Comparative Analysis of Two Logics for Adaptive Control of Isolated Intersections

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Adaptive signal control has the potential to provide improved control at isolated intersections. Adaptive control, however, has limitations due to its need to rely on estimated flow conditions for making signal timing decisions. Such estimated flow conditions always differ from the actual conditions, and the discrepancies can offset the benefit of having an elaborate decision making process in a control logic. Therefore, an issue can be raised as to whether it is necessary to rely on strenuous decision-making processes for adaptive control. This study compares the relative merits of a simple queue based logic and a logic that relies on a much more complicated procedure for making timing decisions. It is found that the queue-based logic is nearly as effective as the more complicated logic. This finding points to a direction for the development of new control logics that can be widely used to replace existing traffic-actuated control logics.

Adaptive control, referred to herein, is a mode of control which relies on very short-term advance vehicle arrival information in an attempt to achieve real-time optimization of signal operations. Several adaptive control logics have been tested in the field, implemented, or recommended for use at isolated intersections. Examples of such logics include modernized optimized vehicle actuation strategy (*1*), Miller's algorithm (*2*), optimization policies for adaptive control (*3*), traffic optimization logic (*4*), and stepwise adjustment of signal timing logic (*5*). The split, cycle, and offset optimization technique (*6*), which is intended mainly for signal coordination, has also been tested for the control of isolated intersections (*7*).

It should be noted that, regardless of the level of sophistication of a control strategy, optimal signal operations can never be achieved in a real life situation. The term optimization is often used casually to represent a process of searching for a better course of action. Such a process can be based on a straightforward trade-off analysis in order to determine whether the current green duration should be extended for a short time interval (*4*). It can also be based on an elaborate procedure to evaluate alternative signal switching sequences and, subsequently, to identify the best sequence for a relatively long (e.g., 100 sec) future period of time (*3*). This liberal interpretation of optimization is also adopted in this paper.

INTRODUCTION

The extent to which adaptive control can improve signal operations depends in part on the specific adaptive control logic employed, the quality of the information used for making timing decisions, the level of control efficiencies delivered by existing control devices, and the traffic flow patterns involved. Field tests conducted so far have shown mixed but encouraging results for adaptive control. A test of Miller's algorithm (*8*) at an intersection revealed that the resulting control efficiencies were poorer than those provided by vehicle-actuated controls when the flows approaching the intersection were less than 1,300 vph. A test of modernized optimized vehicle actuation strategy (*1*) for ten time-of-day periods resulted in delay reductions of 5% to 12% for seven periods, a delay increase of 7% for one period, and delay reductions of 20% and 30%, respectively, for the remaining two periods. The implementation of the traffic optimization logic (*4*) at one intersection yielded delay reductions of more than 20% when compared with a traffic-actuated operation.

As demonstrated in these field tests, the incorporation of an optimization capability into signal control does not necessarily guarantee improved signal operations. The accuracy of the information utilized to make timing decisions is also critical to adaptive control. This can be a drawback, because adaptive control usually relies on estimated flow conditions rather than on actual flow conditions. To facilitate the estimation of flow conditions, it is necessary to place detectors several hundred feet upstream of the intersection in order to provide advance vehicle arrival information. Such detectors can provide perhaps no more than 115 sec of advance information at most intersections. In order to overcome this limitation, some researchers (*3, 8*) have resorted to the use of predicted vehicle arrival data to supplement the detector data. This approach tends to introduce errors into the information that is used to make signal timing decisions. Even if the estimation of the flow conditions is based entirely on detector data, the resulting estimates can be expected to deviate from the actual flow conditions. The discrepancies between the estimated and the actual conditions can be attributed to lane changes and to variations in vehicle speeds, queue discharge headways, driver responses to signal change interval, and so forth.

In light of this drawback, it is worth investigating whether strenuous decision-making processes can be replaced by simple decision rules for adaptive control. To address this issue, two adaptive control logics are compared in this study. One logic is stepwise adjustment of signal timing (SAST) (*5*), which requires the evaluation of alternative signal switching sequences in order to reach a signal timing decision. The other logic is based on the consideration of queue length and determines whether the current green should be terminated by comparing the expected maximum queue length of the current green phase with a threshold queue length.

