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CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

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of

the Optimized Policies for Adaptive Control Strategy

(OPAC)

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What is OPAC? -- Introduction

Optimized Policies for Adaptive Control (OPAC) is a real-time demand-responsive traffic signal timing optimization algorithm for individual intersections. It was developed at University of Lowell under the sponsorship of U.S. Department of Transportation in the early 80s. OPAC distinguishes itself from traditional cycle-split signal control strategies by dropping the concept of cycle. In OPAC, the signal control problem consists of a sequence of switching decisions made at fixed time intervals. At each decision point the question is whether to extend or terminate current phase. Dynamic programming techniques are used to calculate optimal solutions. OPAC utilizes on-line data obtained from upstream detectors as well as historical data in the optimization. The objective is to minimize performance measures, such as vehicle delays and stops. Each phase is constrained only by the minimum and maximum phase lengths. Consequently, the duration of a phase is never prespecified. It depends solely on the prevailing traffic flow conditions. The dynamic optimization process is carried out continuously to ensure that the signal control is always up-to-date.

Though designed originally for signal control at individual intersections, OPAC can serve as a building block for demand-responsive decentralized control in a network. For example, OPAC is an integral part of the RT-TRACS (Real-Time Traffic Adaptive Control System) project which has been developed for use in an ITS environment (1996). The primary objective of RT-TRACS is to develop algorithms for real-time control of the network and provide capability that alternative control algorithms can work in parallel to optimally control different sections of the network on a continuing basis. A RT-TRACS prototype will be implemented and field tested by 1997.

Why OPAC? -- Design philosophy

Over the course of traffic control systems development the goal has always been to achieve higher responsiveness. It is a common notion that increased responsiveness will lead to improved traffic performance. However, several major experiments of traffic signal control systems in the 1970's show mixed results. A full-scale field test of different traffic

signal control strategies was conducted by the British Transport and Road Research Laboratory (TRRL). They concluded that the most effective strategy was the fixed-time plans generated by TRANSYT (1973). *An* extensive study of the effectiveness of various control strategies was conducted by the Corporation of Metropolitan Toronto (1974-1976). Results indicate that the Real-Time Optimization Program performed better than the existing fixed-time strategy in CBD but did worse in suburb area. The Urban Traffic Control System (UTCS) research project was conducted by the U.S. Department of Transportation in the early 1970's. The results also show that more responsiveness actually degrade the performance of traffic signals (1976).

After reviewing the results of those experiments, the developer concluded that in order to make substantial improvements to then current systems a new demand-responsive traffic control strategy should be developed based on the following principles (1982):

1. *The system shall provide better performance than off-line methods. This is obviously the primary criterion, but it has not been always recognized as such explicitly in past efforts.*

2. *Needs development of new concepts and not merely the extension of existing concepts.* **As** *demonstrated by the experiments reviewed in this report, effective responsiveness is not achieved by just implementing off-line methods at an increased frequency. New methods have to be developed.*

3. *Be truly demand-responsive, i.e., adapt to actual traffic conditions and not to historical or predicted values that may be far off from the actual.*

4. *Not be arbitrarily restricted to control periods of any length, but can be updated at any time, at any location.*

5. *Is not encumbered by a network model structure that requires extensive centralized computer capability, but is decentralized in its decision-making and uses only those data that are directly pertinent to the decisions it has to reach.*

6. *Obviates the conventional notions of offset, split, and cycle time, which are inherent in all existing signal optimization methods.*
7. *The pattern of any individual signal should consist of a continuously varying, demand-responsive, sequence of ON (effective green) and OFF (effective red) times that are only subjected to appropriate lower and upper bounds.*

How does OPAC evolve? -- Development history

OPAC-1

The first version of OPAC, OPAC-1, is a computer program that calculates demand-responsive optimal control policies for individual intersections. Dynamic programming technique is applied to solve the problem. Due to the global optimization nature, this program requires perfect knowledge of arrivals over the entire control period and heavy computation workload. Consequently, it does not suit for real-time implementation.

OPAC-2

OPAC-2 is a simplification of OPAC-1. In OPAC-2, a control period is divided into stages. The length of a stage is roughly equal to a typical cycle length. Each stage is further divided into intervals of five seconds. The number of signal phase changes is limited to be at least one and no more than three at each stage. For every switching sequence, a delay function is defined for each approach. It is the sum of the initial queue length plus the difference of arrival and departure of each interval in the stage. Given the initial queue length on each approach and the arrivals in each interval, the control problem for each stage now becomes finding the optimal switching sequence which minimizes total vehicular delay. The optimization procedure used for solving this problem is an optimal sequential constrained search method. The optimal switching policies are calculated independently for each stage, in a forward sequential manner for the entire process. Therefore, this approach is geared for incorporation in an on-line system.

