Use of INTEGRATION Model To Study High-Occupancy-Vehicle Facilities

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A study was undertaken to assess the potential use of the INTEGRATION computer model to simulate high-occupancy-vehicle (HOV) facilities and to perform some preliminary investigations with the model. It was found that the model is capable of simulating a wide range of HOV facility types. Of those types tested, none was found that the model was not able to reasonably simulate. However, a few problems were encountered in using the model. First, the model works using units of vehicles, not passengers. It was found that this problem could be rectified by simple modification of some of the input and output files. Second, it is possible to indirectly model lanes whose status changes with time by creating an incident on a link that is to be closed for certain periods. Overall, the model seemed to accurately simulate HOV facilities. A number of runs were made on a simple straight-pipe network and a network that represents a portion of the Santa Monica freeway corridor in Los Angeles to determine if the results derived from INTEGRATION conform to what would be expected in the field. Initial analysis of the results from various sensitivity studies indicated that the model was accurately modeling the facilities in question. Because of the preliminary nature of the research, a number of recommendations for future research and some potential modifications to the model are given.

High-occupancy-vehicle (HOV) facilities are becoming an increasingly important tool to control urban freeway congestion and increase the person-carrying capacity of the road system. In fact, the federal government mandates that federal funds for added freeway lanes often can be spent only if the added lanes are HOV or auxiliary lanes. Because of the importance of these facilities, there is a need among transportation engineers and planners to develop analytical tools with which to determine their operating characteristics, effectiveness, and implementation strategies. Because priority treatment for HOV vehicles has been implemented only recently on a widespread basis, a limited number of before-and-after evaluation studies have been undertaken from which to extract meaningful information.

One very new and promising tool with the potential to address this need is the INTEGRATION computer simulation model, developed at Waterloo and Queen's Universities in cooperation with the Ontario Ministry of Transportation. INTEGRATION is unique among models of traffic behavior because it combines the ability to simulate deterministic traffic flow with the ability to replicate dynamic route choice behavior (traffic assignment). This allows the users to study the long-term effects of alternatives on the facility in question and on the surrounding street system. In addition, phenomena such as instantaneous traffic diversion in reaction to prevailing conditions and the provision of real-time route information to drivers can be studied. The INTEGRATION model can represent several different types of users, each having different access to real-time information, including HOV and non-HOV users.

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PURPOSE AND SCOPE

The purpose of this paper is to investigate the feasibility of using the INTEGRATION computer simulation model for HOV facilities and to perform some preliminary investigations with the model. First, the model itself was tested to determine its capabilities as well as its strengths and weaknesses in simulating HOV facilities. Second, numerous simulation runs were made to assess the potential benefits of HOV facilities given various percentages of passengers in HOV vehicles. The first series of runs was made on a simple straight-pipe network. The next series of runs was undertaken using a subsection of the Santa Monica freeway corridor in Los Angeles. This network was coded in previous research by Gardes and May (*1*).

SIMULATION OF HOV FACILITIES WITH INTEGRATION MODEL

Simulated Vehicle Types

INTEGRATION has five classes of vehicles that may be used in the simulation. Table 1 contains descriptions of these five vehicle

TABLE 1 Five Vehicle Types of INTEGRATION

Vehicle Type	Description
1	Background Vehicles - Route choice based on free-flow speed unless historic information or specified path trees are provided.
2	Guided Vehicles - Have access to real-time information at every node or at selected locations on which to base their route choice.
3	Drivers with Anticipatory Knowledge - Can use both real-time information and historical information.
4	Trav-Tek Vehicles - Have advanced route guidance systems within the vehicle.
5	Special Facility Users - Have exclusive access to selected links in the network (i.e. HOV vehicles). Can base route choice on specified path trees or on real-time information.

types. These are discussed in more detail in the INTEGRATION user's manual (*2*). Type 5 vehicles, special facility users, can be considered HOV vehicles, and links in the network can be coded as HOV links. In this way, only HOV vehicles can use these HOV links. An additional feature of these vehicles is that they also can be given the route choice capabilities of Type 2 vehicles and can choose the shortest route to their destination, which may include both HOV and non-HOV lanes. The quality of information received by every vehicle type may be varied by using two parameters. The *F*- (frequency) parameter determines the frequency, in seconds, with which the information is updated. The *D*- (distortion) parameter, varying from −0.5 to 0.5, determines the accuracy of the information received. A *D*-parameter of 0 indicates perfect information, whereas movement away from 0 represents ever-increasing error levels.

