

EVALUATING ADAPTIVE SIGNAL CONTROL USING CORSIM

Charlie Stallard

Larry E. Owen

ITT Systems Corporation

P.O.Box 15012

Colorado Springs, CO 80935-5012, U.S.A.

ABSTRACT

This paper discusses the evaluation of adaptive traffic signal control using TSIS/CORSIM. The paper reviews three adaptive control strategies that have been developed through contracts awarded by the FHWA's Turner-Fairbank IST (Intelligent Systems and Technology) Division. The paper discusses the framework and evaluation procedures for testing and assessing these advanced control algorithms, before they are deployed in the field. The paper also discusses sophisticated hardware in the loop experiments that permit the benefits of other ITS concepts and technologies to be assessed and quantified.

1 INTRODUCTION

The timing of most signal control systems in the United States employ first and second generation control strategies. These approaches are based on fixed time plans generated off-line by signal control optimization models, such as TRANSYT and PASSER II. Typically this type of control is not capable nor robust enough to handle many of today's ever increasing traffic requirements. In an effort to develop and evaluate traffic control strategies that can adapt to today's traffic conditions in real-time, the Federal Highway Administration (FHWA) has commissioned the development of a real-time traffic adaptive control system called RT-TRACS. Based on traffic conditions, this system will be able to choose the appropriate control strategy from a suite of control schemes and monitor their performance. To complement the RT-TRACS project, the FHWA has awarded contracts to certain researchers to develop new third generation control strategies (referred to in this paper as prototypes) that will be added to the RT-TRACS suite of control schemes. ITT Systems Corporation was awarded the contract to independently evaluate these strategies.

Before these prototypes were to be deployed in the field, it was critical to evaluate them in a simulation

environment to assess their performance and to reduce their development time as compared with other adaptive control systems, such as SCOOT and SCAT. This laboratory evaluation involved using CORSIM to simulate a variety of traffic networks under certain traffic conditions. CORSIM was chosen as the simulation engine, because it is able to microscopically simulate traffic and traffic control systems on integrated networks of freeway and surface streets, using commonly accepted vehicle and driver behavior models. In addition, it combines two of the most widely used traffic simulation models, NETSIM for surface streets and FRESIM for freeways.

The evaluation consisted of two sets of simulations. One set would model the signal control as it currently exists in the field. The other set of simulations involved interfacing CORSIM and the advanced signal control algorithms. The algorithms would be allowed to read detector data from CORSIM and then control the signal states at certain intersections. Measures of effectiveness, such as delay, throughput, and the number of stops, from the two sets of simulations would be statistically compared to assess the performance of each strategy for the different networks and traffic conditions.

The next section of this paper gives a brief description of the prototypes. This is followed by the results from simulation. The next section discusses further simulation studies that are being conducted in real time environments. The last section of this paper presents pertinent conclusions.

2 PROTOTYPE DESCRIPTION

Before a description of these three prototypes is given a brief summary of the requirements for the prototypes is presented.

2.1 Basic Prototype Requirements

Each of the prototypes was required to meet several functional requirements. First and foremost, it was

necessary for the prototypes to be affordable to implement and have an advantageous benefit-to-cost ratio. The prototypes were also required to be compatible with traffic data provided by conventional traffic detectors. In addition, the prototypes also needed to address one or more of the following:

- Effectively control signals for one or more sets of traffic and roadway conditions commonly encountered in street networks including both undersaturated and saturated flows.
- Recognize the possible requirements for different types of traffic control strategies for different signals/sections within a system, and implement the strategies most appropriate for existing demand characteristics and local area/system wide objectives.
- Respond to different measures of effectiveness (MOE's) based on the requirements of the local traffic engineer and the traffic flow/network situation.
- Influence traffic flows/demand through the use of various signal timing concepts, including metering, variable phasing, reversible lanes, and phase skipping.
- Implement truly intelligent and effective adaptive traffic control, which automatically adjusts its operation based on the success or failure of past performance (Farradyne Systems and Georgia Tech. 1994).