ROPAC

Although OPAC-2 can be used in an on-line system, it still requires future arrival information for the entire stage. This information is difficult to obtain with accuracy in practice. To reduce these requirements the rolling horizon concept is utilized. The resulting version is called ROPAC. The implementation of the rolling horizon concept will be discussed in subsequent section. In ROPAC, the required near future traffic information can be obtained from detectors. However, it is important that the detectors be place well upstream (10-15 seconds travel time) of the intersection to procure accurate traffic flow information.

OPAC-RT

The real-time traffic control system that utilizes ROPAC as the signal timing optimization algorithm is called the Real-Time OPAC Traffic Signal Control System (OPAC-RT). There are two versions of OPAC-RT. Version 1.0 uses the ROPAC algorithm as is and is applied to two-phase operation. After two field tests of Version 1.0 several enhancements were made. The improved Version 2.0 is designed to control the signal timing at an isolated intersection controlled by a dual-ring, eight-phase controller. Only the through phases are actually controlled by the system. Other phases are treated as parts of the intergreen period.

RT-TRACS

A network version of OPAC will be included in the prototype of the Real-Time Traffic Adaptive Control System (RT-TRACS) project (1996). Coordination of the distributed RT-OPAC modules is provided by a multi-level hierarchy consisting of offset and virtual-cycle optimization facilities at the upper levels. Consequently, the system is capable of providing real-time, traffic-adaptive control for signal networks that combines the advantages of distributed cycle-free optimization at the local level with system-wide coordination at the network level.

How does it work? -- Implementation

Optimization procedure

The optimization procedure in OPAC is based on a pseudo-Dynamic Programming method which has the following features:

1. A control period is divided into stages. The stage length should be in the range of 50 to 100 seconds comparable to a cycle time for a fixed-time traffic signal. Each stage is divided into a number of 5-second intervals.

2. During each stage, at least one and no more than three signal changes are allowed.

3. A performance index is calculated for each approach for every switching sequence during a stage. It is the sum of the initial queue length plus the difference of arrival and departure of each interval in the stage. The objective function is the sum of the performance indices on all approaches.

4. *An* optimal sequential constrained search method is used to calculate the optimal switching sequence. The objective function is evaluated sequentially for all feasible switching sequences. At each iteration, current objective function value is compared with the one stored earlier. Whichever is smaller will be saved in storage. The corresponding switching points and the terminal queue-lengths will also be stored. At the end of the search, the values in storage is the optimal solution.

Rolling horizon implementation

The optimization procedure described above requires accurate future arrival information for the entire stage. However, this information is difficult, if not impossible, to get in practice. To reduce the requirements a rolling horizon concept is utilized. This allows the model to compute signal timings using readily available traffic information from upstream detectors.

A stage consisting of k intervals will be called a projection horizon. Each projection horizon is divided into a head portion and a tail portion. One can obtain accurate arrival flow data for the next r intervals, the "head" of the stage, from upstream detectors. For
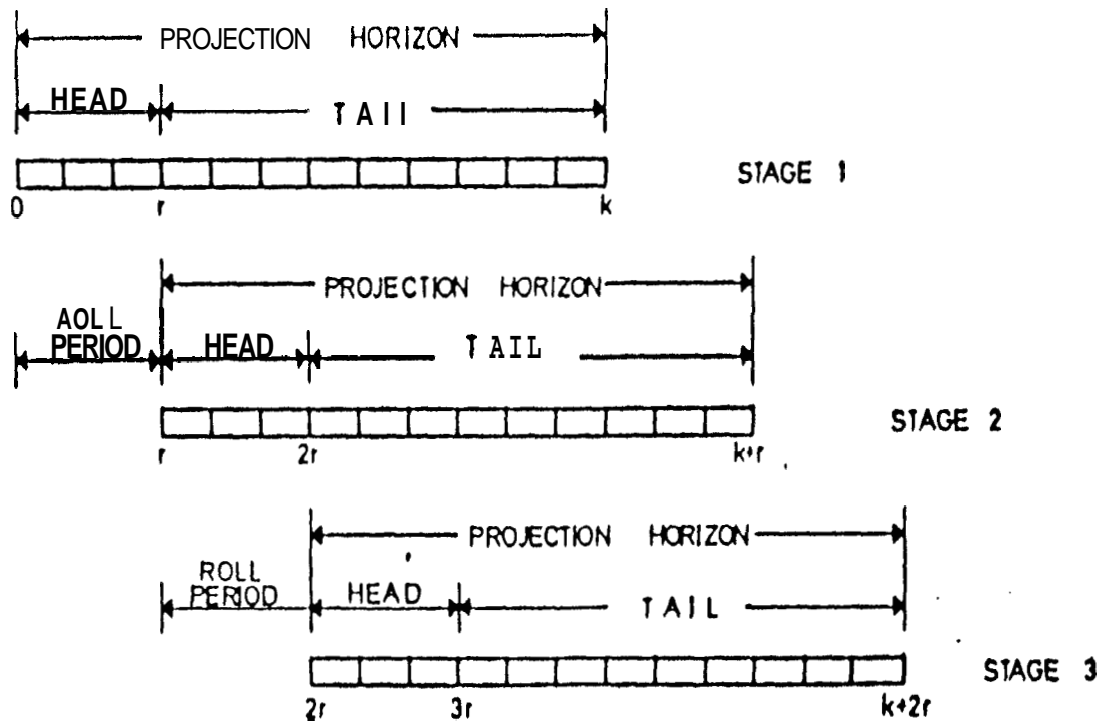
Figure 1. Illustration of the **Rolling Horizon Approach**