Input File Modification

Of the five required and four optional input files to the model, only four are of specific concern to HOV facilities. These nine input files are described in Table 2. In the creation of a typical mainline freeway HOV lane with a shared right-of-way, the first step is to modify input File 2, the link file. An original entry from the link file for the Santa Monica Freeway corridor network is as follows:

73 121 218 0.812 70 1700 5 0.35 1.0 1.0 0 0 0 0 0 1 Freeway EB

From left to right the columns represent link number, start node, end node, length (kilometer), free-flow speed (kilometer/hour), capacity (vehicle/hour/lane), number of lanes, platoon dispersion factor, the *A*- and *B*-parameters of the speed-flow curve, four columns for signal control, the HOV variable (a variable indicating whether real-time information is provided to this link), and a brief description of the link. This entry is copied and modified to produce the following entries:

73 121 218 0.812 70 1700 5 0.35 1.0 1.0 0 0 0 0 01 Freeway EB
257 121 218 0.812 70 1700 1 0.35 1.0 1.0 0 0 0 0 1 1 FW HOV EB

The three changes made are underlined and discussed below from left to right. First, a unique link number needs to be assigned to the new HOV link. Link numbers need not be sequential. The original link number was 73, and the new HOV link is assigned 257. Second, the number of lanes is changed to reflect the addition of an HOV lane. In this example, an HOV lane was added to the network. The last change is in the boolean variable that indicates whether a lane is an HOV lane or not. Switching this from 0 to 1 ensures that only Type 5 vehicles will use this link. The model ensures 100 percent compliance by not allowing for any cheating by non-HOV vehicles. However, the percentage of HOV vehicles can be changed to reflect any rate of expected violation of HOV lane usage.

Adding HOV links in the manner indicated above will simulate an HOV facility with no boundaries between HOV and non-HOV lanes. The HOV vehicles will be able to transfer between HOV and non-HOV links at any upstream node that is common to the two. The modified freeway links in this network were on average 0.44 km (0.26 mi) long. In reality, an HOV vehicle may switch between these links at any point. A more realistic model could have been achieved by dividing these links into smaller segments. To simulate an HOV facility with physically separated HOV and non-HOV lanes requires that the adjacent links not have the same upstream node numbers. This would require the creation of new nodes in input File 1, the node file. This was not attempted in this study. Using these methods, the model can simulate a facility with a continuous barrier, a series of discontinuous barriers, or no barriers at all.

HOV vehicles may be assigned specific routes that they must follow throughout the simulation. These are specified in the optional input File 8. This file is not recommended if the routing of HOV facilities is to be based on the attractiveness of HOV facilities versus non-HOV facilities. For that reason, this file was not used.

Input File 4 contains the origin and destination data. Because of the costly nature of these data, the file usually is generated synthetically using the program QUEENSOD, a supporting module of the INTEGRATION program. A sample entry from this file is given:

3 24 51 1500 1.0 0 3600 0.0 0.85 0.0 0.0 0.15

The first and second underlined values represent the origin and destination nodes for this entry. The third underlined value indicates the demand in vehicles per hour between the indicated origin and destination for the given period (0 to 3,600 sec in this example). The five underlined values on the right define the distribution of vehicle types for this origin-destination pair. In this entry 85 percent of the vehicles are Type 2 and 15 percent are Type 5. These five values must add up to 1. To be realistic, if the percentage of HOV vehicles is increased, the corresponding demand rate should be decreased to reflect the reduction in the total number of vehicles. This will be discussed in greater detail.

