USE OF SIMULATION FOR ESTIMATION OF TRAVEL TIME SAVINGS: A CASE OF HIGHWAY WIDENING

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Abstract

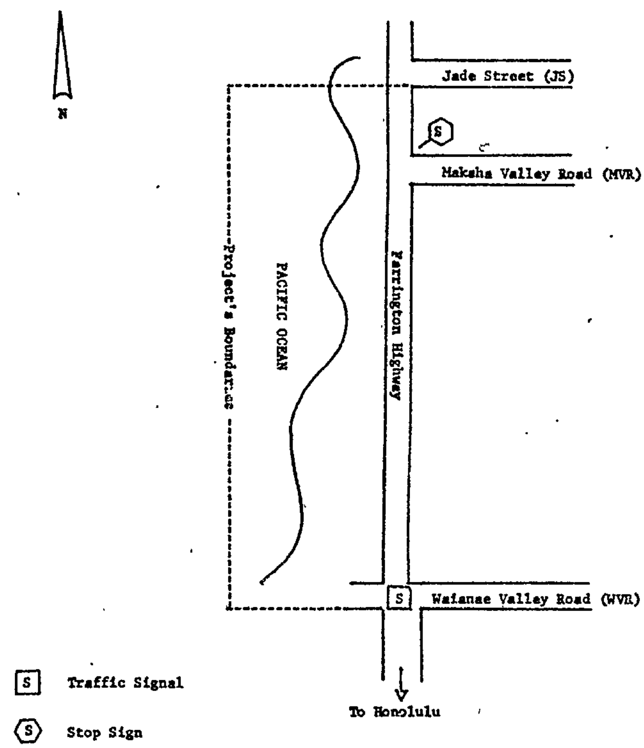
The primary purpose of this paper is to illustrate the use of discrete simulation technique for estimating travel time savings using as a case study a small highway improvement project. The project involves widening from two to four lanes a 2.4 mile section of Farrington Highway on the Leeward side of Oahu. Current and projected traffic flows in the area affected by the project were modelled using IBM/GPSSV. Reduction of travel time attributable to the project was estimated.

INTRODUCTION

Most cost-benefit studies of highway projects have found that the travel time savings is the most important benefit by a substantial margin. However, both the reduction of travel time attributable to the project and the assignment of value to it have been plagued by numerous difficulties. The travel time saving was especially difficult to estimate where system effects are present. The purpose of this paper is to illustrate use of simulation for estimating the travel time savings using as a case study a small highway improvement project. The project involves widening from two to four lanes a 2.4 mile section of Farrington Highway (FH) on the Leeward side of Oahu.

The area affected by the project is shown in Figure 1. Farrington Highway is the only highway connecting communities located along the Pacific Ocean coast on this side of the Island. In addition to improving traffic flow on FH the project is expected to affect the performance of Makaha Valley Road (MVR) and FH intersection. This intersection is currently controlled by a stop sign for cars entering

FIGURE 1



FH from MVR. The predominant flow of traffic here is from MVR toward Honolulu. It is also expected that the project would improve traffic flow at the signalized inter-

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section of Waianae Valley Road (WVR) and FH. From this intersection southbound FH has already been widened to four lanes.

In the proposed project one can identify three sources of travel time savings: (1) Reduction in travel time due to expected higher speed on a four lane highway; (2) Possible reduction in delay by cars making a left turn from MVR into FH southbound; (3) Reduction of delay at the FH and WVR intersection. Because of a short distance involved, it is possible that the reduction of delay at the intersection is a greater source of travel time savings than the reduction of travel time due to higher speed. Consequently, it becomes necessary to model the system in order to capture all the system's effects. Such a model is presented in Section 2.

In the proposed project the choice, in essence, has to be made between two alternatives: (1) Leave the highway as is, hereafter referred to as Option 0; (2) Widen the highway as proposed, hereafter referred to as Option 1. Thus, the task of estimating travel time savings is as follows:

(1) Develop a simulation model of the current traffic flows in the area affected by the project;

(2) Use the model to estimate the average travel time for each of the traffic flows for Option 0 for each year during the expected life of the project (assumed to be 20 years). Then multiply each estimate times the projected traffic flow for each year and sum the products;

(3) Repeat step (2) for Option 1;

(4) Substract the total obtained in (2) from the total obtained in (3) to obtain travel time savings attributable to the project.

