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# Implementation of the OPAC Adaptive Control Strategy in a Traffic Signal Network

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**Abstract: The Real-time Traffic Adaptive Control System (RT-TRACS) represents a new, state-of-the-art system in advanced traffic signal control. It has been developed cooperatively by a team of U.S. academic, private and public researchers under the guidance of the Federal Highway Administration (FHWA). The system provides a framework to run multiple traffic control algorithms, existing ones as well as new adaptive algorithms. The OPAC (Optimized Policies for Adaptive Control) control strategy, which provides a dual capability of distributed individual intersection control as well as coordinated control of intersections in a network, is the first adaptive algorithm implemented within the RT-TRACS framework. OPAC was the first comprehensive strategy to be developed in the U.S. for real-time traffic-adaptive control of signal systems. This paper presents the operational features of the OPAC algorithm and describes the implementation and field testing of OPAC within the RT-TRACS system.**

**Background:** In 1992, the Federal Highway Administration (FHWA) of the U.S. Dept. of Transportation decided to advance the state-of-the-art of adaptive traffic signal control as a major focus of its ITS (Intelligent Transportation Systems) research program. The Real-time Traffic Adaptive Control System (RT-TRACS) is a state-of-the-art system in advanced traffic signal control. This system is the result of an FHWA sponsored research effort led by PB Farradyne Inc. (PBFI) in conjunction with the University of Massachusetts, Lowell (UML). A team headed by PBFI was selected to lead the adaptive control research program and to develop the RT-TRACS prototype, working cooperatively with FHWA.

The objective of the RT-TRACS project was the development of a system capable of adapting to fluctuating traffic conditions as they occur by selecting the optimal control strategy from a "suite" of real-time traffic signal timing control strategies [1]. Thus, RT-TRACS serves as a platform for the implementation of a variety of traffic signal control algorithms, including several new adaptive control algorithms as well as existing signal timing systems. As part of this program, the FHWA also sponsored parallel research efforts to develop alternative real-time, adaptive control algorithms and enhance existing algorithms (including OPAC) for integration into the RT-TRACS platform. The FHWA is also sponsoring several field tests to evaluate the performance of the different algorithms.

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In the spring of 1998, the first version of RT-TRACS introducing the coordinated OPAC real-time adaptive algorithm with PBFI MIST® (Management Information Systems for Transportation) was implemented in a network of 16 intersections on Reston Parkway, in Reston, Virginia. Advanced type 2070 traffic controllers were employed for the first time in the U.S. to operate a coordinated network of signals under both coordinated and isolated modes of OPAC adaptive control algorithm as well as Time Base Coordination (TBC). Integration of the above state-of-the art technologies into an advanced traffic management and signal control system involved a number of challenges including various system integration and institutional issues. After introducing the OPAC real-time traffic adaptive control algorithm, this paper presents an overview of the issues encountered during the integration of OPAC into the RT-TRACS system. The paper also discusses field implementation issues and findings of the Reston field test.

## I. OPAC Adaptive Control Algorithm

The Optimized Policies for Adaptive Control (OPAC) strategy is a real-time signal timing optimization algorithm, which was originally developed at the University of Massachusetts, Lowell [2,3]. OPAC is a distributed control strategy featuring a dynamic optimization algorithm that calculates signal timings to minimize a performance function of total intersection delay and stops. The algorithm uses measured as well as modeled demand to determine phase durations that are constrained only by minimum and maximum green times and, if running in a coordinated mode, by a virtual cycle length and offset that are updated based on real-time data.

Development of this strategy was based on the following principles [4,5]:

a. The strategy must provide better performance than off-line methods. Although this may seem self-evident, this principle was not always explicitly incorporated in the development of previous responsive strategies.

b. The strategy must be truly demand-responsive, i.e., it must adapt to actual traffic conditions and not be responsive to historical or predicted values that are unreliable and may be far off from actuality.

c. The strategy must not be restricted to arbitrary control periods but should be capable to provide continuously optimized controls. Effective responsive-ness cannot be achieved by implementing off-line methods at shorter and shorter intervals.

d. Development of new control concepts that are better suited to the variability in traffic flows is needed and not merely the extrapolation of existing concepts. Conventional notions of cycle time, splits and offsets, which are inherent in existing signal optimization methods are not always suited for adaptive

control. On the other hand, direct minimization of performance measures can provide much improved performance.
e. Finally, the strategy must not be encumbered by a rigid network structure; rather, it should be based on decentralized decision-making.

