Abridgment

Potential Performance Characteristics of Adaptive Control at Individual Intersections

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ABSTRACT

Adaptive signal control of individual intersections relies on advance information obtained primarily by detectors for real-time optimization. The development of this mode of control involves a number of decisions about detector utilization, prediction of flows, selection of optimization procedures, data processing requirements, and so forth. In an effort to search for an effective adaptive control, computer simulation is used in this study to analyze the potential characteristics of an adaptive control strategy. The analysis concerns (a) the effectiveness of signal optimization, (b) the impact of information availability and utilization, and (c) the sensitivity of control efficiency to information errors.

Adaptive signal control, as referred to in this paper, is a mode of control that relies primarily on advance information provided by detectors to search for and to implement optimal signal-switching sequences. The technology for adaptive signal control of individual intersections is already available. Limited field experiments ($\underline{1},\underline{2}$) have also been conducted to assess several adaptive control strategies. Currently, however, it is not clear what would constitute an adaptive control strategy that is far superior to the various traffic-actuated controls being used today.

As a first step toward resolving this issue, computer simulation is used in this study to analyze three aspects of the performance characteristics of an adaptive control strategy. This strategy is similar to the Optimization Policies for Adaptive Control (OPAC) as proposed by Gartner ($\underline{3}$). The objectives are to (a) examine the effectiveness of signal optimization in improving signal operations; (b) determine the amount of advance information needed, and how such information can be effectively utilized; and (c) assess the sensitivity of the control efficiency to certain types of information errors.

CONTROL STRATEGY

The control strategy examined in this study utilizes a series of overlapping optimization stages (Figure 1). A stage is a time interval for which an optimal signal-switching sequence is to be identified. An optimal switching sequence, in turn, is a combination of green, signal-change, and red intervals that minimize the total delay at an intersection.

To facilitate the optimization, each stage is divided into subintervals. In each subinterval, the right-of-way is allocated to a particular phase or to several phases that have no conflicting movements. An algorithm is used to generate all alternative ways of allocating the right-of-way and to identify the corresponding feasible switching sequences. A feasible sequence is one that satisfies a set of speci-

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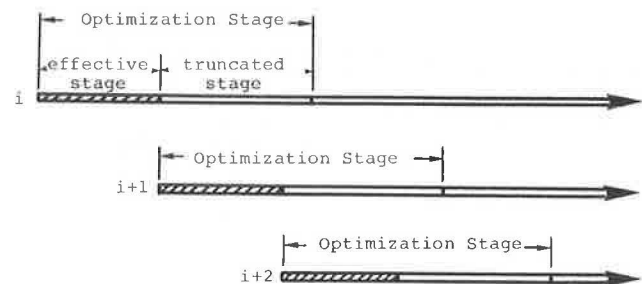
FIGURE 1 Effective stage and truncated portions of overlapping optimization stages.

fied requirements for minimum green, maximum green, and signal-change intervals.

Each feasible sequence is evaluated by a traffic model in terms of the total delay. Such a traffic model is part of the control strategy. The evaluation is based on the flow conditions at the beginning of the current stage and on new information provided by a detector in each lane. The optimization process involves the identification of the sequence that minimizes the total delay.

A microscopic simulation model is used to provide simulated settings for adaptive control operations. It also serves as a tool for evaluating the optimal switching sequences generated by the control strategy. Delays determined from this model for pretimed control agree well with delays estimated from Webster's delay formula ($\underline{4}$) when the delays are not time dependent.