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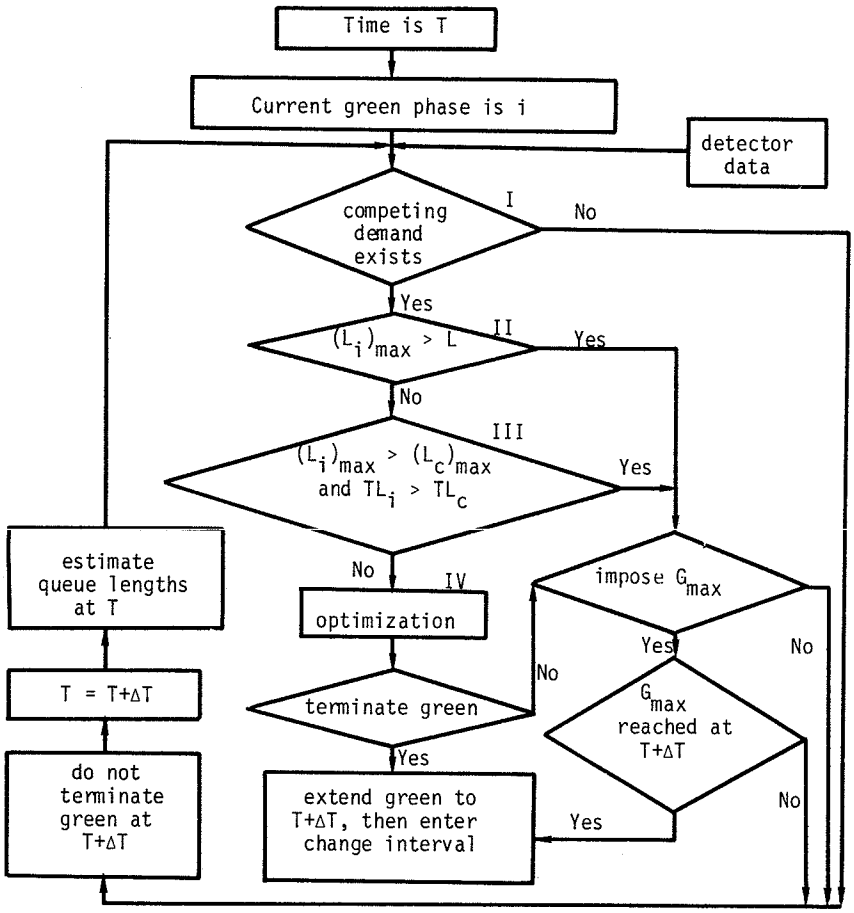

FIGURE 1 Decision-making process for stepwise adjustment of green.

SAST LOGIC

SAST logic relies on a binary choice decision-making process for stepwise adjustment of signal timing. In this decision-making process, time is divided into small intervals, or steps. In each step, an analysis is made to determine whether the current green should be terminated at the end of that step. The rationale for the development of this logic is discussed elsewhere (*5*).

The decision-making process adopted in SAST logic for stepwise adjustment of a green duration is shown in Figure 1. This process has four levels of decision-making activities, which are marked in the figure as I, II, III, and IV, respectively. The first three levels employ simple decision rules which either permit the current green to be extended beyond the first step or call for additional analyses. The data processing requirements for these three levels are very limited. Signal optimization, which is the last level of the decision-making process, comes into play only if the first three levels fail to choose a definitive course of action.

The manner in which SAST logic processes and utilizes information to reach signal timing decisions is described in detail below.

Data Acquisition and Processing

Time is divided into successive steps in SAST logic. Each step is ΔT sec in length. A decision must be made in each step either to extend the green beyond the current step or to terminate the green at the end of that step. Referring to Figure 2, let T be the beginning of a step. At least two types of data are needed for making a timing decision. One type of data is the vehicle arrival sequence that is expected at the stop line in several steps beyond T. This type of data is derived from vehicle arrival data obtained by the upstream detectors. The procedure for deriving such data is simple.

Let t_i be the arrival time of a vehicle at an upstream detector location and r the average travel time between the detector and the stop line in the absence of interferences by signal operations. Then, the expected arrival time of that vehicle at the stop line is assumed to be $A_i = t_i r$. This expected arrival time can be used directly for decision making. It can also be represented as one arrival in a specified step. The latter approach enables more efficient data processing. Therefore, it is adopted in SAST logic. Following this approach, A_i is transformed into one vehicle arrival in the kth step beyond T if A_i falls in that step. Since the efficiency of adaptive control can be sensitive to the errors in the vehicle arrival sequence that is used for signal optimization, the step size ΔT should be sufficiently small. Large step sizes will distort an arrival sequence. Two second steps are a reasonable choice. In each of such steps, the number of vehicle arrivals will rarely exceed one. On the other hand, the step size should be sufficiently large in order to allow time for data processing, signal optimization, and implementation of a timing decision.

Because the number of arrivals in each step is derived from

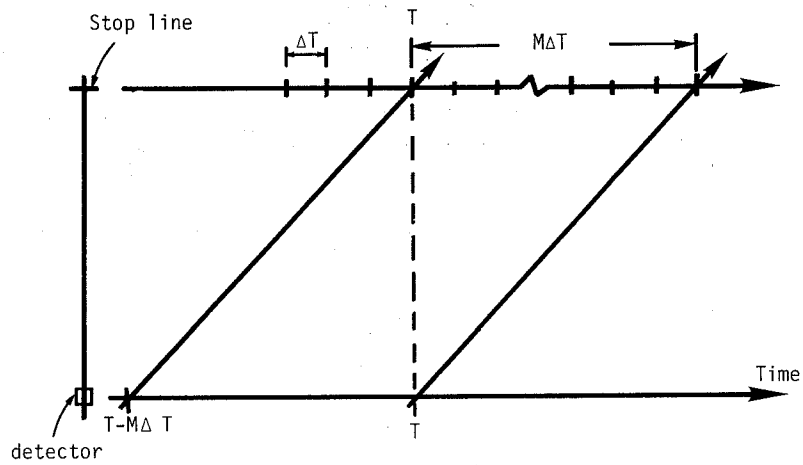

FIGURE 2 Discretization of time for timing adjustment.

detector data, a finite amount of advance information is available at a given point in time. Referring again to Figure 2, if the average travel time between an upstream detector and the stop line is equivalent to M steps, then only those vehicles detected between $T - M\Delta T$ and T will produce advance information for decision making at T. In other words, the amount of advance information available at T is $M\Delta T$ sec.