TABLE 2 Nine Input Files of INTEGRATION

Input File	Description
* 1 (required)	Node File - Specifies x and y coordinates of all nodes in the network for purposes of graphical display.
* 2 (required)	Link File - Contains start and end nodes and physical characteristics of the links.
3 (required)	Signal File - Signal timing plans.
* 4 (required)	Origin/Destination Traffic Demand File - Specifies demand rates for all O/D pairs for each time slice.
5 (required)	Incident File - Includes length, severity and location of any incidents during the simulation.
6 (optional)	Average Travel Times File - Provides average travel times for all links for use as historical information.
7 (optional)	Time Series of Anticipated Travel Times - The same as file 6 except that travel time information is given for each user-specified time slice.
* 8 (optional)	Static Path Tree File - This file has the user-specified path trees for type 5 vehicles.
9 (optional)	Time Series of Multipath Background Traffic Routings - The same as file 8 but used for type 1 vehicles.

* Specific to HOV Studies

Potential Modeling of HOV Facilities with INTEGRATION

Network Possibilities

By modification of the input files a wide variety of HOV facilities can be modeled with INTEGRATION. Any combination of links may contain HOV lanes to reflect HOV lanes of any length or at any part of the network. Any number of HOV or non-HOV lanes can be simulated. The analysis of a possible list of proposed HOV lane designations is feasible with the INTEGRATION model. Also, the simulation of HOV lanes is not restricted to freeways. The above discussion applies to arterial streets as well as freeways. By adding an additional link at an on ramp one can simulate priority bypass of ramp meters. The model also allows one to vary the traffic demands and HOV user levels over both individual origin-destination pairs and time slices.

Lanes Whose Status Will Change with Time

One potential problem is modeling lanes whose status will change throughout the simulation period. Examples of this are a shoulder lane that can be used during certain hours, lanes that are for HOV use only during certain hours, and reversible lanes. The link file does not provide for changes to be made to the physical structure of the network during the simulation period. One possible way around this problem would be to use input File 5, the incident file. The incident file allows for any number of lanes on a link (including portions of a lane) to be blocked for any period of time. Any number of incidents can be simulated. For example, to simulate a lane that switches from non-HOV to HOV for a certain period, one could set up two links, one for the HOV lane and one for the non-HOV lane. The entire link could be blocked for the period that the link is HOV to ensure that no non-HOV vehicles use the link during that period. Reversible lanes could be blocked in a similar manner.

Vehicle-People Conflict

Another potential problem is that the INTEGRATION model uses demand data that are measured in units of vehicles and not passengers. Of course, the decision of how many vehicles may use the HOV facility is not decided on a percentage basis but on an occupancy basis. Typically there are only two values that are chosen from when a cut-off level is selected: two or more persons per vehicle or three or more persons per vehicle. These two values will translate into three percentages that would be allowed onto the HOV facility.

As mentioned, if a study is conducted to determine the effects of altering the percentage of HOV passengers (or percentage of HOV vehicles), the number of vehicles must be altered to reflect the corresponding change in the total number of vehicles in the system. To accomplish this with the model, two steps were taken. First, a spreadsheet was used to calculate the change in the number of vehicles given the change in percentage of HOV passengers. Second, a simple computer program was written that can change the demand for all of the origin-destination pairs by any given percentage. This will be discussed in detail. It was believed that it would not be difficult to develop programs to automate this process.

The output from the model is also presented in terms of vehicles and not passengers. The process of manipulating the output files to reflect average passenger travel time as opposed to average vehicle travel time was also quite simple. Again, an average occupancy rate for HOV vehicles must be provided to the model.

STUDIES USING STRAIGHT-PIPE NETWORK

In this section the simulation experiments conducted with the straight-pipe network are discussed and presented. The design of the experiment is discussed first followed by the presentation and interpretation of the numerical results.

