

Adaptive Control Software for Distributed Systems

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Abstract—Traffic control systems in United States evolved from electro-mechanical time-clock based to computer-based in late 1970's. The research and development sponsored by the Federal Highway Administration resulted in mainframe computer based centralized systems called Urban Traffic Control Software (UTCS). The key aspects of these systems were second by second command and control by the central computer of electro-mechanical controllers at each intersection. The communication technologies at the time were twisted pair time division multiplexing with a maximum of 12 intersections per pair of communication cable. A majority of the urbanized cities in the U.S. implemented such systems.

In the 1990's, the Federal Highway Administration (FHWA) started research called Adaptive Control Software (ACS). This research generated four adaptive traffic control software prototypes called RHODES, OPAC, RTACL and ATCS. The key aspect of the RHODES, OPAC, and RTACL is that the control software is decentralized with link by link short time prediction of traffic demand. ATCS extended the UTCS approach to include adaptive capabilities. This research constitutes a major advancement in traffic signal control since the deployment of UTCS.

I. INTRODUCTION

The primary motivation for the development and deployment of adaptive control systems is the promise of improved performance with reduced requirements of staff time to develop signal timing plans. One of the primary deficiencies of current signal control strategies is the need to frequently update timing plans based on changing network volumes. It has been estimated that traffic experiences an additional 3% delay per year as a consequence of not retiming signals for evolving conditions (Bell and Bretherton, 1986).

Due to limited resources and workload requirements, many agencies are not able to update signal timing plans frequently enough to maintain the desired level of performance. Adaptive control strategies attempt to address this need by continually adapting to traffic demand without the dependence on signal timing plans that were developed for assumed volume levels.

The ability of adaptive control strategies to improve operational performance is based on the ability to respond to changes in traffic flow. These changes can be characterized as long-term and short-term changes. Long-term changes result from changes in traffic patterns that result in land-use changes, population growth and other slowly changing factors. Short-term changes may be the result of the arrival of

a transit vehicle (bus, train, light rail) at a park-and-ride station, the changes of classes at a university, or other traffic generating event. Other changes may be subtler such as the natural stochastic variation in traffic flow. A truly effective traffic adaptive control strategy can respond to these changes without the need for operator intervention.

The real desires are for systems that improve the performance of our transportation systems through improved signal system performance, maintainability, and responsiveness for the signal timings. Adaptive signal control is only one important component of Advanced Traffic Management Systems. Other components include tools to support monitoring and analyzing on-line, real-time performance, tools that reduce the workload required to maintain traditional signal timing plans, and a support system for a variety of strategies to address a wide range of traffic management scenarios.

This paper describes the FHWA research program for ACS algorithms and systems.

II. ACS SYSTEMS

The Federal Highway Administrations (FHWA) Adaptive Control Software (ACS) research program was established in the 1990's with the specific goal of developing distributed adaptive traffic signal control techniques that take advantage of the advances in traffic signal controller technology. FHWA commissioned the development of several adaptive control strategies under a research project called Real-Time Traffic-Adaptive Signal Control Systems (RT-TRACS). FHWA recognized that different strategies might perform better under different network and traffic conditions. Under RT-TRACS the system was to select among the different available strategies depending on several factors including network characteristics, traffic conditions, and other factors that differentiated each of the different strategies.

Traffic control systems in the U.S. differ from those found in other parts of the world, such as those developed in Europe and Australia. For example, the traffic signal controllers are based on the concept of rings and barriers rather than stages and intergreen times. Emerging technologies, such as the industry standard Advanced Traffic Signal Controller (ATC) and practices such as distributed control, rather than the traditional centralized command and

control, presented the need for the application of theoretical advances in adaptive control algorithms, computation and communications to be applied to U.S. adaptive control system developments.

The ACS based systems have several unique characteristics including:

- Support for dual-ring controller logic
- Peer-to-peer messaging
- Computational power located at the intersection
- Utilize traditional detection technologies (loop, video, radar)
- Proactive (predictive) decision making.

Support for the dual-ring controller logic is essential for interoperability with existing systems. This characteristic also makes the maintenance and support more viable. Peer-to-peer messaging takes advantage of developments in communications capabilities (such as IP-networking capabilities of the ATC) to provide a reliable, proactive coordination and cooperation among controllers in a network. Additional computational power is located at each intersection utilizing the expandability of the ATC to run the ACS algorithms. Utilization of existing detection technologies has been an important consideration in the design of ACS since the technological limitations of advanced sensors, for values such as queue length, limit the algorithms capabilities.

A key characteristic of the ACS systems is proactive decision making. Each of the ACS prototypes makes predictions of the traffic flow and vehicle arrivals. These predictions are used in the optimization process to make decision about the future rather than the traditional approach of making decision for future operation based on data observed in the past. This has proven to be a significant design feature in ACS. Each of the prototype systems addresses this proactive decision making slightly differently, but each has an effective approach.

The ACS research has resulted in four mature adaptive control systems:

- OPAC
- RHODES
- RTACL
- ATCS

OPAC (Gardner, 2001) was developed by PB Farradyne based on research conducted at the University of Massachusetts at Lowell. RHODES (Head, et. al. 1992) was developed by The University of Arizona. RTACL (Memon, 1996) was developed by researchers at the University of Pittsburgh and the University of Maryland with support from PB Farradyne. ATCS has been developed by the City of Los Angeles. OPAC, RHODES, and RTACL were prototypes included in the FHWA RT-TRACS research and are based on the distributed system principles. ATCS was developed by the City of Los Angeles as an extension to their existing

UTCS system. It utilizes similar concepts as the other systems, but has been implemented in a centralized fashion.