The second type of data needed for decision making is the expected queue length in each traffic lane at time T. Such queue lengths are determined from a traffic model, which is an integral part of SAST logic, and are defined as the differences between expected cumulative arrivals and departures as measured at the stop line for a specified point in time.

Level I Decision Making

If competing demands for the right-of-way do not exist, there is no reason to terminate the current green phase. At a given time T, competing demands are considered to be nonexistent if all the phases waiting for the right-of-way have the following expected flow conditions:

1. There are no queuing vehicles in any lane at T, and
2. There are no vehicles expected to arrive at the stop line in n steps following T.

A reasonable value of n is one such that $n\Delta T$ is about 6 sec. If a competing demand after a period of $n\Delta T$ results in a decision to terminate the green, $n\Delta T$ shorter than 6 sec may unnecessarily force an approaching vehicle to a complete stop before it is given the right-of-way.

Level II Decision Making

This level of decision making is based on the maximum expected queue length $(L_i)_{max}$ of the current green phase at $T + \Delta T$. If this queue length exceeds a specified threshold value L, the current green is automatically extended beyond $T + \Delta T$, subject to a maximum green constraint. This feature is important: if adaptive control relies exclusively on signal optimization, a phase with a relatively low demand is likely to lose the right-of-way before most of its queuing vehicles enter the intersection. The result is poor signal operation. This problem can be eliminated when a threshold queue length is used to bypass signal optimization.

For example, if the threshold queue length is set at four vehicles, the queue lengths of the current phase can be reduced to about four vehicles before other phases are allowed to compete for the right-of-way through signal optimization. This ensures that the queue lengths of every phase will not grow at excessive rates due to the existence of short green intervals. A previous study (*5*) reveals that the best threshold queue length to use appears to be about four vehicles. This implies that it is best to allow the queue lengths of the current green phase to be reduced to approximately four vehicles before other phases are allowed to compete for the green.

To prevent exceedingly long green durations, SAST logic also allows the imposition of a maximum allowable green G_{max} on the current phase. This G_{max}, however, is imposed only when the maximum queue length of all completing phases exceeds a specified threshold value.

Level III Decision Making

This level of decision making takes into consideration the queue lengths of the current green phase and those of all competing phases. The current green in extended beyond $T + \Delta T$ if the following two conditions are satisfied:

1. The maximum queue length $(L_i)_{max}$ of the current green phase i is longer than the maximum queue length $(L_c)_{max}$ of all competing phases, and
2. The total number of queuing vehicles TL_i of the current green phase is larger than the total number of queuing vehicles TL_c of all competing phases.

Level IV Decision Making

This level of decision making involves signal optimization. SAST logic allows minimization of the total delay either of all vehicles or of the vehicles in certain critical lanes. The subject vehicles include the queuing vehicles at T and those

vehicles which are expected to reach the stop line between T and $T + M\Delta T$. The critical lanes to be included for signal optimization can vary from one step to another. They are determined according to the following criteria for each phase:

1. A lane that has a long queue length at time T is more critical than a lane that has a short queue.
2. If two lanes have equal queue lengths at time T, the lane that has a larger number of expected arrivals between T and $T + 2\Delta T$ is more critical.
3. If two lanes have equal queue lengths at T and equal numbers of expected arrivals between T and $T + 2\Delta T$, the lane which is ahead in the data processing order is more critical.

Optimization Process

The signal optimization process is illustrated in Figure 3. The first task in this process is to examine the option of terminating the green at $T + \Delta T$. This option leads to several alternative signal switching sequences. These sequences are generated and evaluated in order to estimate the minimum delay D_{min} associated with this option. The next task is to determine whether D_{min} can be reduced by extending the green beyond $T + \Delta T$. This task is carried out by first considering the option of terminating the green at the end of the second step, i.e., at $T + 2\Delta T$. The signal switching sequences associated with this option are generated and evaluated one at a time. If the delay D_n resulting from such a switching sequence is less than or equal to D_{min}, it is more desirable to extend the green beyond $T + \Delta T$. In such a case, the current green is allowed to continue unless the maximum green constraint prohibits further extension of the green. If D_n is greater than D_{min} instead, another signal switching sequence is generated and evaluated in the same manner until all alternative sequences associated with terminating the green at $T + 2\Delta T$ are exhausted. Following that, the option of terminating the green at $T + n\Delta T$ for $n = 3, 4, \ldots$ may be evaluated.

SAST logic uses a decision variable N_{max} to limit the maximum number of options that are to be evaluated. For example, if $N_{max} = 3$ is specified, only those signal switching sequences involving the termination of the green at $T + \Delta T$, $T + 2\Delta T$, and $T + 3\Delta T$ are considered for evaluation. With M steps of advance information, the value of N_{max} can vary from 2 to M.