Design of Experiment

The first freeway network considered is a straight-pipe network consisting of a directional freeway 14.8 km (8.9 mi) long. The bottleneck itself is 0.8 km (0.5 mi) long and is located 0.8 km (0.5 mi) from the downstream end of the network. The purpose of the bottleneck and its location was to ensure that congestion would occur in the non-HOV lanes and that the queue would not block HOV vehicles from entering the HOV lane. With the HOV lane added, the network contains only 17 nodes and 32 links. The 17 nodes are all in a straight line. Between each pair of adjacent nodes there are two links—an HOV link and a non-HOV link.

The initial design of the freeway is a mixed-flow facility that has four lanes, except for the potential bottleneck, which has three lanes. A continuous lane is then added for the entire length of the freeway and will be analyzed as an added mixed-flow lane and alternatively as an HOV lane with varying HOV demand levels. All traffic demands originate at the upstream end of the directional freeway and have destinations at the downstream end.

Studies were made on this network using two levels of peak-hour demand: 8,000 and 10,000 persons per hour. For each demand level, the following investigations were made:

- Existing freeway design without an added lane;
- Existing freeway design with an added mixed-flow lane; and
- Existing freeway design with an added HOV lane and the percentage of passengers using HOV vehicles varying from 2 to 35 percent in 2 percent increments.

These three scenarios are shown in Figure 1. For simplicity the HOV vehicles were assumed to carry two persons each, and non-HOV vehicles were assumed to carry one person. Values above 32 percent were not studied because they represent a situation in which the travel times would be roughly equal between HOV and non-HOV lanes. There would be little benefit to constructing and operating the HOV facility in this manner.

Presentation and Interpretation of Results

The results using the peak-hour demand of 8,000 persons per hour are shown in Figure 2. The average travel time for the entire length of the freeway under the existing design was 18.3 min and resulted in a total travel time of 2,440 passenger-hours. Similar

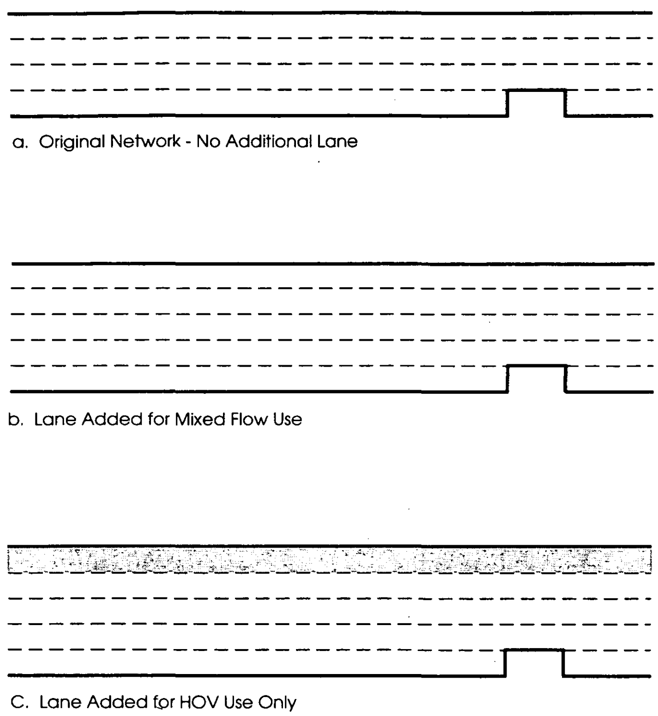

FIGURE 1 Three straight-pipe scenarios.

values for the existing freeway design with the added mixed-flow lane were 14.8 min and 1,979 passenger-hours. These values represented a reduction of 3.5 min in average trip travel time and 461 passenger-hours in total travel time with the added mixed-flow lane.