Since the primary purpose of this paper is to illustrate the technique the simulation is performed only for the first and the last year of the project's useful life. Furthermore, since a significant difference is expected, simulation is performed during the peak and off-peak periods. The results are reported in Section 3 followed by overall evaluation in the last section of the paper.

The Model

Both Options 0 and 1 were modelled using IBM/GPSSV (General Purpose Simulation System). GPSS is a widely used and well-known simulation language designed specifically for studying waiting line and scheduling type problems. It is a transaction flow type of language and a model can be readily constructed of a system involving dynamic movement of units through various components of the system. Hence, it is particularly well-suited for modelling traffic and queueing systems.

An analysis of the problem identifies four major independent phenomena: (1) Southbound traffic on FH; (2) Northbound traffic on FH; (3) Southbound traffic turning left on FH from MVR; (4) Traffic signal at the FH/WVR intersection. Vehicles are represented by transactions in the first three phenomena. A traffic signal is simulated by a single transaction continuously setting a logic switch at the appropriate time for a green and red light. The signal cycle length is set to 60 second green and 30 second red for the FH traffic for all the simulations.

The model for Option 0, shown in the GPSS block diagram in Figure 2, is rather simple. The Option 1 model is very similar to the two-lane option since its construction required only minor modifications to the Option 0 model. The current traffic flow data as well as traffic projections needed for simulation were supplied by the State of Hawaii Department of Transportation (Table 1) and the car arrivals were assumed to be Poisson-distributed.

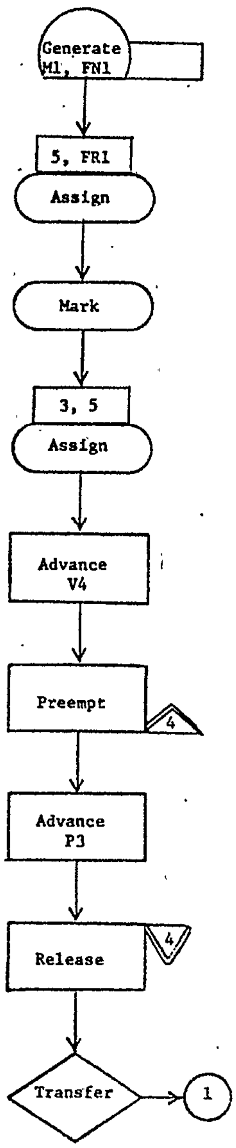
The speed/flow relationships, however, which were needed for simulations and which were assumed to be site-specific, required empirical estimation. Travel time data for the estimation of these relationships were collected during randomly selected days in 1980. They consisted of the measured time of 134 trips over the two-lane section of the highway proposed for widening and the concurrent measurement of traffic flow per 15-minute period. For Option 1, the data consisted of the measured time of 77 trips over the same distance of the four-lane section of FH just below the FH/WVR intersection and the concurrent measurement of traffic flow per 15-minute period.

These data were used to estimate the linear approximation to the speed/flow relationship shown in Figure 3. It was assumed that the maximum point A corresponds to the two-lane maximum highway capacity of 2,000 cars/hour in both directions and to the four-lane maximum highway capacity of 4,000 cars/hour in each direction. Thus, in each case the linear equation was constrained to go through the respective maximum point. The results were:

FIGURE 2

GPSS Block Diagram for Option O (2 Lanes) Model

1. Southbound Traffic on FH



Car arrivals according to poisson interval rate with mean value of M1

Assign flow rate to parameter 5

Set the timer

Assign intersection time of 5 seconds to parameter 3

Travel towards the intersection of MVR/FH

Seize the intersection

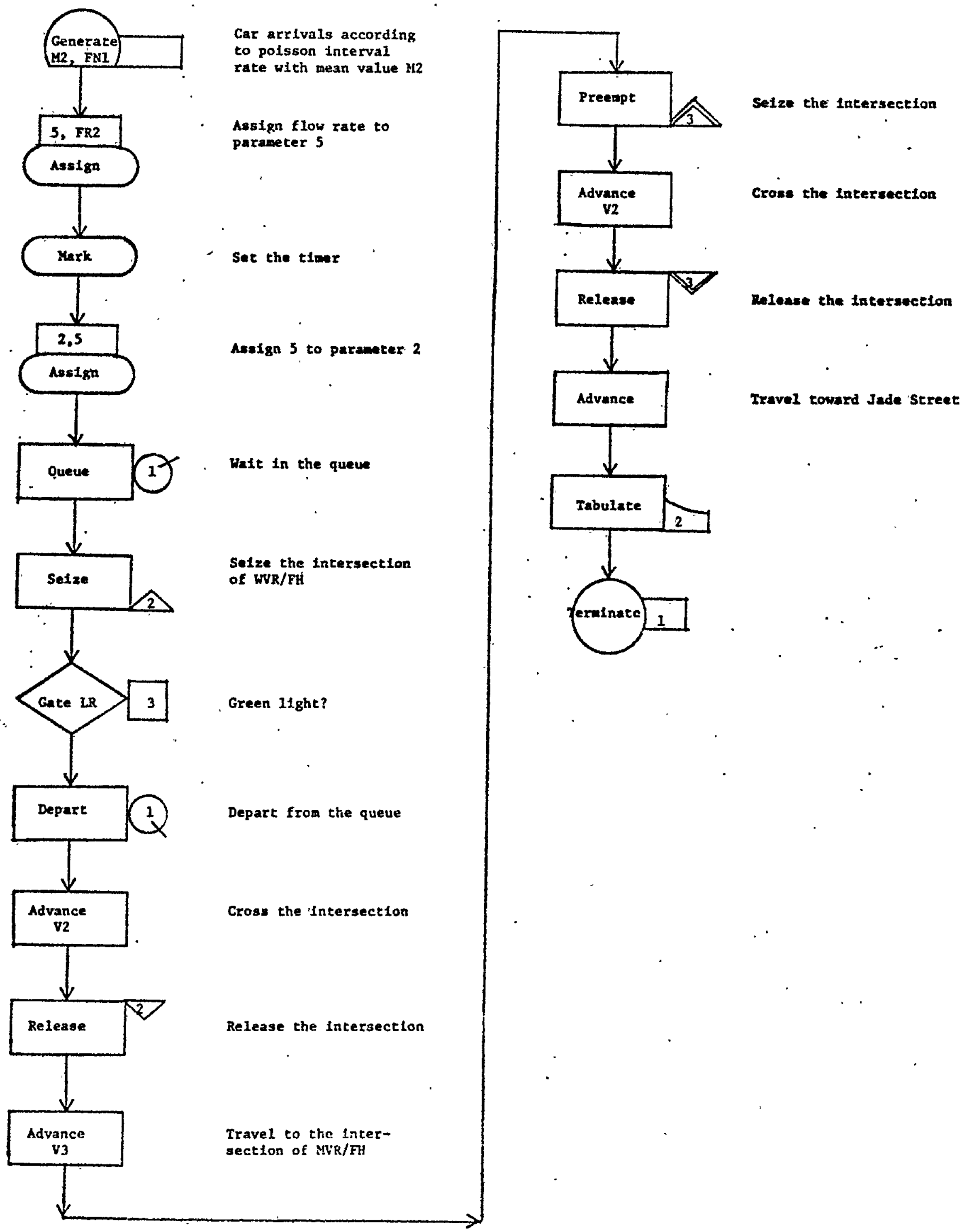
Cross the intersection

Release the intersection

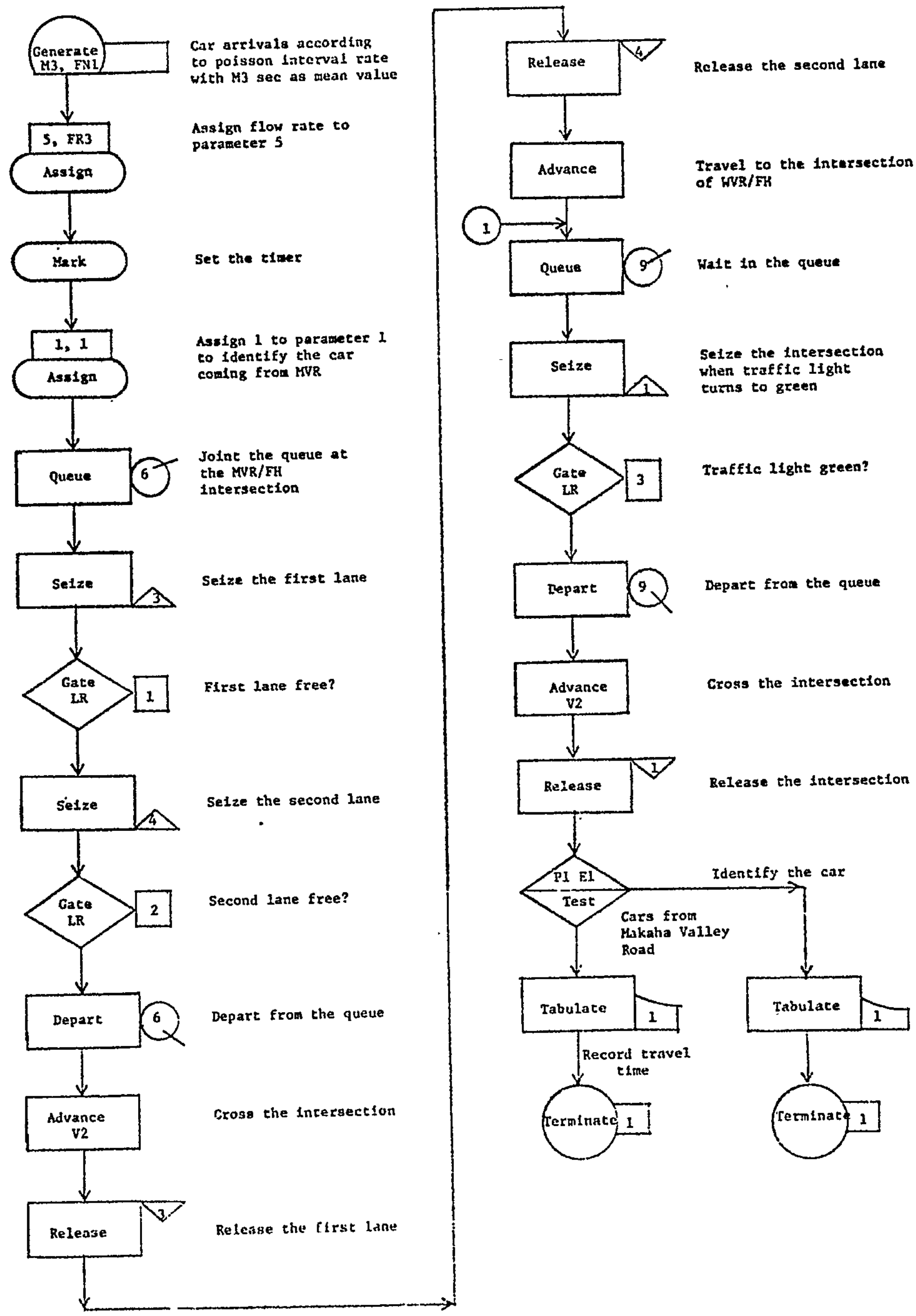
Travel to the intersection of FH/WVR

Merge with 3

2. Northbound Traffic on FH



3. Southbound Traffic Turning Left on FH from MVR



4. Traffic Signal at the FH/WVR Intersection