2.2 RHODES

The University of Arizona's prototype is composed of a main controller (called RHODES), APRES-NET, which simulates platoons, REALBAND (a section optimizer), PREDICT, which simulates individual vehicles, and COP (a local optimizer). This prototype, which is a hierarchical control system, has two levels of optimization.

2.2.1 Global Optimization

The global optimization is performed by APRES-NET and REALBAND. Traffic is detected about 100 ft. to 130 ft. upstream of each intersection. APRES-NET uses this information to simulate the platoons at each intersection and determine their arrival times. These platoon predictions serve as inputs to the section optimizer, REALBAND, which computes target phase timings for network optimization.

When the arrival times of simulated platoons at an intersection are in conflict, REALBAND splits the simulated scenarios into two branches. Each branch gives one of the conflicting approaches a red phase until the opposing platoon has passed. APRES-NET simulates each branch and all of its sub-branches to determine the optimal solution to the conflict.

2.2.2 Local Optimization

The detected data is also passed to the local simulator, PREDICT. It takes traffic detected just upstream of the adjacent intersections and knowledge of each upstream signal phasing for the present rollover period and simulates the movement of these vehicles through the upstream intersection to predict the arrival times at the downstream intersection of interest. COP uses these arrival times to optimize signal phasing for the next rollover period.

COP employs dynamic programming to optimize a single intersection, while taking into account the target phase timing requirements imposed by REALBAND. COP can renew its optimization process at intervals of one second, and therefore need only commit its tentative optimal phase timings for one second at a time, allowing it to be responsive to unforeseen variations (University of Arizona 1994).

2.3 OPAC

The OPAC (Optimization Policies for Adaptive Control) prototype used in this study was developed by PBF and the University of Massachusetts - Lowell. Each subnetwork is considered independent and can transition between the uncongested and congested modes, based on MOE's and thresholds.

2.3.1 Uncongested Networks

For uncongested networks, OPAC uses a level of control at the local intersection which determines the phase on line and a network level for synchronization, which is provided by fixed-time plans, obtained off-line, and/or a "virtual" cycle, determined on-line. The type of control and levels of local and global influence are flexible. OPAC bases the local signal timings on detected data from all directions for a head period (typically 15 seconds) and predicted data for a further tail period (typically 60 seconds). At the same time it determines the virtual cycle. These are implemented for a time-step (roll period) of about 2-5 seconds. The length of the virtual cycle is varied according to the needs of either the critical intersection or the majority of intersections. The virtual cycle is allowed to change by typically one second per cycle. Within this limitation, OPAC provides local coordination by considering flows into and out of an intersection in selecting its offset and phase lengths.

2.3.2 Congestion Control within OPAC

The congestion control process in OPAC generally attempts to maximize throughput, by selecting the phase that will pass the most vehicles through the intersection. OPAC does this by considering saturation flows and space

available to store vehicles on each link. The first step of congestion control involves determining the next phase given that there is not a critical link that is on the verge of or currently experiencing spillback. On the basis of these calculations, the algorithm determines whether it is necessary to revisit the timings at neighboring intersections in light of throughput constraints that their physical queues impose on each other's effective service rates (Owen, Stallard, Glitz, 1997).

2.4 GASCAP

GASCAP (Generic Adaptive Signal Control Assessment Program) was developed by ITT Systems. The purposes for developing this tool were:

- To test the interface between TSIS/CORSIM and the signal control prototypes.
- To assess the benefits of a control strategy that minimizes complexity.
- There was a shortage of prototypes mature enough to interface with CORSIM and be tested.

At the time of development, It was assumed that this algorithm would perform better than the signal control currently existing in the field but not as well as the more sophisticated algorithms presented above. Because the results from simulation for GASCAP were quite good, it would be illogical to preclude it from this paper.

There are two different algorithms within GASCAP, depending on whether or not an intersection is experiencing congestion or not. GASCAP makes this determination based on the occupancy of upstream detectors on opposing approaches at the intersection.

