Abridgment

Simulation of the Effect of Pedestrians on Vehicle Delay at Signalized Intersections

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The vehicle capacity of signalized roadway intersections is dependent on the sequence and timing of several elements that are characteristic of intersections, including pedestrian and vehicle movement. The number of pedestrians and vehicles that jointly use the intersections of many urban roadways is constantly increasing. The pedestrian-vehicle conflict at intersections is becoming a more and more important contributor to vehicle delay and reduction of the capacity of intersections. Unfortunately, many of the methods currently used to calculate the capacity of intersections give little consideration to the effect that pedestrians have on vehicle delay and the capacity of intersections.

The purpose of this study was to determine, through simulation, the effects of pedestrian movement on the flow of vehicles at signalized at-grade intersections. Specifically, the objectives of this study were to develop and validate a computer simulation model to quantify the effects of pedestrian movement on vehicle delay and to suggest possible criteria for the inclusion of a separate pedestrian phase in signal cycles as a method of reducing the delay to vehicles caused by pedestrians.

Three measures of vehicle delay at intersections were computed by the simulation model: the average length of the vehicle queue, the average time the vehicles spend in queue, and the number of vehicles passing through the intersection. These three delay measures were considered to be functionally related to volumes of pedestrian traffic, pedestrian crossing behavior (three types), volumes of vehicle traffic, length of signal cycles, and percentage of turning vehicles.

Because a large number of independent variables were used in the simulation model, the simulation experiments concentrated on two typical categories of intersection operation, ideal and undesirable. The ideal intersection operations had a short signal cycle, a small percentage of turning vehicles, and few illegal pedestrian movements. The undesirable intersection operations had a long signal cycle, a high percentage of turning vehicles, and many illegal pedestrian movements. Both types were two-way, two-lane by four-lane intersections. Simulation runs for each of the two types were used to illustrate the sensitivity of vehicle delay to varying volumes of pedestrian and vehicle traffic.

SIMULATION MODEL

Numerous simulation programs have already been written, but very few consider, let alone incorporate, any form of pedestrian movement. The literature, however, provides a basis for building a simulation model in terms of such previously investigated components as rate of flow of pedestrian traffic, pedestrian gap acceptance, and vehicle arrival rates (1).

For the purposes of this study we developed a detailed simulation program capable of handling the movement of both pedestrians and vehicles at signalized intersections. The model used the problem- and time-oriented general purpose simulation system (GPSS) language and was constructed to tabulate data on all pedestrian-vehicle interactions encountered during the simulation of activity at a two-lane by four-lane signalized intersection (1).

This model was designed to facilitate the input of data. It is quite flexible, partly because of the computer language used in the handling of the five major variables mentioned earlier (volume of pedestrian traffic, volume of vehicle traffic, length of signal cycle, percentage of turning vehicles, and pedestrian crossing behaviors). Any number of these can be held constant or be allowed to vary according to the characteristics of intersections that are to be studied. In this manner, the model can be used to simulate intersections with problems peculiar to traffic flow that cannot be analyzed by conventional methods. The model, therefore, need not be restricted solely to analyzing and quantifying pedestrian-caused vehicle delay.

RESULTS OF THE SIMULATION

Because of the large number of independent variables incorporated in the model, all but two were held constant during the simulation of the ideal and undesirable intersection operations. Only the volumes of pedestrian and vehicle traffic were allowed to vary from one simula-

Publication of this paper sponsored by Committee on Pedestrians.

tion to another. In general, it was expected that vehicle delay at intersections would increase with an increase in pedestrian or vehicle traffic. The ideal intersection operations were also expected to produce less vehicle delay than the undesirable intersection operations, the characteristics of which were less conducive to smooth pedestrian and vehicle flow.

The volumes of pedestrian and vehicle traffic were varied so as to comprehensively cover a range from no pedestrians and little vehicle traffic to many pedestrians and a high level of vehicle traffic (1).

Pedestrian-caused delay was calculated as the difference between the delay value of the simulation run with no pedestrians and the delay value for a given volume of pedestrian flow.

Results of the simulation runs showed that pedestrian-caused vehicle delay increased steadily until a volume of 300 pedestrians per hour per direction was reached. Between this volume and a volume of 470 pedestrians per hour per direction, there was a sharp increase in vehicle delay. Higher volumes of pedestrian traffic continued to increase the delay, but at a lesser rate (1).

The effects on the undesirable intersection operations compared with those on the ideal operations were as expected. If similar volumes of pedestrian and vehicle traffic were used, the average vehicle delay was greater for the undesirable intersection operations than for the ideal operations.

USE OF PEDESTRIAN SIGNALS

The addition of a pedestrian phase to a traffic signal at an intersection not only provides for safer pedestrian movement, but in some cases also reduces the delay to vehicles using the intersection. Separate pedestrian phases added to fixed-time traffic signals must be of sufficient length to allow pedestrians to make a safe crossing. The inclusion of this phase into the signal cycle ensures that pedestrians will not have to wait longer than one signal sycle before being able to cross the intersection. At the same time, however, unwarranted pedestrian phases in fixed-time signals can unfairly increase the total delay to vehicles at the intersection.

For greatest safety, the minimum pedestrian-caused vehicle delay cited to warrant the use of a pedestrian signal phase should be less than the time required for a pedestrian to cross the intersection; this should decrease the possibility of accidents before the critical volumes of pedestrian and vehicle traffic are reached. A reduction factor applied to the minimum safe crossing time for pedestrians can be used to determine the minimum vehicle delay to warrant the use of pedestrian signals at any particular intersection.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study, which are valid only for intersections that exhibit the same physical and operating characteristics as those simulated, are as follows:

1. Pedestrian-caused vehicle delays increased with an increase in the volumes of pedestrian or vehicle traffic.
2. In every case in which volumes of pedestrian and vehicle traffic were held constant, the undesirable intersection operations showed greater vehicle delay than the ideal intersection operations. Improving the operational characteristics of intersections can therefore reduce pedestrian-caused vehicle delay.
3. Intersection operations that exhibit pedestrian-caused vehicle delays longer than the time required for safe pedestrian crossings would benefit from the inclusion of a pedestrian phase in the signal cycle by reducing delay to vehicles and promoting safe pedestrian movement.

Specific recommendations for future research are as follows:

1. Research should be continued to develop models for pedestrian-caused vehicle delay at other types of intersections.
2. Reduction factors to determine the length of pedestrian-caused vehicle delays that warrant the use of pedestrian signals should be developed. The trade-off between vehicle delay and pedestrian safety must be considered.
3. Consideration should be given to the possibility of developing a set of capacity-reduction factors, based on the use of intersections by both pedestrians and vehicles, to be incorporated into the calculation of intersection capacity.
4. Experimentation with the simulation model should be continued in order to determine the effects on vehicle delay of other variables such as the percentage of turning vehicles and the length of the signal cycle.

REFERENCE

1. T. P. Harpst. Simulation of Pedestrian Effects on Vehicle Delay at Signalized Street Intersections. Virginia Polytechnic Institute and State Univ., Blacksburg, master's thesis, March 1975.