Generation of Switching Sequences

Given that the current green is to be terminated at $T + n\Delta T$ ($n = 1, 2, \ldots, M$), SAST logic does not attempt to generate all feasible signal switching sequences for evaluation. Instead, it generates a small number of switching sequences that are likely among the best few of all feasible sequences.

The process of generating signal switching sequence can be

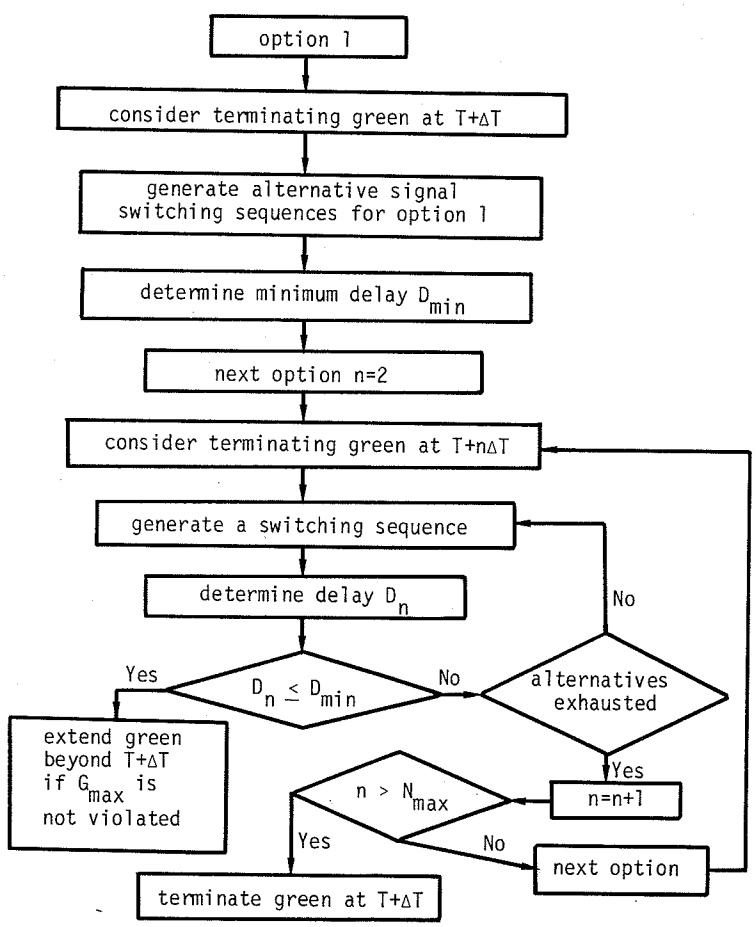

FIGURE 3 Signal optimization process.

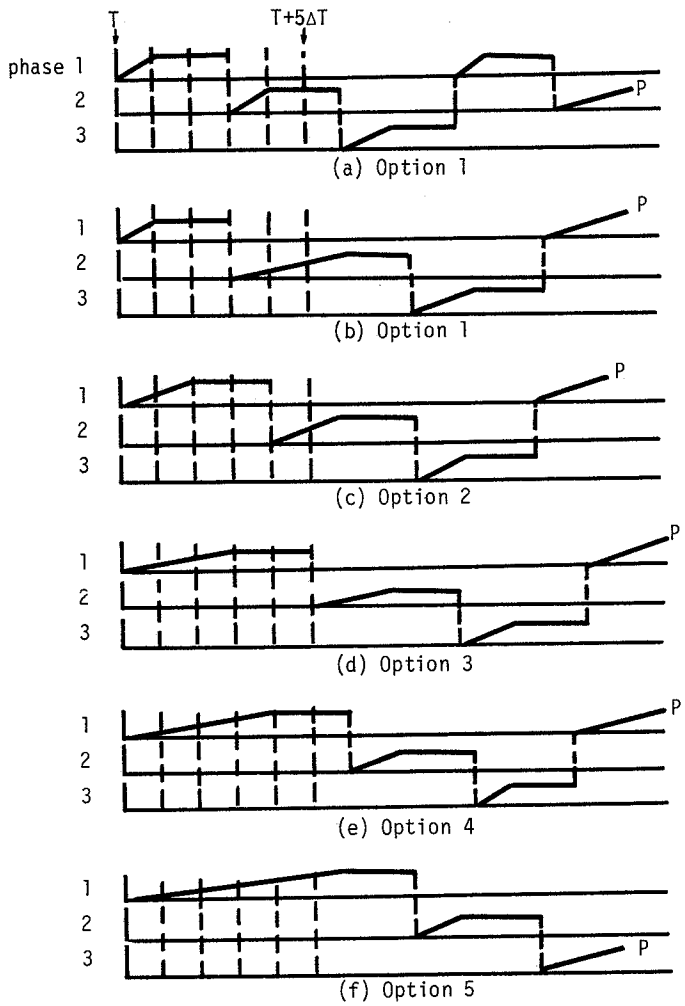

FIGURE 4 Example of generated signal switching sequences.

better described with the example shown in Figure 4. This figure should be interpreted as follows:

1. The total number of signal phases is three.
2. Phase 1 has the green at time T.
3. The signal change interval following each green equals two steps.
4. A bold ascending line indicates that a phase has the green, and a bold horizontal line signifies a signal change interval.
5. Advance information is available for $M = 5$ steps beyond T.
6. Switching sequences marked as (a), (b), (c), (d), (e), and (f), respectively, are arranged according to the order in which they are generated.