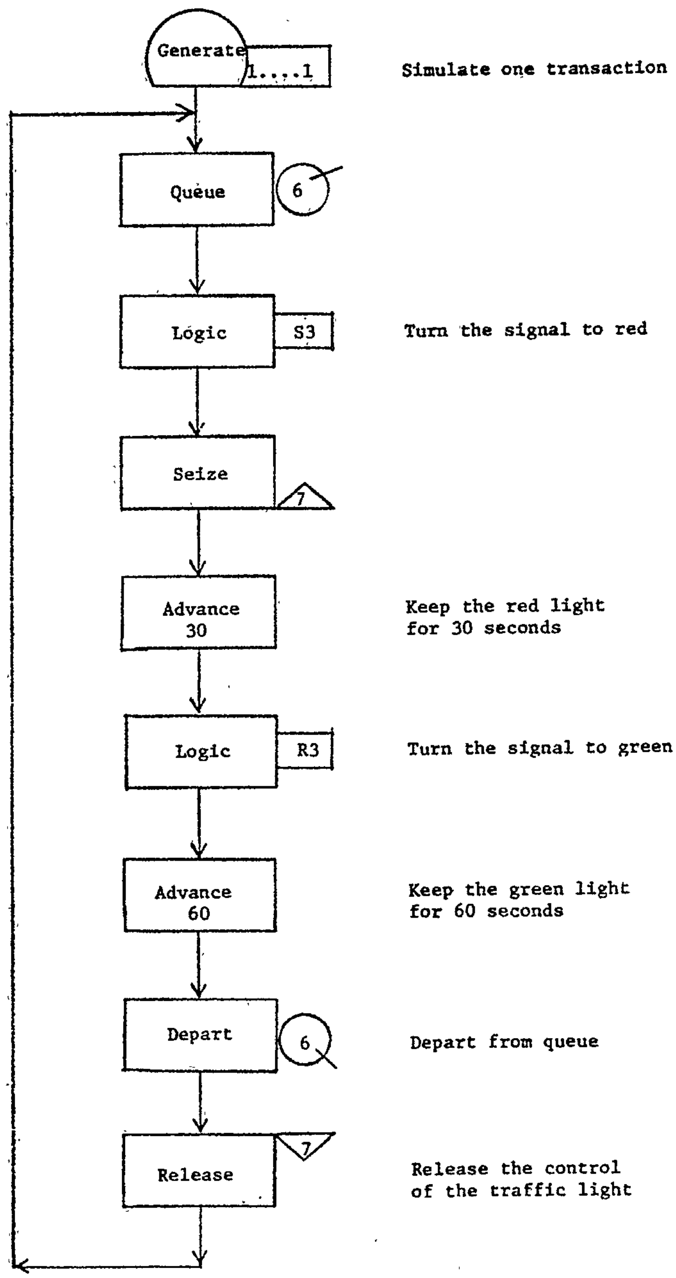


TABLE 1

Current Traffic Flows and Traffic Projections

Location	Year	Average Daily Traffic
Lualualei Homestead Road to Waianae Valley Road *Kam=8.0 Kpm=7.6 **Dam=55/45 Dpm=55/45	1980 2000	22,500 37,900
Waianae Valley Road to Makaha Valley Road Kam=7.5 Kpm=7.5 Dam=55/45 Dpm=55/45	1980 2000	19,600 33,000
Makaha Valley Road to Jade Street Kam=7.0 Kpm=7.5 Dam=55/45 Dpm=55/45	1980 2000	14,700 24,700
Makaha Valley Road at Intersection with Farrington Highway Kam=6.0 Kpm=7.5 Dam=55/45 Dpm=55/45	1980 2000	6,000 10,000
Farrington Highway, south of intersection with Jade Street Kam=7.0 Kpm=7.5 Dam=55/45 Dpm=55/45	1980 2000	12,000 20,200
Farrington Highway, south of intersection with Makaha Valley Road Kam=7.0 Kpm=7.5 Dam=55/45 Dpm=50/50	1980 2000	17,400 29,200
Farrington Highway, south of intersection with Waianae Valley Road Kam=8.0 Kpm=7.5 Dam=55/45 Dpm=55/45	1980 2000	21,800 36,800

*Kam and Kpm refer to the percent of daily traffic in the peak during am and pm hours, respectively.

**Dam and Dpm refer to the directional proportion of flow during am and pm peak hours, respectively.

Source: State of Hawaii Department of Transportation

2 lanes:

$$\text{SPEED} = 34.7004 - \underset{(0.0009)}{0.0087}\ \text{FLOW} \qquad R^2 = 0.04$$