As a result, OPAC was developed as a distributed strategy featuring a dynamic optimization algorithm for traffic signal control without requiring a fixed cycle time. Signal timings are calculated to directly minimize performance measures, such as vehicle delays and stops, and are only constrained by minimum and maximum phase lengths. Development of the strategy so far has progressed through four versions, which are briefly outlined below.

1. **OPAC-1:** Dynamic Programming

The first version, designated OPAC-1, was designed to serve as a basis for future OPAC strategy development. OPAC-1 utilizes Dynamic Programming (DP) techniques for the solution of the traffic control problem [6]. DP is a global optimization strategy for multistage decision processes. As such, it provides a standard against which all other strategies can be compared.
While this procedure assures globally optimal solutions, it requires complete knowledge of arrivals over the entire control period. It cannot be used for real-time implementation due to the amount of processing involved as well as due to the lack of available real-time information for this period. Much of the output from the program is never implemented because optimized policies are generated for all possible combinations of initial conditions at each stage of the control period. In practice, only one 'optimum policy' would be implemented. By being able to produce the theoretically optimal control strategy for each input state, OPAC-1 serves as a standard for the evaluation of the relative effectiveness of other, more practical strategies.

2. **OPAC-2:** Sequential Optimization

The second optimization algorithm that was developed, designated OPAC-2, consists of a simplification of the OPAC-1 algorithm. It was designed to serve as a building-block in the development of a distributed on-line strategy. OPAC-2 has the following features:

•The control period is divided into stages T seconds long. In this case, T is equals approximately a typical cycle length, though it could be longer.
•Each stage is divided into an integral number of intervals 's' seconds long; typically, s = 2 - 5 sec.
•During each stage there must be a sufficient number of phases to guarantee that no optimal solution will be missed. The phase change (switching) times are measured from the start of the stage in time units of s.
• For any given switching sequence at stage n, the performance function for each approach is defined to be the sum over all intervals in the stage of the initial queue length plus the arrivals minus the departures during each interval, i.e., this is the integral of the queue-length curve for the duration of the stage.

The optimization problem in OPAC-2 is stated as follows:

For each stage, given the initial queues on each approach and the arrivals for each interval of the stage, determine the switching times, in terms of intervals, which yield the least delay to vehicles over the whole stage.
The procedure used for solving the problem is an optimal sequential constrained search (OSCO) method. It is an exhaustive search of all possible combinations of valid switching times within the stage to determine the optimum set. Valid switching times are constrained by minimum and maximum phase durations.

3. **OPAC-3:** A Rolling Horizon Approach

While OPAC-2 is an optimization procedure which lends itself more readily to operation in real-time than does OPAC-1, it requires knowledge of arrivals over the entire stage length. Typically, the stage might be 1 or 2 minutes long. Obtaining actual arrivals over this length of time is difficult in practice. OPAC-2 could be implemented with a traffic prediction model which predicts accurately the traffic pattern over the entire stage. However, experience has shown that, in this context, predictors are unreliable as estimators of future traffic arrival patterns and are even less effective than historical data.

In order to use only readily available flow data without degrading the performance of the optimization procedure, a 'rolling horizon' concept was applied to the OPAC-2 algorithm, which is OPAC-3 (also named ROPAC). In this version, the stage length consists of n intervals. The stage is called the Projection Horizon (or simply Horizon) because it is the period over which traffic patterns are projected and optimum phase change information is calculated. The horizon is typically equal to an average cycle length.

From detectors placed upstream of each approach actual arrival data for k intervals can be obtained for the beginning, or head, portion of the horizon. For the remaining n-k intervals, the tail of the horizon, flow data may be obtained from a model. A simple model consists of a moving average of all previous arrivals on the approach. An optimal switching policy is calculated for the whole horizon, but only those changes which occur within the head portion are actually being implemented. Thus, there is a chance for dynamically revising the decisions when more recent (i.e., more accurate) real-time data are obtained.