EFFECTIVENESS OF SIGNAL OPTIMIZATION

Because of the need for real-time operation, adaptive control has to optimize the signal operation for an expected flow condition rather than for an actual condition. The discrepancies between the expected and the actual conditions may partially offset the benefits of optimization. Even if the impact of such discrepancies is negligible, there is still a limit to what optimization can do for signal control. This point is demonstrated by Figure 2, which shows vari-
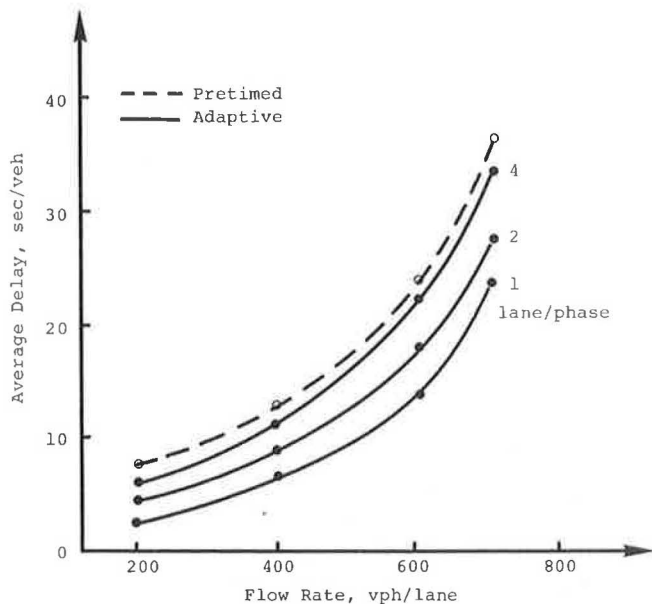
FIGURE 2 Variations in efficiency of adaptive control with traffic volume.

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Figure 2 shows that, with only one lane per phase for a two-phase operation, adaptive control is much more efficient than pretimed control. When the number of lanes per phase increases, however, the efficiency of adaptive control decreases. The obvious reason for this phenomenon is that the optimal switching sequence for multiple lanes is not the optimal sequence for each individual lane. Therefore, a careful experimental design is needed for the potential of an adaptive control strategy to be assessed.

IMPACT OF STAGE SUBDIVISION, STAGE TRUNCATION, AND STAGE SIZE

Stage Subdivision

Dividing a stage into smaller subintervals results in a larger number of feasible switching sequences. In contrast, long subintervals could result in a sluggish transfer of the right-of-way under light flow conditions. Therefore, in the absence of information errors, smaller subintervals can produce better control efficiencies. This point is demonstrated in Figure 3, which shows variations in control efficiency with stage subdivision.

A statistical analysis shows that the use of 3-sec subintervals can produce statistically significant improvements (at a 5 percent level of significance) over the use of 5-sec subintervals. Such improvements, however, are less than 0.9 sec/veh in delays for two-phase operations with flow rates of up to 700 vph/lane.

The advantage of using smaller subintervals can be fully realized only if expected events in a given subinterval take place within that interval. Furthermore, it should be noted that the use of smaller subintervals could increase data processing requirements.

Stage Truncation

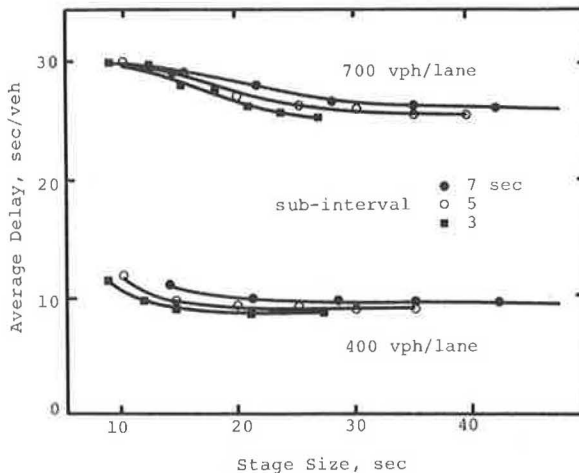Generally, it is preferable to truncate the tail portion of an identified optimal switching sequence

FIGURE 3 Variations in control efficiency with stage subdivision.

and to implement only the remaining portion of the sequence (see Figure 1). The reason for this is that, when additional arrival information becomes available and is used for optimization, a better switching sequence may be found for the tail portion of a stage. The issue is how large a truncation is needed.

Figure 4 shows that stage truncation can exert a noticeable influence on control efficiency. The control efficiencies produced without truncation are always poorer than those produced with truncation. The importance of truncation, however, diminishes when the traffic volume decreases. Simulation results based on a large sample of arrival patterns indicate that there is no significant difference (at the 5 percent level) between control efficiencies produced respectively by 15-sec truncations and 20-sec truncations.

