ESTABLISHING WARRANTS FOR CONTROL OF A BICYCLE CROSSING THROUGH SIMULATION

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ABRIDGMENT

A simulation model calibrated from data collected where bicycles cross a two-lane, two-way street was developed for a crossing controlled by a yield sign to bicycles. Experimentation was done with the model to determine delay and queue formation of bicycle traffic. Various levels of motor vehicle and bicycle demands were tested with the model. Situations in which a yield sign to bicycle traffic are ineffective at a crossing are discussed, and warrants for signalization are suggested based on these situations.

•EXCLUSIVE bicycle paths are becoming more and more popular as recreational and transportation facilities. A significant problem arises when such a path crosses a busy urban street. Several control options are available to the traffic engineer who wishes to operate the crossing in a safe and efficient manner. The options include stop and yield signs for bicycles or motor vehicles, traffic signals, and complete grade separation. The appropriate control strategy is a function of both the motor vehicle volume and bicycle volume wishing to use the crossing. Unfortunately, no warrants or guidelines exist to aid the traffic engineer in developing an appropriate control strategy. Simulation modeling was chosen as a method to determine appropriate warrants.

THE MODEL

A model to simulate operation of a bicycle crossing was developed. The crossing is at mid-block on a two-way, two-lane street. Bicycles arriving to cross are controlled by a yield sign. The practice of simulating intersection operation is not new (1, 2, 3, 4, 5). Some researchers have used simulation for suggesting warrants for control of motor vehicle traffic (1, 2, 5). There has been no work reported on the simulation of bicycle traffic.

The basic structure of the model developed for this study is shown in Figure 1. Motor vehicle and bicycle arrivals are generated randomly. When a bicycle arrives to make the crossing, the operator must decide to accept or reject gaps in the motor vehicle traffic. The modeling of this gap acceptance decision has been shown to be critical to delay measurements with a simulation model (5). The gap acceptance criteria used in this model are shown in Figure 2. A random number drawn from a uniform distribution is generated by the model. This number is then used in the relationships of Figure 2 to select the minimum gaps the cyclist is willing to accept. Simple straight-line relations were used because available data were insufficient to warrant a more complex treatment.

Motor vehicle traffic flow on the roadway and the rate at which bicycles attempt to cross are model inputs. Output of the model includes delay and queue formation data of the bicycle traffic for each 15-min period simulated.

The model was validated by collecting delay measurements at a crossing on the University of California, Davis, campus. For three 15-min periods, bicycle flows, motor vehicle flows, and cyclist delay time were recorded. Two model simulations were made for comparison to each set of field data. The second computer model run used random numbers equal to one minus the random numbers in the first run. Average bicycle delay was selected as one variable for use in validating the computer model. In all but one of the six comparisons there is general agreement between observed and predicted average bicycle delay. However, for the one case where the difference in mean delay was greatest, the motor vehicle flow rate between field and model differed by 12 percent. Because bicycle and motor vehicle flows are generated by a stochastic process in the model, observed field flow rates could not be duplicated exactly. In the other tests, motor vehicle flows varied by less than 4 percent.

Paired comparisons were also made on the same data by using the χ^2 contingency table test. In this test the proportion of bicycles delayed in the model and in the field were compared. The hypothesis that the model and field data are the same could not be rejected at the 5 percent level of significance in five of the six tests. Again the worst comparison occurred in the case where model and field motor vehicle flows differed by 12 percent.

APPLICATIONS TO ESTABLISH WARRANTS

Three output variables of the model were used to begin to establish warrants for signal installation: percentage of bicycles delayed, total delay to bicycles, and maximum queue length occurring in 15 min.

Adequate Gaps

The percentage of bicycles delayed was the model output analyzed to determine whether the gaps in the motor vehicle stream are adequate to permit bicycles to cross. Groth suggested that, when 75 percent of bicycle traffic is delayed, cyclists might begin to take chances by accepting inadequate gaps (6). The author feels that assumption is reasonable. This 75 percent figure of bicycles delayed is predicted by the model to occur at a motor vehicle flow rate of approximately 1,000 vehicles per hour. Levels of 800 and 600 motor vehicles per hour for four- and six-lane crossings were determined to be safe limits for bicycle crossings based on field observations in Holland and Denmark (6). The conclusions here for two-lane crossings are not in disagreement with those findings. More bicycles are delayed by multilane streets because longer gaps are required for safe crossings.

Total Delay

Total delay to bicycles was measured with the model. No conclusions can be drawn regarding the flow levels at which signals produce less delay than the yield sign. Operations with signal control were not investigated because adequate saturation flow rates for bicycle facilities were not available.

Normally, total delay under signalized operation is greater when motor vehicle delay is included. Thus, it is expected that the other criteria presented here based on safety considerations will warrant a signal at lower traffic demands than the minimization of delay objective will.