If the detectors are placed well upstream of the intersection (10 to 15 sec. travel time) one can obtain actual arrival information over the head period. Having information of actual arrivals allows for the exact calculation of delay for any given phase change decisions. At the conclusion of the current head period, a new projection horizon containing new head and tail periods is defined with the new horizon beginning at (rolled to) the termination of the old head period. The calculations are then repeated for the new projection horizon. Figure 1 is an illustration of the rolling horizon procedure. The layout of intersection detectors and the information flow is illustrated in Figure 2. The roll period can be any multiple number of steps, including one. A shorter roll period implies more frequent calculations and, generally, closer to optimum (i.e., ideal) results.

4. **OPAC-4:** The VFC Network Version

As part of FHWA's Real-Time Traffic-Adaptive Signal Control System (RT-TRACS) project, the University of Massachusetts, Lowell (UML) expanded the OPAC control logic to include, at the option of the user, a coordination/synchronization strategy that is suitable for implementation in arterials and networks. This version is referred to as Virtual-Fixed-Cycle OPAC (VFC-OPAC) because from cycle to cycle the yield point, or local cycle reference point, is allowed to range about the fixed yield points dictated by the virtual cycle length and the offset. This allows the synchronization phases to terminate early or extend later to better manage dynamic traffic conditions. VFC-OPAC consists of a three-layer control architecture as shown in Figure3[7].

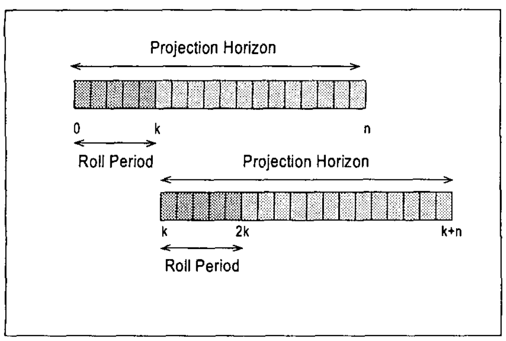



Figure 1: Implementation of the rolling horizon approach in OPAC.

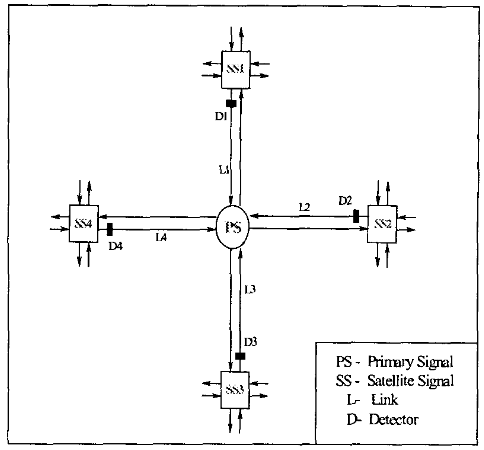



Figure 2: Information processing at an OPAC controlled intersection.

Layer 1, the Local Control Layer, implements the OPAC III rolling horizon procedure: it continuously calculates optimal switching sequences for the Projection Horizon, subject to the VFC constraint communicated from Layer 3. Layer 2, the Coordination Layer, optimizes the offsets at each intersection (once per cycle). Layer 3, the Synchronization Layer, calculates the network-wide virtual-fixed-cycle (once every few minutes, as specified by the user). The cycle length can be calculated separately for groups of intersections, as desired. Over time the flexible cycle length and offsets are updated as the system adapts to changing traffic conditions.