Similar results for the existing freeway design with an added HOV lane assuming HOV passengers varying from 2 to 32 percent in 2 percent steps are shown in Figure 2. The results conform to what would be expected in the field. At very low percentages of HOV passenger volume the HOV passengers enjoy a very low travel time. As this percentage increases and the HOV lane becomes more congested, their travel time increases. The travel times for non-HOV passengers and the system as a whole decrease as the percentage of HOV passengers rises for two reasons: the HOV lane is utilized better and the number of vehicles in the network is lower. A frequent argument against these system benefits achieved by HOV facilities is that more latent vehicular demand would be induced on the roadway; therefore the reduction in the total number of vehicles would not be as significant. Attempting to resolve this conflict is well beyond the scope of this paper.

Figure 3 shows the results with a demand of 10,000 persons per hour. The results are similar to those in Figure 2. As expected, HOV passengers benefit more at low percentages on the more congested network. Also, the difference between average travel times with and without an added lane is greater with the increased congestion. The average travel time savings associated with the added lane with 10,000 persons is 9.2 min versus 3.5 min for 8,000 persons. The total travel time savings increased from 461 to 1,532 hr.

STUDIES USING SANTA MONICA FREEWAY CORRIDOR NETWORK

The Network

A number of sensitivity studies were done to assess the model's ability to simulate HOV facilities on a more complex network. The Santa Monica Freeway corridor network was used for all of the following runs. This network consists of an 18.2-km (11.4-mi) section of the Santa Monica Freeway with two parallel and eight crossing arterial streets. The network contains 171 nodes and 308 links, and the simulation period is from 6:00 a.m. to 10:00 a.m.

Design of Experiment

Two potential scenarios were examined using the network: adding an HOV lane to the entire eastbound freeway portion of the network and taking a lane away for conversion to an HOV lane. These were chosen to represent two scenarios with very different levels of congestion. Neither of these possibilities is actually expected to happen in the near future. Taking a lane away would be physically very simple but politically very difficult. In fact, there once was an HOV lane on the Santa Monica Freeway that was removed because of public opposition. Adding a new lane would be costly and likely encounter opposition.

These runs were made with the *F*- and *D*-parameters set at 10 and 0, respectively. These values means that the drivers have virtually continuous and perfect information about the travel times

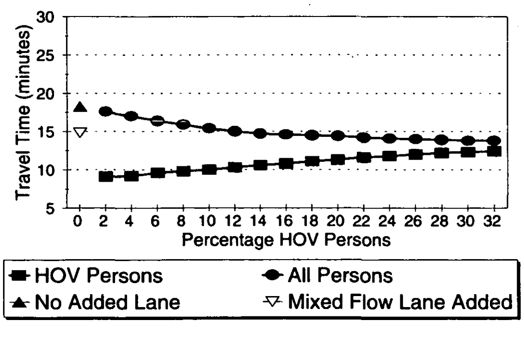

FIGURE 2 Straight-pipe network with 8,000 persons.

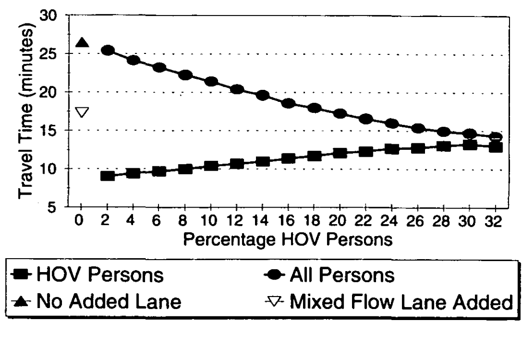

FIGURE 3 Straight-pipe network with 10,000 persons.

on the network. Because this network is simulating only recurring congestion, real-time information is essentially the same as historical information. Thus, this simulation represents the equilibrium that will be reached after the system is in place for some time and drivers have determined their shortest path. Another series of runs was done with the *F*- and *D*-parameters set to 60 and 0.2, respectively, to represent a poorer quality of information. The results were similar, except that travel times as a whole were slightly higher and there was significantly more variation in travel times with the poorer quality of information.