In Figure 4a, the current green is terminated at $T + \Delta T$. Subsequently, a signal change interval is timed out at $T + 3\Delta T$. The green is then given to the next phase, i.e., phase 2, if that phase has a demand for the right-of-way. If phase 2 has no demand, the green is given to phase 3 by skipping phase 2, provided that phase 3 has a demand for the right-of-way. If neither phase 2 nor phase 3 has a demand for the right-of-wav, the green is given to phase 2 which follows the current green phase. The resulting signal switching sequence is likely to be inefficient, and this will be reflected in the timing decision.

A demand is recognized in SAST logic if any lane of the phase in question satisfies either of the following conditions:

1. Expected queue length at the time the last change interval is terminated (e.g., $T + 3\Delta T$) is greater than zero.
2. Expected number of arrivals within 4 sec after the termination of the change interval is greater than zero.

If phase 2 receives the green at $T + 3\Delta T$, this green can be extended by one step (Fig. 4a), or by two steps (Fig. 4b). Once the generated portion of a switching sequence reaches the end of the last step, i.e., $T + 5\Delta T$, one of the following actions is taken in generating the portion of the switching sequences beyond $T + 5\Delta T$:

1. If a signal change interval is in effect at the end of the last step, i.e., at $T + 5\Delta T$, that interval is allowed to be timed out at or beyond $T + 5\Delta T$ (Fig. 4a, 4d, and 4e). Afterwards, the green is given to the next phase that still has vehicles waiting to enter the intersection. This green is allowed to continue until all the vehicles in that phase are discharged.
2. If a green interval is in effect at $T + 5\Delta T$ (Fig. 4b, 4c, and 4f), this green interval is extended beyond $T + 5\Delta T$ until all the vehicles are discharged.
3. The generation of a signal switching sequence is completed when all the vehicles included in the analysis are presumably discharged. This point in time is denoted as P in Figure 4.

Estimation of Delays

The delay experienced by a vehicle is measured as the expected departure time minus the expected arrival time at the stop line in the absence of interferences by signal operations. SAST logic estimates only the delays of those vehicles which are expected to reach the stop line by $T + M\Delta T$. Therefore, it is assumed that there are no additional vehicle arrivals beyond $T + M\Delta T$.

Delays are estimated simultaneously with the generation of each signal switching sequence. When the front portions of several signal switching sequences are identical, the delays related to such portions are only estimated once in order to reduce the CPU time. For example, the first two signal switching sequences depicted in Figure 4 have the same switching pattern between T and $T + 3\Delta T$. Therefore, the delays incurred in this period and estimated for the first switching sequence are used directly for the second sequence.

The total delay associated with a signal switching sequence is the sum of the delays incurred in each step. The delays in each step can be estimated from the cumulative arrivals and departures both at the beginning and at the end of that step. To estimate such delays for each lane, the following two quantities are defined first:

$$CA_o = \text{Que}(T) \tag{1}$$

$$CD_o = 0 \tag{2}$$

where

CA_o = cumulative number of expected arrivals at T,
Que(T) = queue length at T, and
CD_o = cumulative number of expected departures at T.

Next, the cumulative number of arrivals CA_i at the end of Step i (i = 1, 2, 3, . . .) can be determined as

$$CA_i = CA_i - 1 + NA_i \quad (3)$$

where NA_i = number of expected arrivals in step i.

For $i = 1, 2, \ldots, M$, NA_i is derived from the detector data. For $i > M$, NA_i is set equal to zero because SAST logic does not consider the delays of those vehicles not yet detected by T.

The cumulative number of departures CD_i at the end of step i is determined as

$$CD_i = CD_i - 1 + ND_i \leq CA_i \quad (4)$$

where ND_i = number of expected departures in step i.

In the original SAST logic, vehicle departures from the stop line were treated as discrete events. In this study, the departures of queuing vehicles are treated as a continuous variable in accordance with a nonlinear function of saturation flow. After a queue is completely discharged from the stop line, the number of expected departures in a step is set equal to the number of expected arrivals in the same step, i.e., $ND_i = NA_i$.

Equations 3 and 4 are applied in a stepwise manner, beginning with the first step (i = 1) that starts at T. The combined delay of the vehicles in a lane in step i is estimated as

$$\text{DELAY}_i = (CA_{i-1} + CA_i - CD_{i-1} - CD_i)\Delta T/2 \quad (5)$$

Choice of N_{max}

N_{max} is used in SAST logic to limit the maximum number of options to be evaluated in the signal optimization process (Fig. 3). If N_{max} = 4 is chosen, the signal optimization is limited to the evaluation of the options of terminating the current green at $T + \Delta T$, $T +$, $2\Delta T$, and $T + 4\Delta T$, respectively. For the example depicted in Figure 4, this means the optimization process will be forced to terminate after the first five switching sequences are generated and evaluated. Of course, the optimization process may end as soon as the third switching sequence is generated and evaluated.