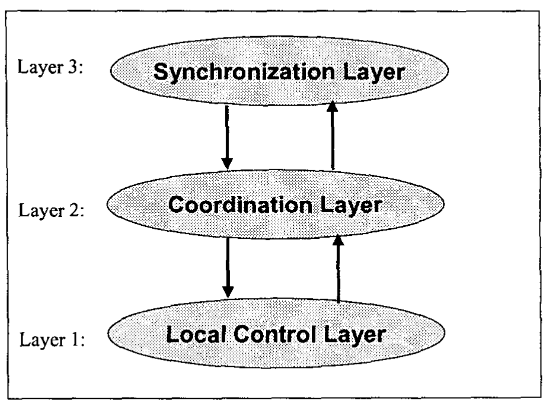



Figure 3: Control architecture in VFC-OPAC

II. IMPLEMENTATION OF OPAC IN RT-TRACS

With the above enhancements, the coordinated OPAC now provides a true adaptive control algorithm with many features, including:

- Full intersection simulation with a platoon identification and modeling algorithm
- Split optimization for up to 8 phases in a dual-ring configuration.
- Configurable performance function of total intersection delay and/or stops
- Optional cycle length and offset optimization
- Free and explicit coordinated modes
- Phase skipping in the absence of demand.
- Automatic response to changes in phase sequence

OPAC has been subjected to field tests and continuous enhancements since 1986 [8,9]. The earlier field tests evaluated the single intersection versions of the program. The coordinated version was tested for the first time in conjunction with the RT-TRACS demonstration project in the Reston Parkway in Reston, Virginia. In order to evaluate the performance of OPAC in RT-TRACS, the system was installed in a selected corridor and evaluated against the best fixed-time plans that were developed prior to the implementation. The scope of work for the demonstration project in Reston included: upgrading the site to meet RT-TRACS hardware and communications requirements; retiming signals to provide the best base case scenario; installing RT-TRACS software and performing calibration and fine tuning; and, collecting before/after study data to evaluate system performance.

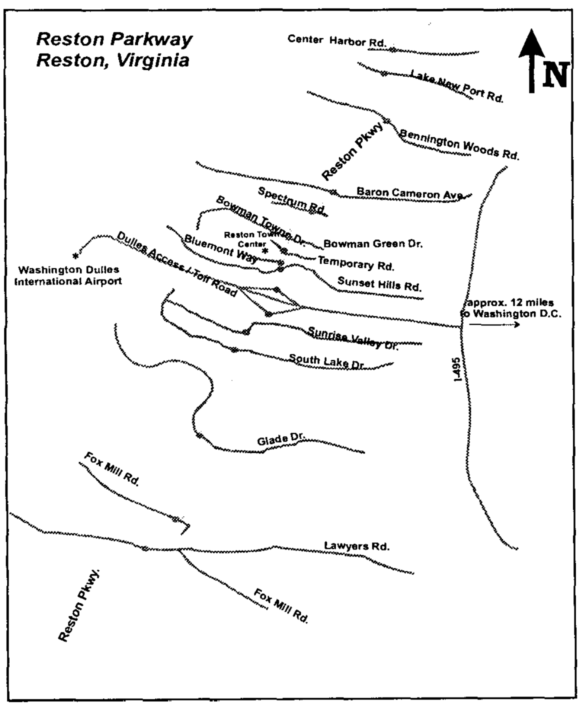



Figure 4: Reston Parkway RT-TRACS demonstration site.

This process began in the spring of 1996 and the system became operational in the spring of 1998.The test network depicted in Figure 4 consists of 16 signalized intersections along a 4-mile section of Reston Parkway in Northern Virginia. The corridor is a major travel and commuter route between Reston and the Washington Metropolitan Area through the Dulles Access/Toll Road. The test area, comprised of residential and commercial buildings, is a highly congested area during peak periods, as well as mid-day, evening hours and weekends. The Reston Town Center located in the middle of the corridor is a major shopping and entertainment center. Furthermore, the Washington Old Dominion (WOD) trail attracts hundreds of bikers and joggers every day of the week. This trail intersects the corridor at Bluemont Way, where a 32 sec all-red pedestrian crossing time is pedestrian actuated. During good weather conditions, the pedestrian traffic at this intersection would hamper the signal coordination and cause vehicle queues extending to the upstream intersection 450 ft from Bluemont.

## III. EVALUATION

The before and after study data collections were conducted by ITT Systems, an FHWA independent evaluator. The before data were collected in November 97 once the signal timings were optimized and implemented. However, due to delays in upgrading the hardware and communications system, the after data collection was carried out four months later, in March 98.

