U.S. Department of Transportation
Federal Highway Administration

TURNER-FAIRBANK
HIGHWAY RESEARCH CENTER
Office of Operations R&D

ADAPTIVE CONTROL SOFTWARE

Research that is Essential, Indispensable, and Connected to our Customers.

PURPOSE

As part of its role as "leaders for national mobility," the Federal Highway Administration (FHWA) aims to mitigate traffic congestion and help State departments of transportation manage traffic volume to meet the needs of the traveling public. Classical and centralized traffic control systems are becoming obsolete and are unable to meet growing demands. In response, researchers at FHWA's Turner-Fairbank Highway Research Center began a 10-year research effort in 1992 to develop Adaptive Control Software (ACS).

The goal of this effort was to study and apply traffic control systems that operate in real time, adjusting signal timing to accommodate changing traffic patterns. Unlike their predecessors, these adaptive systems are not based on a fixed cycle length; they can adjust the split, offset, cycle lengths, and phase order of the control signal. ACS uses sensors to interpret characteristics of traffic approaching a traffic signal, and using mathematical and predictive algorithms, adapts the signal timings accordingly, optimizing their performance.

DESCRIPTION

Project participants developed five initial prototype algorithms, called control strategies, to address different geometric and traffic conditions. Three of these, identified below, were deemed viable and have been tested in the laboratory and in the field.

OPAC—Virtual Fixed Cycle

The OPAC prototype uses a predictive type of optimization with a rolling horizon. This congestion control strategy, which attempts to maximize throughput, adjusts splits, offsets, and cycle length, but maintains the specified phase order. For uncongested networks, OPAC uses a local level of control at the intersection to determine the phase online, and a network level of control for synchronization, which is provided either by fixed-time plans (obtained offline), or a virtual cycle (determined online). The types of control and levels of local and global influence are flexible. Predictions are based on detectors located approximately 10–15 seconds upstream. After the initial 10–15 seconds, a model predicts traffic patterns.

RHODES

RHODES is a hierarchical control system that uses predictive optimization, allowing intersection and network levels of control. RHODES includes a main controller, a platoon simulator (APRES-NET), a section optimizer (REALBAND), an individual vehicle simulator (PREDICT), and a local optimizer (COP). The detector requirements for RHODES are fairly flexible. At minimum, RHODES requires upstream detectors for each approach to the intersections in the network. RHODES also can use stop-bar detectors to calibrate saturation flow rates and improve traffic queue estimates.

RTACL

RTACL uses a macroscopic simulator to estimate traffic flow and evaluate signal-phasing alternatives. The algorithm is very distributive, and most of the logic for control is at the local level. Each local controller optimizes its own timings based on stopped traffic queues on all links into or out of a particular intersection. The local controller determines signal timings for two cycle lengths (i.e., two red-light phases for each approach). These optimized signal timings include short-term recommendations for current phase length and the next phase, and provide tentative recommendations for future phases and timings. The network model and local controllers at adjacent intersections then use these recommendations to predict traffic flows and signal timings to accommodate progression among the neighboring cluster of intersections.

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PROTOTYPE	STRENGTHS	APPLICABILITY
OPAC (Virtual Fixed Cycle)	• Extension of tested isolated intersection techniques.	• Arteries with widely spaced intersections. • Undersaturated conditions with possible extension to saturated.
RHODES	• Automated setup. • Amenable to lab testing. • Consistent with traffic response objectives.	• Arteries and widely spaced grids. • Undersaturated conditions only.
RTACL	• General applicability. • Based on proven hydrodynamic wave theory.	• Diamond interchanges, grids, and closely spaced intersections. • Saturated and undersaturated conditions.

Table 1. Comparison of Prototype Algorithms

FINDINGS

Results from laboratory simulation testing demonstrated that, compared to optimized signal timing plans, the adaptive control algorithms can decrease travel time and improve traffic volume handling by approximately 3–7 percent, when the algorithms are applied to the specific traffic conditions for which they were developed. These improvements assume normal operating conditions and highly directional flows. Given less favorable conditions, the adaptive control algorithms perform just as well as optimized signal timing plans.

Field tests of OPAC in Reston, VA, RTACL in Chicago, IL, and RHODES in Seattle, WA and Tucson, AZ supported the simulation testing results. Researchers found that the effectiveness of the algorithms was inversely related to the number of constraints (e.g., no phase sequence changes, fixed cycle length, suboptimal intersection spacing, lack of detection) placed on the control strategy. During high directional flows (such as peak traffic hours), OPAC and RHODES improved travel times by approximately 5 percent when compared to optimized signal timing plans. RTACL dramatically improved travel times (12–53 percent) and decreased delay (up to 100 percent) along certain paths within the network, while travel times along other paths were degraded significantly.

RESULTS

Although there are significant costs associated with deploying ACS, these systems are updated continually as they adapt to real time traffic conditions and require less maintenance than optimized signal timing plans.

Depending on the current field configuration, installing the controller, communication, and detection components needed to support ACS will cost between $10,000 and $40,000 per intersection. The cost of maintaining this infrastructure is estimated at $1,000 per intersection per year. These costs must be compared to the expense of retiming traditional signals, at $5,000 per signal every 2 years. In addition, ACS saves users $8 for every reduced vehicle-hour of delay, and $20 for each reduced commercial vehicle-hour of delay.

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