Given that M steps of advance information are available, SAST logic allows the evaluation of up to M options of terminating the current green. It is not necessary, however, to consider all the options. Simulation analyses (*5*) reveal that the efficiencies of SAST-based signal operations are not very sensitive to the choice of N_{max}. With detectors installed at a distance of 400 ft upstream of the intersection, N_{max} = 2 is sufficient to achieve a high level of control efficiencies. With a longer detector setback of 600 ft, a larger N_{max} may be desirable. Nevertheless, N_{max} of 3 or 4 is sufficient in such a case.

A QUEUE-BASED CONTROL LOGIC

The queue-based logic analyzed in this study is depicted in Figure 5. This logic retains the same decision-making structure as the SAST logic. The only difference is that the optimization process of the SAST logic (level IV) is replaced by a simple decision rule based on queue length. It should be noted that the level II decision making of this queue-based logic can be eliminated without affecting the resulting control efficiencies. This level of decision making, however, was not removed in this study when the relative merits of the SAST logic and the queue-based logic were evaluated.

The queue-based decision rule that replaces the optimization process of SAST logic involves a comparison of the following two values:

1. $(L_i)_{max}$ = expected maximum queue length of the current green phase at $T + \Delta T$, and
2. L_f = predetermined threshold queue length.

If the maximum queue length $(L_i)_{max}$ is less than or equal to the threshold value L_f, the current green phase is terminated at $T + \Delta T$. Otherwise, the green phase is allowed to extend beyond $T + \Delta T$, subject to a maximum green constraint.

In appearance, the queue-based control logic is as simple as the gap seeking logic of traffic-actuated control. They differ, however, in significant ways. Traffic-actuated control attempts to terminate the current green when the arriving vehicles can no longer utilize the green efficiently. Unfortunately, the gap-seeking logic of this mode of control can easily misjudge the actual flow conditions. The queue-based logic also attempts to terminate the current green when the arriving vehicles can no longer utilize the green efficiently. However, it requires the synthesis of detected vehicle arrivals to form a reasonably accurate picture of the conditions for decision making. Consequently, this decision-making process is more intelligent than the gap-seeking logic of traffic-actuated control. For general application, the queue-based logic also needs a more sophisticated vehicle detection system, because accurate estimation of queue lengths is not necessarily a simple problem.

The idea of using queue length as a control criterion is not new (*9, 10*). A conventional wisdom of queue-based control is to extend the current green until the vehicles in the governing queue are completely discharged into the intersection. In analyzing SAST logic, it was found that allowing queuing vehicles to dissipate completely before calling for optimization can be detrimental to the control efficiency (*5*). Therefore, it is necessary to choose a proper threshold queue length for implementing the queue-based logic.

ASSESSMENT OF CONTROL LOGICS

A microscopic, event-oriented simulation model was used to compare the performances of SAST logic and the queue-based logic. A major component of this model is a flow processor, which generates vehicle arrivals and processes vehicles downstream according to prevailing signal indications. Another major component is a signal processor, which allows various signal logics to be implemented for evaluation. Delays estimated from the model agree very well with the estimates obtained from Webster's formula (*11*) for pretimed operations (*5*). Simulated delays under traffic-actuated operations have also been compared with delays measured on six intersection