2.4.1 Uncongested Control

Uncongested control within GASCAP consists of 4 sets of rules. Each set of rules submits its recommended movement to an event list. Each movement is assigned a priority level, and GASCAP selects the movement with the highest priority for the current movement at the intersection. The priority for the movements is based on the estimated number of vehicles that will request that particular movement. This number is estimated using information from detectors that are typically 600-700 ft. upstream of the intersection.

The 4 different sets of rules have evolved in parallel with increasingly more difficult traffic conditions and more complicated network geometries. For example, the first category of rules is called the Demand Rules. This set of rules corresponds to intelligent control of an isolated intersection. However, if intersections are more tightly spaced, the progression of vehicles from intersection to intersection must be considered, and an effective adaptive control strategy must coordinate green times at adjacent intersections. To accommodate this, GASCAP contains a

set of rules called the Progression Rules. As traffic demand increases and conditions become saturated, another set of rules called the Urgency Rules are required. When traffic conditions begin to move from saturated to congested, it is necessary to consider the conditions downstream of an approach. This is the purpose of the Cooperative Rules. The uncongested control within GASCAP is strongly dependent on the estimates of the queue on a particular approach. However, as traffic conditions reach the congested level, it is more difficult to estimate the queues for each movement. Consequently, this type of control will tend towards instability, and it is necessary to have a different control strategy, when an intersection is congested.

2.4.2 Congested Control

GASCAP maintains a 30-minute record of detector information. From this information, the occupancy and then the volumes from the previous 15 minutes are computed for each movement. Using these volumes, GASCAP creates a timing plan for the congested intersection. This timing plan has a fixed cyclelength and is updated every other cyclelength. Essentially, GASCAP adjusts the splits and offsets for the intersection based on previous volumes, when an intersection is congested.

3 SIMULATION RESULTS

The original reason for simulating the prototypes was to determine the best control strategy for a given geometry and set of traffic conditions. However, simulation of this type is vital during the development process of these control strategies. During initial testing and evaluating, simulation helped reveal several inadequacies in the control algorithms. Prototype developers were also able to debug their algorithms using the TSIS simulation environment.

Figure 1 shows the software interface between TSIS/CORSIM and the advanced signal control prototypes. Basically, the simulation engine, CORSIM, and the signal control algorithms exist as separate DLL's (dynamically linked libraries). The TSIS environment allows these two separate DLL's to share certain critical information that resides in memory. For example, CORSIM populates the detector data structure with information about vehicles, which have activated the detectors, and the TSIS environment allows the signal control algorithm to read this information. The prototype processes this data and returns signal state information to the shared memory. CORSIM reads this information and sets the traffic signals in the simulation appropriately.

The signal control prototypes have been tested for three different high type arterial networks. The traffic demands for these networks range from unsaturated, to saturated, to

congested. In addition, the geometries for the networks become increasingly complicated.

The first network is called Tara Boulevard. It is located in Atlanta, GA and is an unsaturated network of 10 intersections. The traffic volumes for the simulations correspond to the time varying demands experienced during morning peak times (8 a.m. – 10 a.m.) through the week. The simulations were run for 30 different random number seeds to account for the stochastic variation of day to day traffic.

Figure 2 shows the assumed normal probability density functions for the throughput, delay, and number of stops for the four different control strategies. The signal control strategy that is currently in the field at this site has been denoted by the term “Baseline”. The variance for the distributions from RHODES and GASCAP were smaller, indicating that these adaptive control algorithms performed well and adjusted to the stochastic nature of the varying traffic conditions dictated by the different random number seeds. The throughput and delay for these strategies are profoundly better than the results from OPAC and the Baseline.