In addition to the typical hardware and software problems that are expected in implementing a new traffic signal control system, several other issues also contributed to the list of problems. One major problem was caused by the local phone service provider in upgrading the system, which resulted in loss of communications at several intersections. This problem was not resolved completely during the evaluation, resulting in frequent random loss of communications between the central system and field devices. This had a serious impact on coordination of the signalized intersections. Another issue was the construction activities scheduled to begin in early spring 98 concurrent with the system implementation and evaluation activities. The deadline imposed by this activity prevented adequate calibration and fine-tuning of the newly installed system before the after study data collection was carried out.

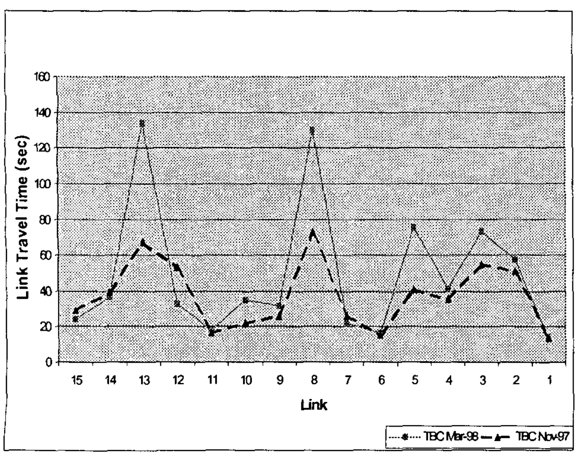
While an official evaluation report has not been released, the following results were prepared based on real-time data collected by the MIST system on OPAC timing parameters, signal status and traffic volume and some preliminary data provided by ITT Systems. The examples presented below are for the periods that the network was running under OPAC control without interruption due to communication system malfunction.

*A. Data Analysis*

At this stage of RT-TRACS development it is necessary to evaluate the effectiveness of coordinated OPAC under different traffic conditions and network geometry. This could provide insight into the various functionalities of the program, including calibration of OPAC parameters, to satisfy the needs of different segments of the network. Therefore, the evaluation should consider separately different times of day, different days of the week, and separate segments of the study area including critical intersections and coordination with closely spaced non-OPAC controlled intersections.

One of the interesting observations was the level of variation of traffic conditions between before and after study periods. This included changes in vehicular traffic patterns as well as a significant increase in pedestrian presence in the middle of the corridor during the after study period. Pedestrian traffic was a significant impedance during the after study but was very minor during the before study. Figure 6 presents a typical example of changes in travel time under the before-study-condition (with TBC) within four months. One set of travel time data was collected in November 97 as part of the before study data collection and the second set in March 98 prior to the after study conditions. Both cases show the southbound direction with long delays at two major intersections; namely, Sunset Hill (on Link 8) and Baron Cameron (on Link 13). Furthermore, collected data in March 98 show much higher overall delays compared to those in November 97. Similar observations have been made for the northbound direction with less variation. Figures 7 and 8 present a comparison of OPAC cycle length and phase durations (WB Baron Cameron), respectively, versus existing pre-timed plans. As seen in these figures, while OPAC was closely following the best fixed-time parameters, it was also responsive to traffic demand by adjusting phase durations and cycle length with respect to phase demand and total intersection volume, respectively.

Figure 6: Variation of travel time due to seasonal change




It was also following the constraints imposed by VDOT's minimum and maximum green times and cycle lengths. The TBC phase and cycle lengths, on the other hand, even though they reflected recently optimized values, could not meet the network needs to deal with dynamically varying traffic volumes. Poor communications hampered peer-to-peer data exchange which rendered the offset optimization inefficient. Cycle optimization was also affected due to lack of information from some critical intersections