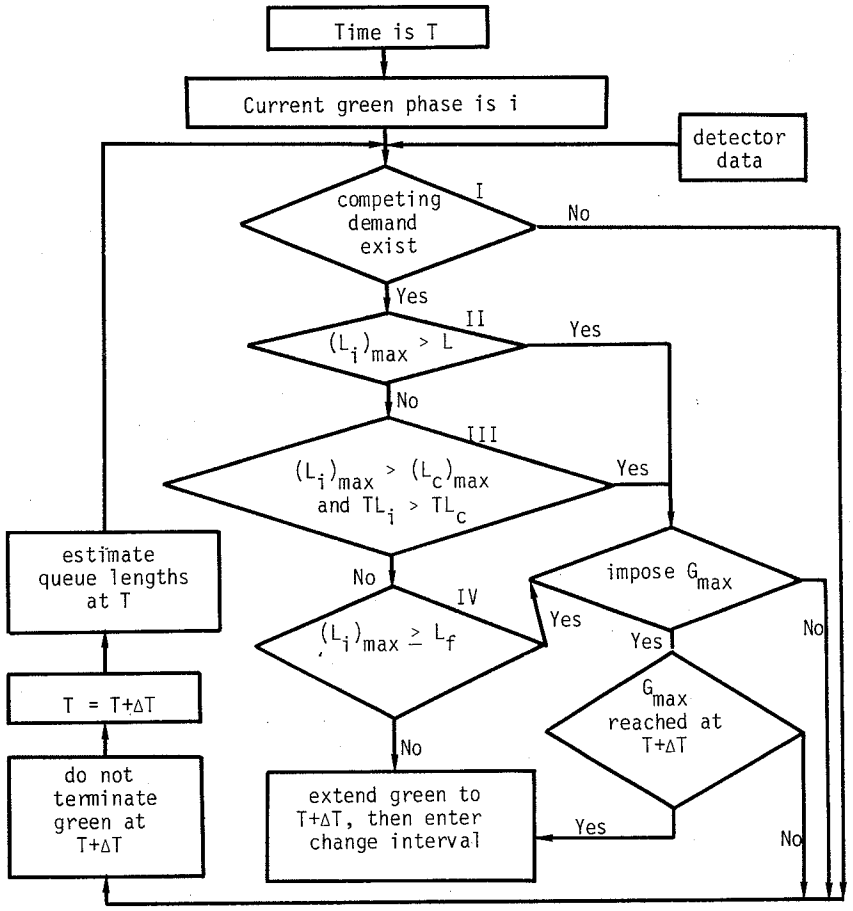

FIGURE 5 Queue-based control logic.

approaches (*5*). They differ by less than 3% when actual vehicle arrival sequences are used as inputs into the simulation model. The differences between the simulated and the measured delays can be greater if vehicle arrivals are generated from specified flow rates.

To provide an insight into the desirability of replacing traffic-actuated control with adaptive control, SAST logic was compared with conventional loop occupancy control logic. This comparison was based on various hourly flow patterns which were subjected to either two- to four-phase control. The number of lanes associated with a phase was varied from two to four. The lane flows ranged from 100 to 750 vph per lane. The total flows approaching the intersection were in the range of 600 to 5,600 vph. No conflicting movements were present. The four-phase control had two protected left-turn phases to accommodate vehicles in continuous left-turn lanes. The simulated vehicle had an average approach speed of 40 ft/sec.

For the loop occupancy control, the maximum allowable green was set at 60 sec. When two-phase operations were encountered, 50-ft detectors were used if a phase was associated with four lanes, and 70-ft detectors were used if a phase was associated with two lanes. For four-phase operations, 50-ft detectors were used in left-turn lanes, while 70-detectors were used in others. The extension interval was set at zero seconds for all the cases examined. These timing settings and detector configurations yield near optimal operations under heavy flow conditions.

For SAST-based operations, 5-ft detectors were placed 400 ft upstream of the intersection to detect vehicle arrivals. The step size ΔT was set at 2 sec and N_{max} was limited to 2. The maximum green was set at 60 sec. This constraint, however, took effect only when a queuing vehicle was stopped by a red light. In addition, the current green was extended automatically if the maximum queue length of the current green phase exceeds four vehicles.

Referring to Figure 6, it can be seen that the advantages of the SAST based control over the loop occupancy control can vary from one hourly flow pattern to another. When the flow rates are low, and the delays under the loop occupancy control are less than 10 sec/veh for two-phase operations, the SAST-based control can be only as efficient as the loop occupancy control. For four-phase operations, the SAST-based control cannot be expected to deliver significant improvements when the delay under the loop occupancy control is less than 20 sec/veh. Under moderate to heavy flow conditions, however, the SAST-based control can improve the control efficiency in some cases by more than 20%; the most likely level of improvement appears to be in the range of 8% to 15%. Since traffic-actuated signals are not necessarily utilized to their best ability, the actual improvement through adaptive control can be greater than what is implied in Figure 6.

Traffic-actuated control based on loop occupancy or volume density logic can be very efficient under light flow conditions. Under heavier flow conditions, two problems may emerge. One problem is the failure of the control to allow

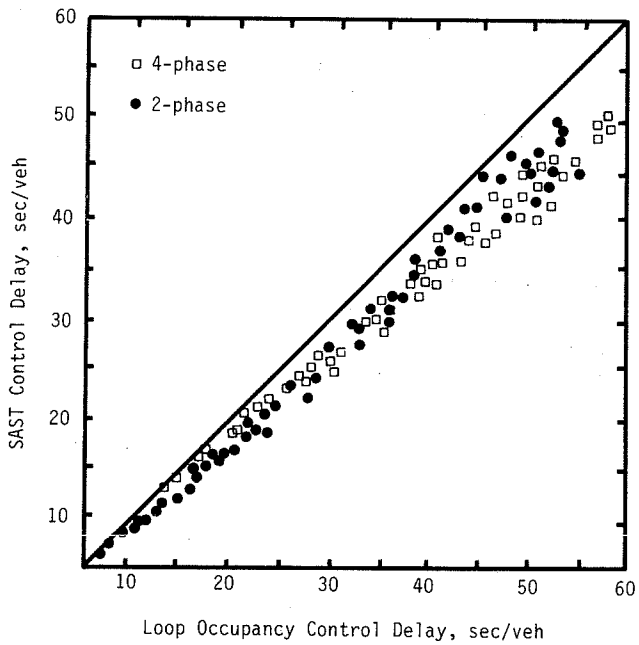

FIGURE 6 Delays of SAST control versus delays of loop occupancy control.