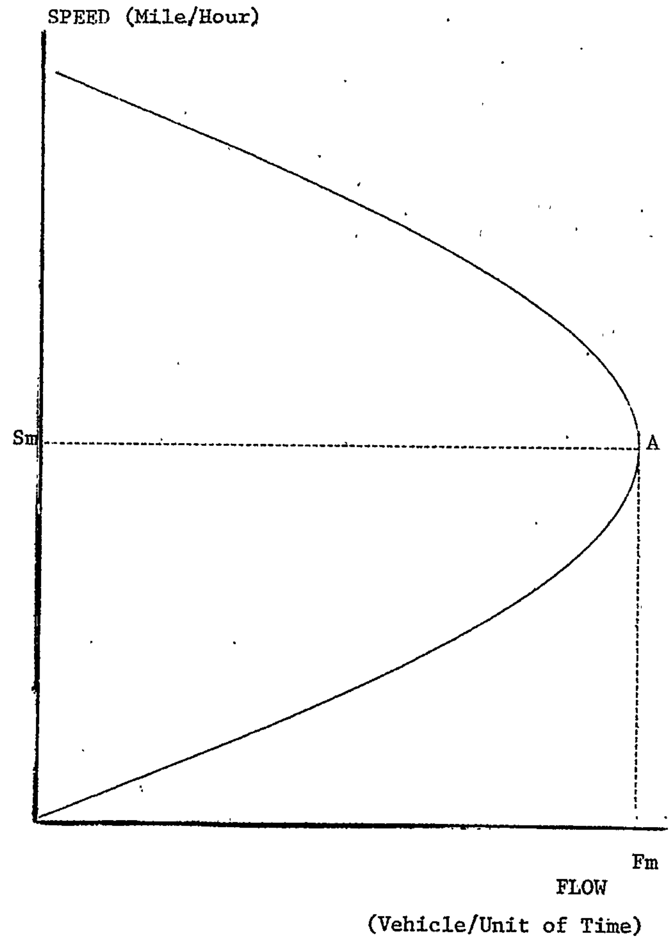
4 lanes:

$$\text{SPEED} = 42.9785 - \underset{(0.0002)}{0.0027}\ \text{FLOW} \qquad R^2 = 0.02$$

As indicated by the asymptotic standard error shown in the parentheses the coefficient of FLOW variable is statistically significant in both equations. The overall fit, however, is rather poor, in part, because the traffic flows in the proposed project area do not exhibit sharp A.M. and P.M. rush-hour peaks. Rather, the fluctuations during a typical day are very moderate. Consequently, the sample observations cluster within a narrow range.

Furthermore, because of the short distances involved, the occurrence of random events (e.g., entry of vehicles from private driveways or parking spaces along the beach, exit from the highway, buses, ambulances or fire engines on the highway, etc.) have a more significant effect on travel time than do the traffic flows. Nevertheless, the above equations appear to provide plausible speed estimates and, therefore, were used in the simulations.

Figure 3. A Theoretical Speed/Flow Relationship



The Results

The simulations of the traffic flows for peak and off-peak periods for Options 0 and 1 for the years 1980 and 2000 yielded a set of average travel time estimates shown in Table 2. They were collected after one hour of simulated time for each case. It should be noted that they do include the delay, if any, at both intersections.

As expected, travel times are shorter with Option 1 and remain stable over the 20-year time horizon. With Option 0 travel times increase more rapidly, especially during the daily peak periods and at the end of the 20-year time horizon. In fact, toward the end of the 20-year period, the traffic flows during the peak hours exceed the capacity of signalized FH/WVR intersection. In the absence of any changes in the intersection capacity, the queue would continue to build up during the rush hours. The peak thus would have to widen in order to dissipate the accumulated queue, or travelers would have to change their starting times, even though this may mean starting at a less preferred time.

The results also indicate that with Option 0 toward the end of the useful life of the project, drivers will experience a difficulty in entering FH from MVR causing a long queue to build up rapidly. Thus, it may be necessary to install a traffic signal at the FH/MVR intersection. However, the signal is likely to increase travel time for southbound and northbound traffic on FH. To estimate its impact the model for Option 0 was modified to include a traffic signal at the FH/MVR intersection.

Simulations were performed using the modified model for the year 2000 for peak period with various signal cycle lengths. The results are summarized in Table 3. As expected, the average travel time for southbound traffic from MVR is reduced dramatically while the average on FH increases significantly. The results are not sensitive to the signal cycle lengths within the range considered.

Table 4 shows the total travel time estimates for Options 0 and 1 for all cars expected to use FH in 1980 and 2000. The difference between total travel time between the two options is equal to the travel time savings attributable to the project. According to the estimates, also shown in Table 4, over 450 and 1,600 hours would be saved in the years 1980 and 2000, respectively, if Option 1 is selected.