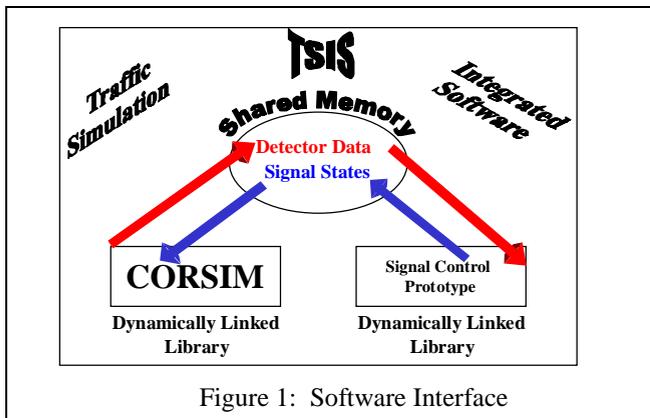


Figure 1: Software Interface

Statistical comparisons using the Dudewicz and Dalal method (Dudewicz and Dalal, 1975) verify this assertion.

The second test network is Airline Highway. It is a long arterial with 8 intersections located in Louisiana. The traffic demands for this arterial are slightly saturated. The volumes for the simulation are constant, and the simulation time was 15 minutes. Since the volumes are constant, the optimized semi-actuated signal control that currently exists in the field should have a distinct advantage over adaptive signal control approaches and perform better.

Table 1 shows the means for the throughput, delay, and number of stops for the GASCAP prototype and the existing signal control that is in the field. Interestingly enough, GASCAP shows marked improvement over the Baseline for the throughput, delay, and number of stops. Also, the normal distributions for these measures of effectiveness from the simulations with GASCAP controlling the signals exhibited a smaller variance. Once again, this indicates that this adaptive control prototype was better able to handle the random variation from simulation to simulation.

Table 1: Measures of Effectiveness for Airline Hwy.

	Throughput	Delay	# of Stops
Baseline	1695 vehs	104.4 sec	1.61 /veh
GASCAP	1726 vehs	98.8 sec	1.51 /veh

The third network is an arterial in Northern Virginia called Reston Parkway. This network consists of 16 intersections and is over saturated. In addition, to being saturated this network presents a host of other problems. For example, Reston Parkway provides direct access to and from the Dulles Tollway. As a result, predicting the nature of cyclical flow profiles, which some adaptive control strategies rely on, is nearly impossible. The four intersections that are closest in proximity to these access routes are critical to effectively controlling the traffic on the arterial. To complicate matters the west approach to the southern most intersection of these four critical intersections is closely spaced, about 300 feet. The northern most intersection of the 4 critical intersections poses the most difficulty, because of the large demand on the cross streets and from left turners. The 2 hour simulations were run for 30 different random numbers seeds and the volumes were varied every 15 minutes to reflect traffic demand in the morning peak.

Figure 3 shows the “assumed” normal probability density functions for the throughput, delay, and number of stops for the different control strategies. These results indicate that GASCAP performed significantly better than the other two alternatives. The smaller variance for the delay shows how well GASCAP responds to the different traffic conditions present in each simulation run. OPAC’s performance is impaired, due to the proximity of the Dulles

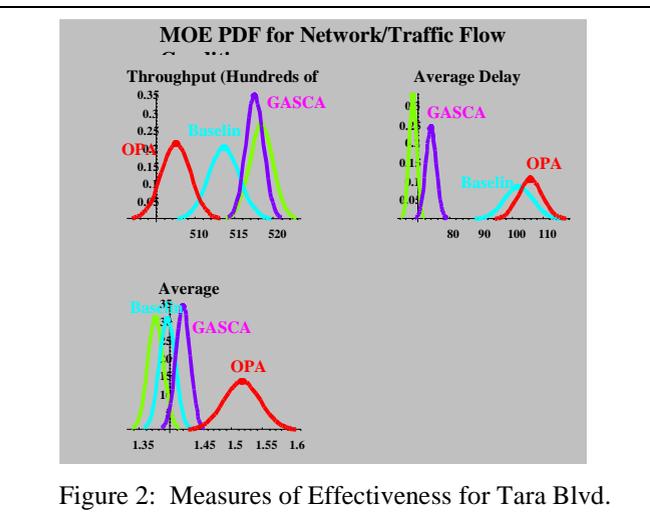


Figure 2: Measures of Effectiveness for Tara Blvd.