A key component of the FHWA research program has been the utilization of microscopic simulation to evaluate the effectiveness of the ACS research products. FHWA's CORSIM microscopic simulation model has been used to model a variety of networks for the evaluation purpose. For the purpose of this discussion, two long arterial networks will be considered: Tara Boulevard, Atlanta, GA. and Reston Parkway McLean, VA. The Tara Boulevard model was developed by FHWA as one network on which each of the prototype algorithms could be compared. It consists of 16 intersections with traffic demands based on the AM peak period. Only RHODES and OPAC were evaluated using the Tara Boulevard model. A baseline condition of well timed coordinated-actuated control was used for comparison. Thirty (30) simulation replications were made of each condition. Table 1 summarizes the results of the simulation study.

Table 1. CORSIM simulation results for ACS prototypes.

Prototype	Throughput Vehicles	Delay Seconds	Stops/Vehicle
RHODES	51844	68.4	1.38
Baseline	51372	102.2	1.40
OPAC	50756	106.0	1.52

In addition to the simulation evaluation, FHWA is conducting several field tests of the ACS prototypes. RT-TRACS using OPAC was evaluated on Reston Parkway in Virginia. Table 2 summarizes the findings of the simulation study and the field evaluation.

Table 2. Field evaluation results of OPAC on Reston Parkway.

Prototype	Throughput Vehicles	Delay Seconds	Stops Vehicle
Baseline	36550	213.64	1.92
OPAC	35078	244.31	2.09

An important consideration for interpreting these results is the comparison of the ACS system to well timed coordinated-actuated control. Recall that one of the objectives of the adaptive control research was to develop systems that could maintain timing plans over several years.

Even if these initial results do not show superior performance over well timed plans, they definitely indicate the ability of the ACS systems to develop timings that will perform better than outdated plans – even after only a few years.

Additional field tests were conducted by FHWA using RT-TRACS with RTACL in Chicago and RHODES in Tucson and Seattle. The Chicago and Seattle field tests have been completed. The Tucson field test will be completed later in 2002.

III. ACS LITE

The FHWA ACS-Lite research program is intended to assess, and then pursue, the best, most cost-effective solution for applying adaptive control system (ACS) technology to current, state-of-the-practice closed-loop traffic signal control systems. This effort is intended to make ACS technology accessible to many jurisdictions that cannot afford, or do not wish to spend, the upgrade and maintenance costs required to implement the full-featured ACS systems. The ACS-Lite project was initiated in February 2002 and is intended to advance the state-of-the-practice in adaptive signal control by building upon the technology that was developed in the previous ACS research program. The project includes:

- Functional requirements development,
- Algorithm development,
- Software planning, development, and testing,
- Evaluation of the algorithm(s) in a simulation environment, and
- A field test.

Figure 1 depicts the general architecture of the ACS Lite system. The key components in this system are the utilization of existing closed-loop field masters and controllers, standard (NTCIP) communication protocols (where appropriate and available), and central monitoring to allow assessment of system operation.

The ACS-Lite research is faced with the challenge of making proactive decision in a technological environment where different levels of information are available than in the full ACS systems. To accommodate this challenge, it is envisioned that decisions will be made less frequently and that changes will be limited to traditional control parameters including cycle, splits, and offset.

The ACS-Lite research program is expected to be completed in July 2003 with a field test to be conducted later in 2003.

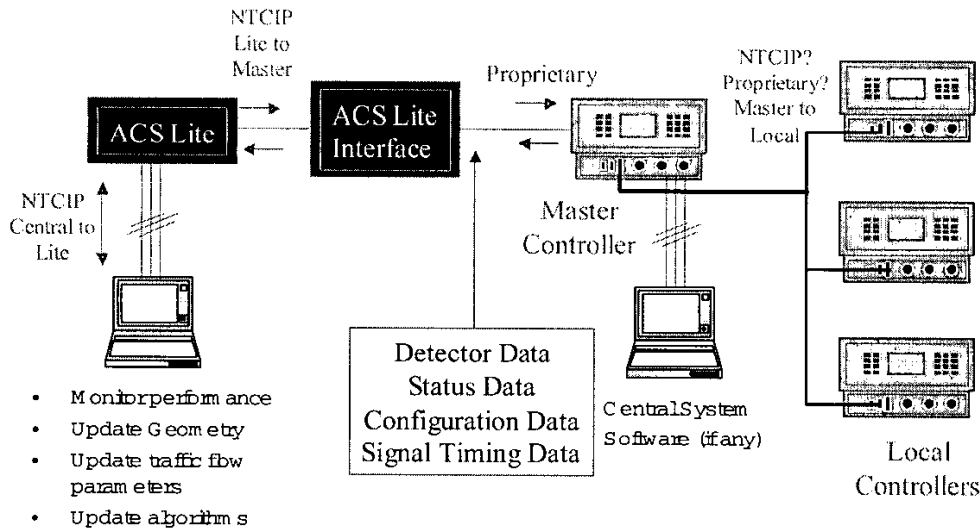


Fig. 1 ACS-Lite architecture.

VI. CONCLUSION

The FHWA ACS research program is addressing the needs for adaptive control in the U.S. traffic management industry. The ACS research resulted in four (4) systems that are either operational (ATCS) or are in various stages of field evaluation (OPAC, RHODES, and RTACL). Simulation experiments have demonstrated that these systems are effective and can address the goals of adaptive control. To address the concern over the cost and technological requirements of the ACS systems, FHWA has initiated a new research project to utilize the ACS developments on existing close-loop traffic control systems.

Adaptive control is a necessary component in addressing the ever increasing demands on our transportation networks. The FHWA research program has been structured to address this need and to result in products that can be applied to traffic control problems across North America. Future developments in this important research area will hopefully support wide spread deployment and operation of adaptive traffic signal control systems.

VII. REFERENCES

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