Stage Size

Stage size determines the amount of advance information needed for optimization. For example, a 20-sec stage would require about 20 seconds of advance in-
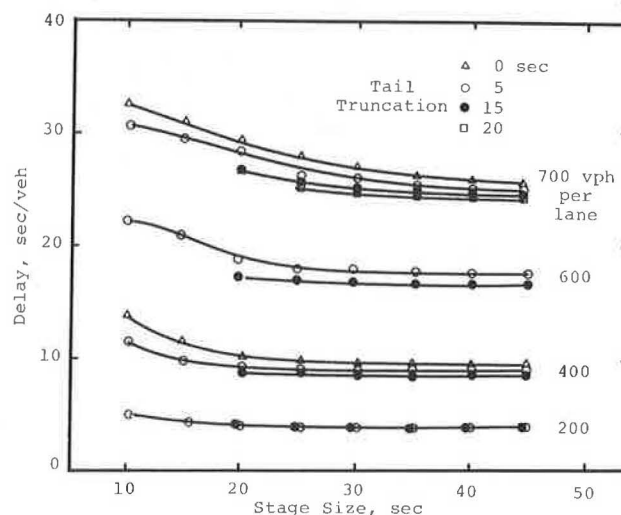

FIGURE 4 Variations in control efficiency with stage size and stage truncation.

TABLE 1   Delays Based on Correct and Incorrect Queue Discharge Times (sec/veh)

No. of Lanes per Phase	Flow (vph per lane)	Case 1		Case 2		Case 3		Average Increase (%)
		Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	
2	200	4.8	5.0	5.0	5.4	4.7	4.9	5.5
4	200	5.7	6.1	5.8	6.1	5.6	6.2	7.6
2	400	8.9	9.7	8.8	9.5	8.6	9.0	7.2
4	400	10.4	11.1	10.6	10.9	10.0	10.7	5.5
2	600	16.7	18.5	16.9	18.0	18.0	18.0	5.8
4	600	20.2	20.6	19.5	20.9	20.0	21.0	4.7
2	700	28.3	31.9	28.0	33.0	27.1	30.2	14.0
4	700	32.2	33.8	31.8	34.4	32.6	34.0	5.8

Note: Data are derived from 50-min, two-phase operations.

formation. If such advance information can be obtained and used without errors, longer stages can result in more efficient signal operations. This point is shown in Figure 4, the implication of which is that an increase in the available amount of accurate advance information can improve control efficiency. It should be noted, however, that lengthening the stage size has a diminishing return. Furthermore, the use of long stages is more important when traffic volume is heavy than when it is light. Little can be gained in control efficiency when more than 25 seconds of advance information is used for optimization.

EFFECTS OF INFORMATION ERRORS

Two types of information errors are addressed in this study: those in estimated queue discharge characteristics and those in expected arrival sequences.

Errors in Estimated Queue Discharge Characteristics

The actual discharge headway or discharge time of a queueing vehicle cannot be known in advance. Under this circumstance, the worst control logic is one that randomly generates a discharge headway or a discharge time from a known distribution to represent the actual discharge characteristic of queueing vehicle. Table 1 shows that the resulting information errors have a small detrimental impact on control efficiency if this logic is adopted. Such an impact can be further reduced if randomly generated discharge times are replaced by the mean observed discharge time for each queueing position.

This reduction is possible because the use of the mean discharge times can result in rather small estimation errors. Based on observed queue discharge times, it can be shown that the use of the mean discharge times would produce a mean absolute error of

estimate of only about 0.8 sec for the first queueing position and 1.5 sec for the tenth queueing position. Therefore, the estimation of queue discharge times is not a critical concern in the development of an adaptive control strategy.

Errors in Expected Arrival Sequences

For a given flow rate, vehicles can arrive at an intersection in numerous sequences of headway. An expected arrival sequence that is used for optimization will differ from the actual sequence. Such differences may result from detector malfunctions, speed variations, lane changes, the use of predicted flows, and so forth. Under the most unfavorable conditions, the expected and the actual arrival sequences may be independent of each other. It is indicated in Table 2 that, in such a case, the use of erroneous arrival sequences has a profound detrimental impact on control efficiency.