Data from California Department of Transportation (Caltrans) indicate that 10 percent of the vehicles on the freeway during the morning peak period contain two or more passengers, and the occupancy for HOV vehicles is 2.2 persons per vehicle. These data come from only a single count done in 1991. Using these figures, it was assumed that a single conversion from non-HOV to HOV would displace 1.2 vehicles and that the existing occupancy ratio for the network is 1.12 persons per vehicle. Because the original origin-destination file called for 191,097 vehicles, it was assumed that the network carries 214,029 passengers.

A spreadsheet was developed and used first to calculate the number of HOV and non-HOV passengers on the basis of the percentage of HOV passengers. Then the spreadsheet was used to calculate the number of both types of vehicles and the percentage of each on the basis of the assumed occupancy rates. The percentage of each vehicle type is then entered into the origin-destination pairs file of the INTEGRATION model. In addition, a vehicle adjustment factor is calculated for each percentile. This factor determines the amount by which the total number of vehicles must be adjusted to reflect the displacement of vehicles as a result of conversion from non-HOV to HOV. A program was written that automatically adjusts the demand data in the origin-destination pairs file by any given factor.

The model assigns traffic in a stochastic manner and the number of vehicles generated in the simulation often differs slightly from that specified in the origin-destination file. As a result the percentage of HOV vehicles and, hence, the percentage of HOV passengers in the simulation often differed slightly from the desired amount. For reasons of clarity, the *X*-axis in Figures 4 and 5 gives the desired percentages, not the actual percentages.

Sensitivity Studies

Sensitivity studies were made by varying the proportion of HOV passengers from 0 to 22 percent in increments of 2 percent for both scenarios, adding and taking away a lane. The value of 22 percent was chosen as a stopping point because this value is beyond the point where the travel times converge for both studies. On the basis of data from Caltrans, the system actually has nearly 20 percent passengers in HOV vehicles. The results of these experiments are shown in Figures 4 and 5.

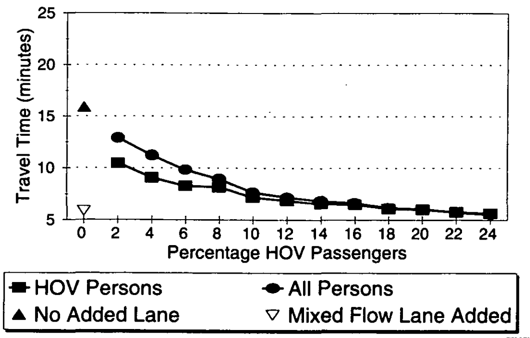

FIGURE 4 Lane added to network: Santa Monica Freeway.

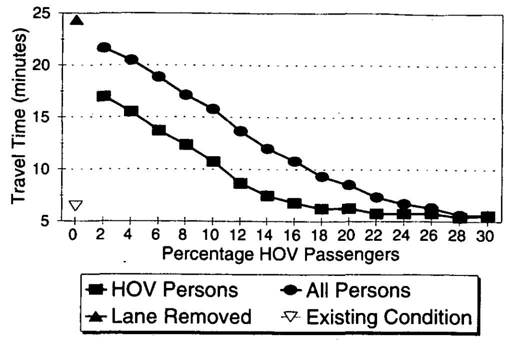

FIGURE 5 Lane converted to HOV usage: Santa Monica Freeway.

Figure 4 shows the results from the scenario in which an HOV lane was added to the existing network. Unlike the straight-pipe network, the travel times for HOV passengers actually decrease as the percentage of HOV passengers begins to rise. The reason for this change is likely that the congestion experienced by non-HOV vehicles affects the HOV vehicles as well. As the congestion is eased, travel times for both vehicle types improve. This is not the case with the straight-pipe network. Another difference between this network and the straight-pipe network is that the travel times for both vehicle types converge at a much lower percentage in the Smart Corridor network. [The Smart Corridor is a project under way on the Santa Monica Freeway to simulate various Intelligent Vehicle-Highway System (IVHS) strategies.] This convergence is expected for two reasons. First, the percentage of the freeway designated for HOV vehicles is much smaller in this example. Adding a lane creates a total of seven lanes at some points. Second, because the HOV vehicles are distributed across all origin-destination pairs evenly, many HOV vehicles take routes in which they do not use the HOV facility. One should also note that the travel times essentially have converged at 14 percent. At percentages of HOV passengers higher than 14 percent, the travel times for both types are essentially the same but continue to decrease because of the decreased number of vehicles on the network.