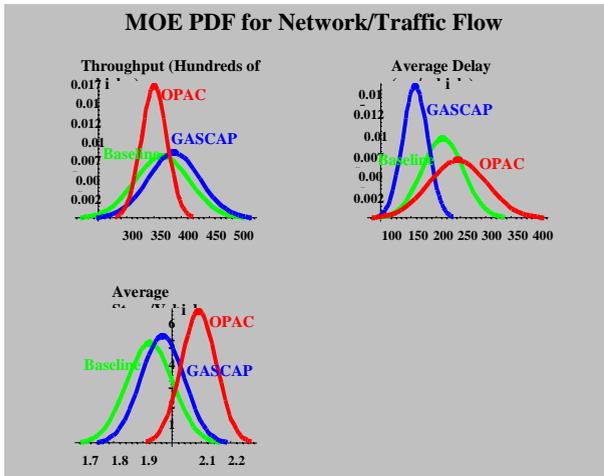


Figure 3: Measures of Effectiveness for Reston Pkwy.

Tollway and its negative effect on the construction of the flow profiles for this network.

4 HARDWARE IN THE LOOP SIMULATIONS

This section of the paper discusses some of the hardware in the loop simulations that have been conducted at the Federal Highway’s Traffic Research Laboratory (TReL). These simulations involve assessing and quantifying the benefits of advanced sensors that detect traffic flow parameters and under what geometric scenarios these sensors might be most advantageous.

Figure 4 shows the network used to in these simulations. Basically the network consists of three intersections each with two one-way approaches. About 5 minutes into the simulation, a surge occurs on the cross street of the center intersection. In addition, 34% of the vehicles approaching the center intersection from the left turn right into the parking lot that is at the lower left corner of the intersection.

The purpose of the simulation was to test three different kinds of control at the center intersection. The other adjacent intersections are under pre-timed control. The first type of control was pre-timed based on the volumes prior to the surge. The second type of control was adaptive signal control that used information from loop detectors placed as far upstream as possible. The third type of control used an advanced video detector to estimate the queues for each approach at the center intersection

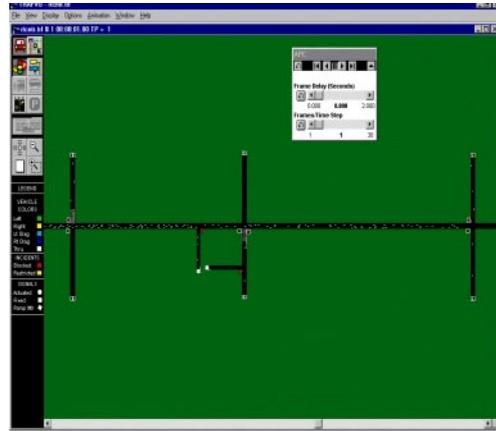


Figure 4: Network for Hardware-in-the-Loop Emulations

The test configuration for the simulation used to test the adaptive control with an advanced video detector is shown in Figure 5. The TSIS computer simulates the network using CORSIM and the adaptive signal control. The camera is focused on the center intersection and sends the video image to the image-processing computer. The image processing software estimates the number of vehicles that are in queue on the two approaches of the center intersection. This information is communicated to the adaptive control algorithm over a window’s socket. The algorithm uses the queue state for each approach to determine the signal state at the center intersection. Since the image processing software can only estimate the queue length once every second, the TSIS tool for this application is configured to run in real time.

Figures 6 and 7 show the delay on the cross street and main street from the simulations. The simulations using adaptive control with the camera detector showed significantly less delay on the cross street but approximately the same delay as the optimized pre-timed plan on the main street. The adaptive control with detectors was able to reduce the delay experienced on the cross street. However, it did not consider the effect of the parking lot on the main street. As a result, its queue estimates for the main street approach were always exaggerated, and the delay on the main street for this strategy was the largest of the three.