The extent of the impact, as shown in Table 2, can be reduced by relying heavily on detectors to collect data. Nevertheless, determining how to provide reliable arrival information for optimization is a real challenge in the development of an adaptive control strategy.

CONCLUSIONS

The efficiency of adaptive control can vary significantly from one flow pattern to another. Field assessments of an adaptive control strategy should have sound experimental designs to avoid generating biased information. Twenty-five seconds of advance information appears to be sufficient when the strategy described in this paper is implemented. Stage subintervals of 3 to 5 sec are adequate and stage truncation does not have to exceed 15 sec. The control efficiency is not sensitive to errors in estimated queue discharge times; however, it is very sensitive to errors in vehicle arrival sequences.

TABLE 2   Delays Based on Correct and Incorrect Arrival Sequences (sec/veh)

No. of Lanes per Phase	Flow (vph per lane)	Case 1		Case 2		Case 3		Average Increase (%)
		Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	
2	200	4.8	11.2	5.1	12.7	4.9	11.4	138
4	200	6.3	10.4	5.9	10.1	6.1	9.5	64
2	400	11.3	18.2	10.2	14.9	10.6	14.5	48
4	400	10.3	14.7	10.8	14.2	11.0	14.3	35
2	600	17.5	28.8	18.2	34.2	16.5	32.7	84
4	600	20.5	26.6	19.6	24.5	20.7	27.8	30
2	700	31.6	48.6	28.8	41.2	29.7	44.8	49
4	700	35.7	47.8	32.5	42.1	34.3	48.0	34

Note: Data are derived from 50-min, two-phase operations.

REFERENCES

1. L. de la Breteque and R. Jezequel. Adaptive Control at an Isolated Intersection--A Comparative Study of Some Algorithms. Traffic Engineering and Control, July 1979, pp. 361-363.

2. Microprocessors and the Control of Traffic at Isolated Intersections. Transport and Road Research Laboratory, London, England, March 1985, leaflet.

3. N.H. Gartner. OPAC--A Demand-Responsive Strategy for Traffic Signal Control. In Transportation Research Record 906, TRB, National Research Council, Washington, D.C., 1983, pp. 75-81.

4. F.V. Webster. Traffic Signal Settings. Technical Paper 39. Transport and Road Research Laboratory, London, England, 1985.

Developing Interconnection Guidelines for Isolated Traffic Signals

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ABSTRACT

The increase in levels of traffic congestion along major urban signalized arterials makes efficient traffic management and utilization of arterial facilities important considerations. Significant improvements in traffic flow and reductions in vehicular delay may be realized by interconnecting individual, isolated intersections into a coordinated signal system, or by adding an adjacent signal to an existing progression system. Current analytical methods and computer programs offer capabilities of optimizing traffic signal coordination for a series of signalized intersections. Recently, transportation research has been directed toward the alternative development of short-range, low-capital improvements for the safe and efficient movement of people and goods. The criteria measuring these alternative improvements include the following: traffic volume distribution, travel time, delay, and quality of traffic flow. However, the proper procedures and methods for analyzing the effects of coordinating isolated signalized intersections are insufficient. Because interconnection can be significant to the total signalized operation, guidelines are needed to identify where to implement signal interconnections. Summarized in this paper is research sponsored cooperatively by the Texas Department of Highways and Public Transportation and the FHWA, U.S. Department of Transportation. In the study, guidelines and procedures are developed to identify where interconnection of signalized intersections should be implemented. Efforts were made to evaluate interconnection of isolated traffic signals into a progression system to provide coordinated operations. Described are the study approach and development of good coordination of isolated traffic signals by using both simulation analysis and field validation. In this way, better signal interconnection, efficient utilization of the street system, and smooth traffic operations can be provided.

The increase in levels of traffic congestion along major urban signalized arterials makes efficient traffic management and utilization of arterial facilities important considerations. Significant improvements in traffic flow and reductions in vehicular delay may be realized by interconnecting individual isolated intersections into a coordinated signal system, or by adding an adjacent signal into an existing progression system.

Current analytical methods and computer programs offer capabilities of optimizing traffic signal coordination for a series of signalized intersections. Recently, transportation research has been directed toward the alternative development of short-range, low-capital improvements for the safe

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