TABLE 2

Average Travel Time per Vehicle, in seconds, Options 0 & 1

	AT1	AT2	AT3
Option 0			
Peak:			
1980	296.0	279.6	218.1
2000	838.7	319.3	508.7
Off Peak:			
1980	282.2	269.2	212.3
2000	318.5	289.3	231.3
Option 1			
Peak:			
1980	193.4	203.9	191.9
2000	196.5	207.5	199.8
Off Peak:			
1980	191.5	203.5	190.6
2000	192.2	204.4	192.6

Note:

AT_1 - average travel time on FH southbound

AT_2 - average travel time on FH northbound

AT_3 - average travel time on FH southbound from MVR

TABLE 3

Average Travel Time per Vehicle, in seconds, Modified Option 0 Peak Period, Year 2000

	AT1	AT2	AT3 1/
no signal	837.7	319.3	508.7
60G-30R 2/	1124.9	896.1	252.4
75G-15R	1125.0	887.9	269.3
80G-10R	1125.0	887.9	275.3
85G- 5R	1125.0	887.9	279.7
87G- 3R	1125.0	887.9	280.6

Note:

1/ AT1, AT2 & AT3 are defined as in Table 2.

2/ 60G-30R indicates 60-second green and 30-second red for FH traffic.

Table 5 compares the total travel time estimates for the peak period for the year 2000 of Option 0 and Modified Option 0. The net increase in travel time is estimated to be over 600 hours regardless of the signal cycle length if Modified Option 0 is adopted to facilitate entry of cars from MVR to FH. Hence, it can be quite expensive to alleviate the long queue at the stop signal of MVR/FH intersection.

Conclusion

Simulation appears to be a useful tool for estimating travel time savings attributable to a proposed project. Complex reactions and interactions of a vehicular traffic system can be readily modelled using the IBM General Purpose Simulation System (GPSSV). In some cases the results may indicate that certain options are not feasible if the projected traffic is to be accommodated. In this case study it happens with Option 0 when in future years the capacity of intersections is exceeded. Thus, "something" may have to be done to increase intersection capacity if Option 0 is selected.

In the case study the effect on travel time savings of placing a traffic signal at the MVR/FH intersection to prevent buildup of long queues was investigated. The simulation results showed a significant (over 50%) increase in total travel time. Thus, if some action has to be taken and if a traffic signal is the best alternative, a failure to incorporate the effect of this action would result in a large underestimate of the project's benefits and an overestimate of costs (due to failure to include costs of the traffic signal).

The use of simulation also has a drawback. The results of Option 0 for 1980 appear to represent the current traffic situation in the project's area. This conclusion, however, is based on our collective but subjective judgment. The actual validation of the model would require a costly collection of suitable field data. However, even if such a test can be performed it would not be conclusive. The fact that the model behaves like reality for the 1980 Option 0 does not prove anything about the validity of the model for a different set of conditions as, for example, in the 1980 Option 1 and 2000 Options 0 and 1. It may be argued, however, that all estimation methods suffer from the same drawback. Therefore, the method that requires fewer data inputs and is easier to use ought to be preferred. According to this criteria, especially in the case of complex systems, the simulation is way ahead of other estimation methods.

TABLE 4

Total Annual Travel Time and Time Savings, in hours, Options 0 & 1

	T_1	T_2	T_3	Total
Option 0				
1980	828.18	647.14	230.07	1705.39
2000	2044.16	1186.62	506.86	3737.64
Option 1				
1980	557.80	485.76	205.79	1249.35
2000	940.19	824.23	349.08	2113.50
Time Savings (Option 0 - Option 1)				
1980	270.38	161.38	24.28	456.04
2000	1103.97	362.39	157.78	1624.14

Note:

T_1 - total travel time on FH southbound
T_2 - total travel time on FH northbound
T_3 - total travel time on FH southbound from MVR
Total - sum of T_1, T_2 and T_3

TABLE 5

Total Annual Peak Period Travel Time, in hours, for Option 0 and Modified Option 0, Year 2000

	T_1	T_2	T_3	Total
Option 0	794.67	249.85	165.89	1210.41
Modified Option 0				
60G-30R	1065.84	701.20	82.31	1849.35
75G-15R	1065.94	694.78	87.82	1848.54
80G-10R	1065.94	694.78	89.78	1850.50
85G-5R	1065.94	694.78	91.21	1851.92
87G-3R	1066.03	694.78	91.51	1852.31

Note: Notations are defined as in Tables 2, 3, and 4.