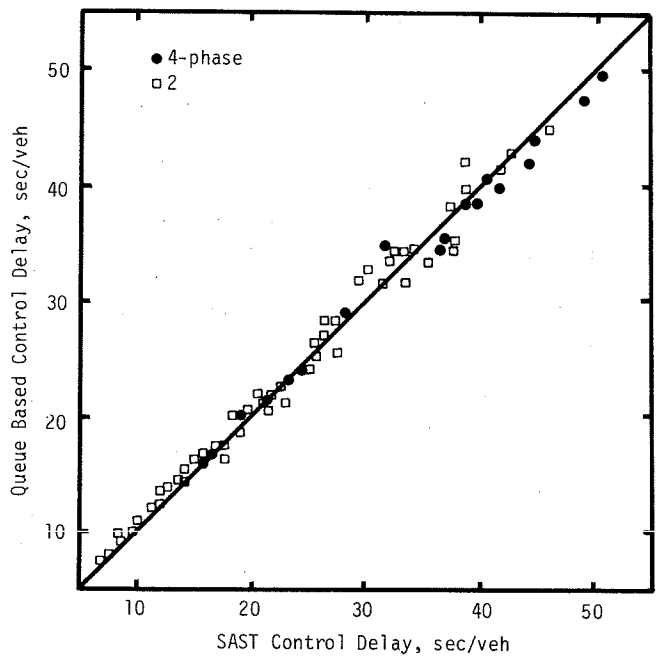

FIGURE 7 Delays of queue-based control versus delays of SAST control (detector setback = 400 ft).

most queuing vehicles to enter the intersection due to premature termination of the green. This problem can arise when short detector lengths, short vehicle intervals, or short maximum greens are employed. On the other hand, excessively long greens may result because of the actuation of detectors by vehicles not in a queue. Such vehicles cannot utilize the intersection capacity as efficiently as queuing vehicles. This problem can become rather acute when many lanes are associated with a signal phase.

Adaptive control can alleviate these weaknesses of traffic-actuated control through real-time optimization. Similarly, the queue-based logic, as shown in Figure 5, can also prohibit vehicles that cannot efficiently utilize the intersection capacity from extending the green. To facilitate a comparative analysis of SAST logic and the queue-based logic, the same simulation model was used to determine the best threshold queue length L_f that should be used for the level IV decision-making of the queue-based logic. The best threshold queue length was found to be in the range of 0.5 to 1.5 vehicles.

Based on a threshold value of $L_f = 1.5$ vehicles, the delays produced respectively by SAST logic and the queue-based logic for a number of hourly flow patterns were estimated through simulation. The results are shown in Figure 7, where it can be seen that, for hourly flow patterns that have delays under 20 sec per vehicle, the SAST-based control is slightly better than the queue-based control. Under heavier flow conditions, however, the queue-based control can sometimes perform better than the SAST-based control.

The ability of the queue-based logic to deliver reasonably high control efficiencies is not without a logical basis. Nevertheless, one reason that the queue-based control can sometimes deliver better signal operations than the SAST-based control can be found in the use of $N_{max} = 2$ and a threshold queue length of $L = 4$ vehicles for the SAST-based control. This combination of N_{max} and L is not necessarily the best for all the hourly patterns tested in this study. At the present time, however, it is unknown which combination of N_{max} and L will result in the best overall operation for an intersection with a wide range of flow conditions. Despite this limitation, it should be noted that, with the exception of a few tested flow patterns that have low flow rates, the queue-based control consistently performs better than the loop occupancy control. This characteristic can be exploited for adaptive control of intersections where short auxiliary lanes, opposed left turns, or frequent right-turn-on-red maneuvers exist. At such intersections, reliable advance information cannot be obtained for all approach lanes. In these cases, real-time information on queuing flows may be obtained and used to complement advance information in order to produce efficient signal operations.

CONCLUSIONS

Adaptive control has the potential to improve the existing level of signal control efficiencies at isolated intersections. Generally, adaptive control requires a logic to identify flow conditions and to use the identified conditions for making intelligent timing decisions. This process of control usually results in the use of estimated flow conditions for making signal timing decisions. Estimated flow conditions always deviate from actual conditions. The detrimental effects of flawed information on signal timing decisions cannot be compensated for by the use of a strenuous process of searching for better signal operations. Therefore, it is pertinent to examine whether simple decision rules can be effectively used to replace a more strenuous decision-making process for adaptive control.

In comparison with conventional loop occupancy control under simulated conditions, the SAST logic, which uses advance information in a vigorous process for making signal timing decisions, can provide significantly better signal operations.

The level of improvement varies with a number of factors, but it tends to be higher when heavier flows are encountered. Under the same simulated conditions, the simpler queue-based logic can produce comparable results. This implies that real-time information on queuing flow can be used to produce improved signal operations. This understanding is important in the development of a versatile adaptive control logic.

With the possible exception of the modernized optimized vehicle actuated strategy (*1*), none of the adaptive control strategies mentioned above can be effectively utilized for the control of intersections where short turning bays, opposed left turns, or right-turn-on-red maneuvers exist. At such intersections, reliable advance information cannot be obtained for all traffic movements. Under the circumstances, it would be logical to use real time information on queuing flow, as well as other advance information, for decision making. A major challenge to facilitate such a use of information is to develop a vehicle detector system that can provide reliable real-time and advance information at all or most intersections controlled currently with traffic-actuated signals.

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