the rest (**k-r**) intervals, the "tail" of the stage, flow data is estimated from a model or from the date collected during previous projection horizons. Those traffic information is used to derive the optimal switching sequence for the entire stage, but only the policy for the head section is implemented. The projection horizon then rolls forward by r units to create a new stage and the whole process repeats itself (see Figure I). The length of the head portion, r, is chosen to be the free-flow travel time from the detectors to the stop bar. The detectors should be placed about 400 to 600 feet upstream from the stop bars so that the value of r will be 2 or 3. There should be one such detector in each lane

Three forms of the tail models are developed and tested. For the fixed model, a constant value equal to the average flow for the control period is used for each interval in the tail portion of the stage. For the static model, different values for each interval in the stage are used. The values are based on average value for that interval within the cyclic pattern ot' arrivals over the control period. For the dynamic model, each interval in the stage contains

the value derived from the actual arrivals during the previous stage exponentially smoothed against the corresponding interval in previous stages. Simulation test results indicate that the fixed model gives better performance. Therefore, the fixed model is chosen to be the tail model.

How does OPAC do? -- Reported performance

A simulation study of OPAC using NETSIM was done with three scenarios: single intersections, arterials and closed grid networks (1987). The purpose of this test is to compare the effectiveness of OPAC strategy with fully actuated, coordinated semi-actuated and fixed time control. For each scenario, a series of simulation runs with varied OPAC parameters were made to study the sensitivity of these parameters. The parameters include travel time from upstream detector to the controlled intersection and discharge rates at the controlled intersection. The results indicate that the performance of OPAC is very sensitive to discharge rates. Under ideal conditions, that is, setting the discharge rates to the ones that give lowest total delay, the OPAC strategy can perform better than optimal fixed-time plans and actuated control. In order words, for OPAC to generate good performance, it is important to have an accurate estimation of the discharge rates at the controlled intersection.

Three field tests were conducted to evaluate OPAC-RT: two for evaluating Version 1.0 and one for Version 2.0 (1991). Version 1.0 is designed for two-phase, fully actuated, isolated intersections while Version 2.0 is for isolated intersections controlled by dual-ring, eight-phase controllers. Each field test consisted of two phases. In the first phase, the values of three parameters required by the algorithm were fine-tuned to yield the best possible performance. These include 1). saturation flow; 2). travel time in seconds from the OPAC-RT detectors to the stop line; and **3).** projection horizon length. The second phase was performed as a before-and-after study. In the "before" study, the performance of full-actuated controls was collected. In the "after" study, the performance of OPAC controls was observed. Two measures of effectiveness were selected for the comparison. They are delay and percentage of stopped vehicles.

During the first field test, both delay and percent of stops were decreased when the intersection was under **OPAC** control. The improvements were modest; on the average, delay was decreased by 3.9 percent and stops were decreased by 1.6 percent. However, the observed volumes during this field test were extremely low and the **OPAC** algorithm was handicapped in its operation. Because there will be at least one switch per stage, despite the volumes, in **OPAC.** When traffic volume is low, it may be advantageous not to switch signals for a time longer than a stage. Therefore, **OPAC** strategy is handicapped under low volume conditions.

During the second field test, delay was considerably reduced under **OPAC** control. On the average, delay was reduced by 15.9 percent despite an increase of 4 percent in average volumes. The percentage of vehicles forced to stop, on the other hand, was increased only by 3.9 percent. During the third field test, which was conducted at an eight-phase intersection, delay was decreased on the average by 7.7 percent and the percentage of stopped vehicles was increased by an average of 9.5 percent. Overall, the results of those field tests show that **OPAC** strategies perform better than well-timed actuated signals, especially when the demand levels are high.

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