The results of taking a lane of the existing freeway and converting it to HOV are shown in Figure 5. The existing condition is assuming an HOV passenger percentage of 20 percent. Note that the results indicate that the percentage of HOV vehicles would have to increase to 26 percent before the average passenger time dropped below that of the existing condition. As with the straight-pipe network, the difference between HOV and non-HOV vehicles is greater under heavier congestion.

FUTURE STUDIES

The overall assessment of the research is that the model is a powerful tool in the analysis of HOV facilities. The results of the sensitivity analysis are that the model gives results that conform with what would be expected in the field. However, the research conducted here is clearly preliminary in nature. Future research with the model is necessary to determine its accuracy and to enhance its capabilities. Some potential areas for future research are discussed below.

Calibration with Actual Data

The test of any model is how well it predicts real-world conditions. Before-and-after study results of a real-world situation should be sought and compared with results from INTEGRATION. One possibility for this type of comparison is the I-80 corridor in the San Francisco Bay Area, where an HOV lane is in the process of being added. This network has been coded for INTEGRATION by researchers at the University of California at Berkeley. Also, efforts are under way to code in great detail a 9.3-mi section of the Santa Monica Freeway in Los Angeles.

Calibration with Other Freeway Simulation Models

Studies could be done that compare the results of other freeway simulation models that incorporate HOV facilities with the results from INTEGRATION. The Santa Monica Freeway currently is being coded with FREQ-11, and comparisons of the two models are planned.

Programs To Manipulate Input and Output Files

The process of using spreadsheets to generate values to be used by the origin-destination file was somewhat laborious. Efforts toward developing a program that can automatically alter this file on the basis of certain user-specified parameters (i.e., average occupancy) would ease the file preparation process. This program could generate a series of input files on its own. The program should allow the user to specify different HOV percentages for different origin-destination pairs. Also, the data are presented in this paper in terms of averages for all of the vehicles on the network. Programs could be written that disaggregate the origin-destination data into certain user-specified groups such as eastbound freeway travelers.

Potential Modifications to INTEGRATION Program

A number of modifications could be made to the INTEGRATION model itself to enhance its capabilities to simulate HOV facilities. For example, a parameter of average vehicle occupancy for HOV vehicles could be added to the origin-destination pairs file. This would allow the program to directly calculate time savings on the basis of passengers and not vehicles. Signal optimization could also be done on a passenger basis. In addition, the model could also contain a growth factor that could determine the effect of various levels of latent demand generated by a reduction in vehicles caused by an increased percentage of HOV vehicles.

Studies with Advanced Traveler Information Systems

As mentioned earlier, a powerful aspect of the INTEGRATION model is its ability to model varying levels of information provided to motorists. One could use the model to assess the potential benefits of an HOV facility alone and in combination with various levels of advanced traveler information systems.

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This paper is part of an effort to simulate various IVHS strategies on the Santa Monica Freeway corridor (I-10) in Los Angeles. This corridor is also known as the Smart Corridor because of the project of the same name that is under way on the corridor. Although much of the data used were obtained from the agencies involved in the Smart Corridor project, this research is not a part of the Smart Corridor project itself.

REFERENCES

1. Gardes, Y., and A. D. May. *Simulation of IVHS on the Smart Corridor Using the INTEGRATION Model—Phase 1: Initial Investigations.* PATH Research Report UCB-ITS-PRR-93-3. California PATH, Institute of Transportation Studies, University of California at Berkeley, 1993.
2. M. Van Aerde and Associates. *INTEGRATION: A Model For Simulating Integrated Traffic Networks—User's Guide for Model 1.4d.* TT&E Branch—Ontario Ministry of Transportation; Transportation Systems Research Group, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada, May 1992.

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