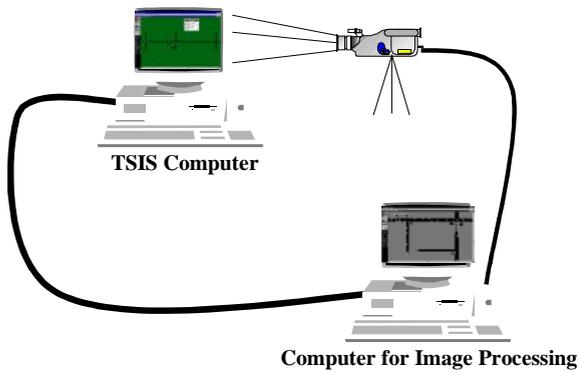


Figure 5: Test Configuration

The results from the simulations show that there are distinct and quantifiable advantages to adaptive control with an advanced detector for this particular type of geometry. It also shows that the performance of an adaptive control system based on loop detector information that has been implemented ignorantly will be inferior to other less costly alternatives, namely pre-timed control.

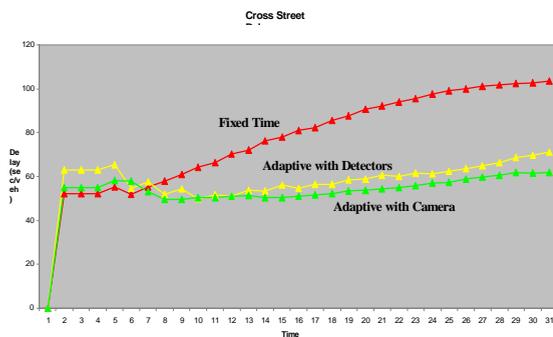


Figure 6: Cross Street Delay

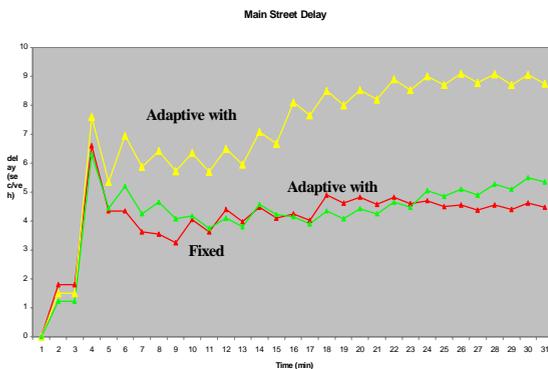


Figure 7: Main Street Delay

5 CONCLUSIONS

This paper has presented the simulation methodology and results that have been used to evaluate the advanced signal control algorithms that may be included in the Federal Highway Administration’s RT-TRACS project. Initial results from simulation were essential in identifying certain unacceptable logic flaws in these control strategies. In addition, evaluating these initial results was a critical step in the overall development process of the algorithms. Subsequent results from further simulation and testing showed that adaptive signal control can significantly improve traffic conditions for a wide variety of networks. In some instances, simulation results showed that it was possible to reduce delay by 25-30%, as compared with the signal control, currently in the field. Surprisingly enough, other results demonstrated that even with constant traffic demand, adaptive control showed improved performance as compared with pre-timed optimized signal control. In short, simulation results presented in this paper strongly suggest that it is possible to significantly reduce traffic congestion and improve overall performance for a variety of network geometries and traffic conditions with these adaptive control strategies.

This paper also discussed some hardware in the loop simulations that have been conducted at the FHWA’s Traffic Research Laboratory. This type of simulation allows advanced ITS concepts and technologies to be evaluated at a higher level of fidelity. In particular, this type of simulation has been used to assess and quantify the benefits from adaptive signal control that uses an advanced camera detector instead of traditional loop detectors to detect vehicles. Results from these experiments showed that there are distinct advantages to using advanced sensors for certain network geometries.

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AUTHOR BIOGRAPHIES

CHARLIE STALLARD is a research analyst at ITT Systems Corporation and a Ph.D. student at the University of Colorado. His research interests include adaptive control, communication systems, and the simulation of complex stochastic processes.

LARRY OWEN is the Principal Analyst for the ITT Systems' Transportation Group. For the past several years he has been doing research in adaptive traffic signal control, traffic flow modeling and validation under contract to the Federal Highway Administration. Mr. Owen has over 25 years experience in simulation development and application, systems analysis, and operations research.