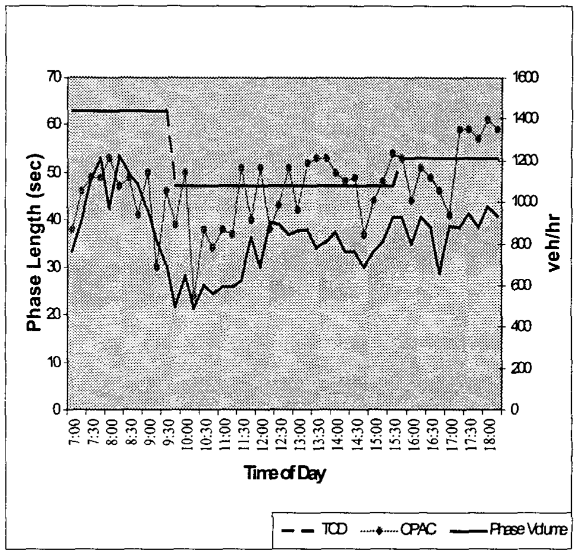



Figure 7: Cycle optimization.

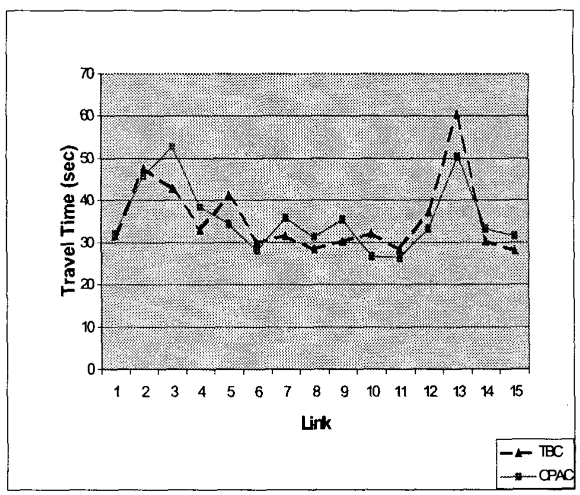



Figure 8: Phase optimization.

Figure 9 is an example of a travel time study during the AM peak period. This is the average travel time for weekdays in the northbound direction. The results show that OPAC performance was very close to that of TBC (overall changes for the corridor were within ±3%). Comparing travel time under OPAC with data collected in March 98 show improved performance under OPAC control. The first implementation of RT-TRACS provided a great deal of insight about the performance of the system. It also provided valuable experience with installation of the hardware and software as well as evaluation of RT-TRACS.

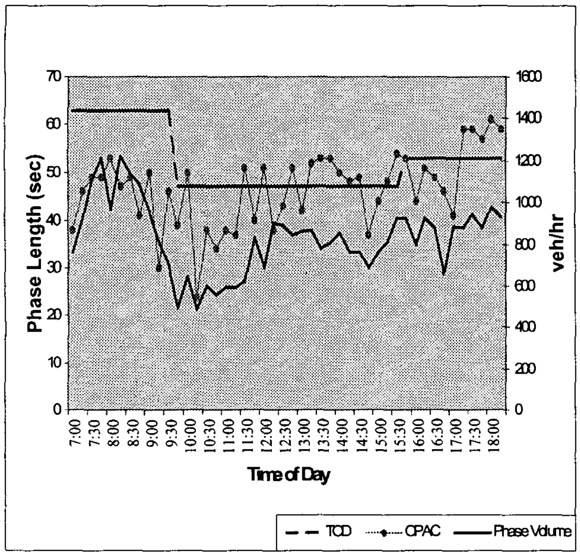



Figure 9: Travel time study.

## IV. Conclusion

The Reston RT-TRACS system was implemented and operated with a considerable degree of success, despite the aforementioned problems. The implementation was the first of its kind in the U.S. to control a network of sixteen intersections by a distributed system of 2070 controllers, running under both real-time adaptive and TBC systems. While the overall results have not been reported yet, the preliminary findings indicate that OPAC has achieved its objectives in reducing stops and delays and providing progression along the arterial. The performance of OPAC could have been further improved if sufficient time was available to perform calibration and fine-tuning of the OPAC parameters. Construction schedules for the area, however, hampered this option.

The evaluation provides valuable insights into the performance of the network version of OPAC under various traffic conditions and site geometry and provides the opportunity for additional enhancements to improve functionality of the algorithm. Furthermore, the findings suggest that the DP-based strategy could yield better results, once the communication system has been optimized and the construction work within the corridor completed.

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