Impedance of Traffic

When bicycle queues become sufficiently long, motorists will often freely yield the right-of-way and allow cyclists to pass. This has been observed when queue lengths reach four to eight bicycles. The crossing is then operating in a mode for which it was not designed. In addition to causing delay to motor vehicles, it causes behavior of bicyclists and motor vehicle operators to become unpredictable and unsafe. At com-

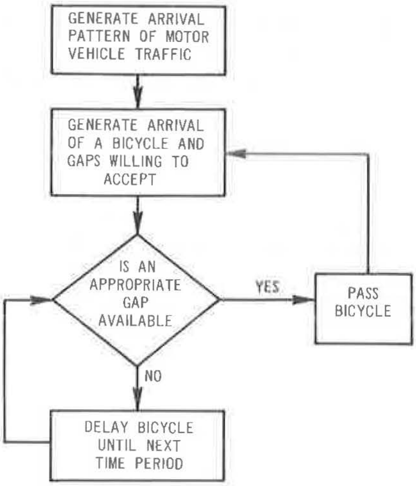


Figure 1. Simulation model.

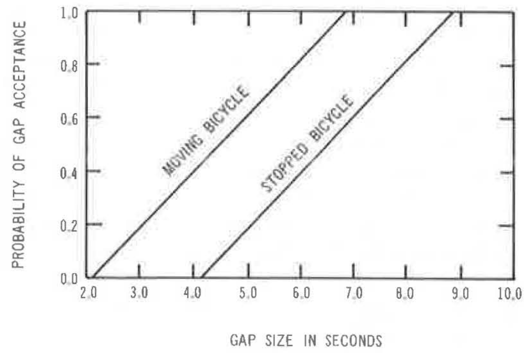
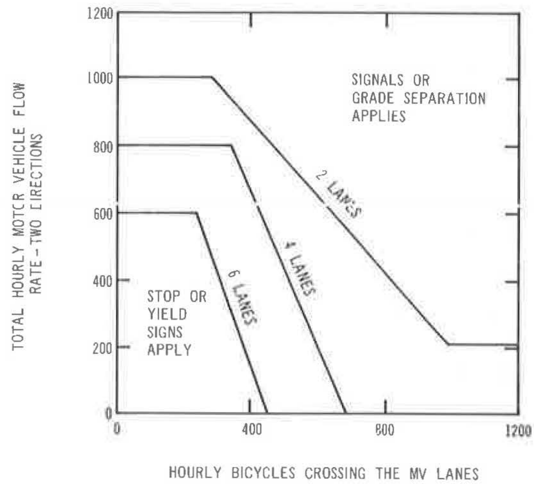


Figure 2. Gap acceptance criteria used in simulation model.

Figure 3. Warrants for controls at bicycle crossings.



binations of motor vehicle and bicycle flows where a queue length of six may be expected to occur each 15 min, it is suggested that signals be installed.

Warrants

The report by Groth drew some conclusions on what might be appropriate warrants for control of a bicycle crossing based on previous work done by Grabe and Raff (6). However, Groth's work was for four- and six-lane crossings. Warrants for installation of signals at bicycle crossings are shown in Figure 3. Specific recommendations for control are not presented inasmuch as more experience with control of bicycle crossings is necessary. Consideration must also be given to factors such as available sight distances, motor vehicle speeds, and the duration of flow. This author feels that flows during the two peak periods should be used in establishing warrants for control.

The four- and six-lane lines in Figure 3 were developed from information in the

Groth report (6). The horizontal limits between signalized and nonsignalized controls were drawn from reported experiences in Holland and Denmark. The remainder of these limits are representations of work done by Grabe.

The two-lane limits are based on results from the model described here. The horizontal portion of the curve at 1,000 motor vehicles per hour represents a level of motor vehicle demand that does not provide adequate gaps in the traffic stream. At this level, 75 percent of the bicycles are delayed. The remainder of the two-lane curve is based on the requirement that the maximum queue should be no more than six bicycles in a 15-min period. It is at this level that motorists have been observed to yield their right-of-way.

CONCLUSIONS

The following comments are offered as aid in selection of crossing controls. The nonsignalized domain in Figure 3 represents an area where a yield sign to control bicycle traffic is appropriate. In the area of low motor vehicle flow (less than 200 per hour), it may be more appropriate to use stop sign controls for the motor vehicle traffic. In general, use of stop signs to control bicycle traffic exclusively is not recommended because observance and enforcement are usually lacking.

The signalized domain represents an area where signals or grade separations are required based on the criteria. Signals may be warranted at lower combinations of demands if such controls produce fewer overall delays. However, this is unlikely. Grade separations are expensive, but they essentially eliminate all delay at the crossing. They do not completely eliminate accidents, for the grades increase bicycle speeds. Bicycles go out of control more often, and the structure provides a fixed object for collision.

The author is eager to hear of other experiences in controlling bicycle crossings. The addition of experience with control of crossings to warrants such as these based on predicted traffic performance is the only way that warrants may be developed that can be applied with confidence. It may take years to develop that experience.

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