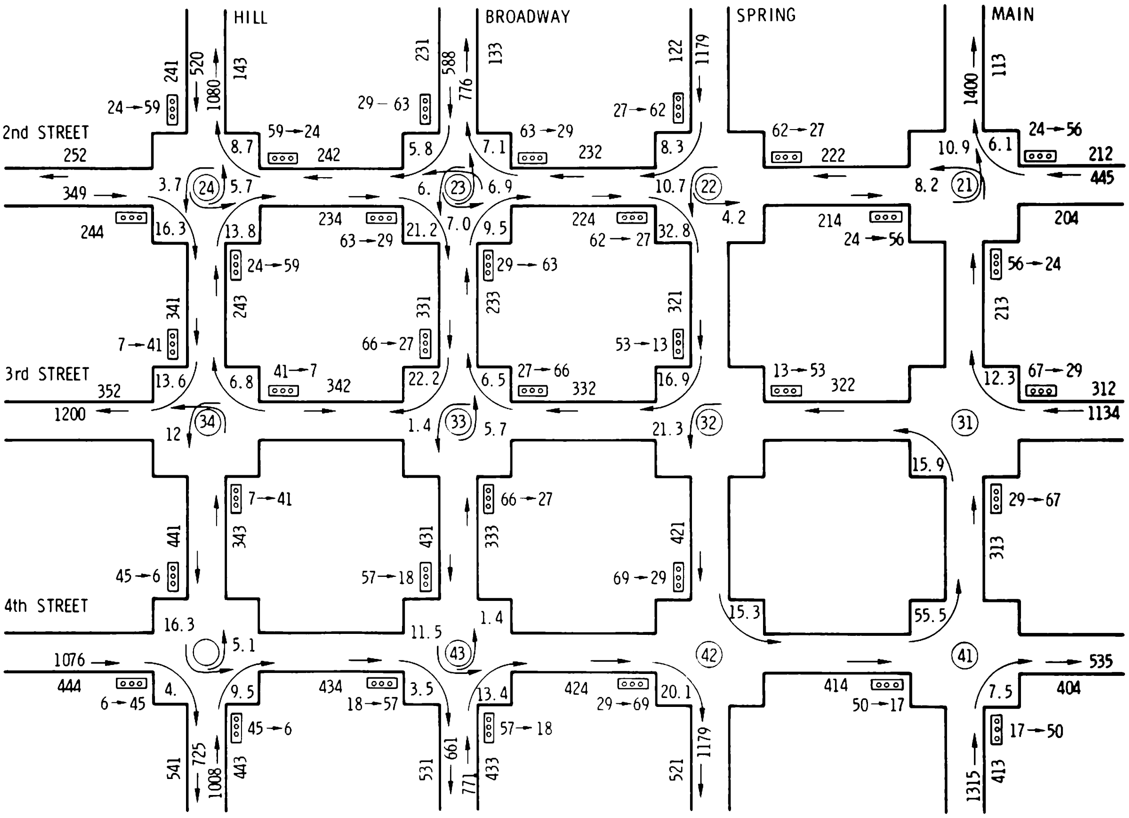

Figure 5. Downtown Los Angeles Street Subsystem

LEG	NAME	L.A. TRAFFIC DEPT. FLOW DATA (VPH)	VPSST SIMULATION FLOW DATA (VPH)
413	MAIN (S → N)	1315	1190
313		2108	1319
213		1203	1387
113		1400	1370
221	SPRING (N → S)	1179	1139
321		1174	1124
421		1714	1086
521		1477	1193
433	BROADWAY (S → N)	771	776
333		750	707
233		800	691
133		776	663
231	BROADWAY (N → S)	588	631
331		654	672
431		668	533
531		661	524
443	HILL (S → N)	1008	1026
343		600	1039
243		1017	1045
143		1080	988
241	HILL (N → S)	520	536
341		733	549
441		644	546
541		725	505

LEG	NAME	L.A. TRAFFIC DEPT. FLOW DATA (VPH)	VPSST SIMULATION FLOW DATA (VPH)
444	4th STREET (W → E)	1076	1070
434		830	1073
424		1286	1098
414		979	953
404		535	792
312	3rd STREET (E → W)	1134	1146
322		895	1133
332		1308	1124
342		1344	1215
352		1200	1143
244	2nd STREET (W → E)	349	369
234		363	416
224		393	481
214		352	337
204		416	328
212	2nd STREET (E → W)	445	442
222		614	426
232		707	502
242		786	454
252		363	423

Figure 6. Downtown Los Angeles Street Subsystem Results

PARAMETER	$\bar{V}$	$\bar{T}$	MPG	HC	CO	NOx
LIGHT TIMING OPTIMIZED (baseline)	-	-	-	-	-	-
TIMING OPTIMIZED FOR HIGH VOLUME STREETS ONLY (percent change from baseline)	-14%	+16%	-7%	+15%	+26%	+8%
TIMING RANDOMLY SELECTED (percent change from baseline)	-25%	+33%	-10%	+29%	+55%	+9%

Figure 7. Light Timing Effects Predicted by VPSST for Downtown Los Angeles Street Subsystem