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An Overview of the Usage of Adaptive Signal Control System in the United States of America

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Abstract. The primary objective of this paper is to provide a comprehensive overview of state-of-the-art and state-of-the practice of ATCSs. The review focuses on the following major aspects: (1) commonly deployed ATCSs in the U.S. and other countries; (2) features and functions of different ATCSs; and (3) evaluation studies based on field tests or laboratory simulation. According to the published literature, the majority of system deployments resulted in significantly improved traffic operations compared to traditional time-of-day coordination plans. Besides, based on the number of system deployments, SCOOT has the largest world-wide deployments, while SCATS has the largest U.S. deployments. Considering the costs of the deployment, ACS Lite was the lowest, while SCOOT was the highest.

Introduction

The Adaptive Traffic Control Systems (ATCSs) are the third generation of urban signal control systems after pre-timed and traditionally coordinated signal systems[1]. Unlike closed loop or centralized signal control systems, ATCSs use real-time traffic data to optimize signal timing parameters such as cycle length, splits, and offsets, so as to minimize traffic delays and stops. One significant difference between ATCSs and traditional closed-loop or centralized systems is that ATCSs can proactively respond to real-time traffic flow changes, thus are expected to be more efficient for signal system operations. In order to improve traffic signal system operations for the urban area, different types of ATCSs were summarized and fully compared in this paper to determine how ATCSs might be applied in urbanized areas as a cost effective means of reducing traffic congestion and air pollution.

ATCSs' Overview

The concept of adaptive signal control was first conceived by Miller in 1963, when he proposed a traffic signal control strategy that was based on an online traffic model. The model calculated what was called time wins and losses, and combined these criteria for different stages in a performance index to be optimized[2]. However, the first real-world application did not occur until the early 1970's when Sydney Coordinated Adaptive Traffic System (SCATS) was first implemented in Australia[3]. A few years later SCOOT was developed and implemented by the UK Transport Research Laboratory [4,5].

After wide applications of SCOOT and SCATS in different countries, the FHWA sponsored several ATCSs developments, including OPAC [6], RHODES [7] and ACS Lite [8]. Nevertheless, the number of ATCS deployments in the U.S. is still limited. Currently, there are only about 30 system deployments in the U.S., and more than 95% of the coordinated traffic signals are still being operated under the traditional closed-loop or centralized computer control system[9]. Table.1 contains a summary of all the system deployments. Table.1 is based on the information included in the database maintained by the Research and Innovative Technology Administration (RITA) of the U.S. DOT[9]. This database was based on surveys conducted between 2004 and 2007 of all the major metropolitan areas. As noted in the table, although the number of signals under ATCS control is listed, no specific type of ATCSs is given. In some cases, very few signals (e.g., one or two) are listed under ATCS control. It is suspected that some agencies may have interpreted "adaptive" systems differently. To further confirm the accuracy of the data presented in Table.1, the research team contacted both FHWA personnel and ATCS vendors about the latest information of ATCS deployments. Fig.1 shows the geographical distribution of the ATCS deployments in the U.S.

Table.1 Summary of ATCS Deployments in the U.S.

Metropolitan Area	**State**	**Signalized Intersections**		
		With ATCSs	**Total Operated**	**Percent**
Albany, Schenectady, Troy	NY	71	436	16%
Atlanta	GA	73	6099	1%
Chicago, Gary, Lake County	IL	1158	8632	13%
Dayton, Springfield	OH	4	639	1%
Denver, Boulder	CO	23	3085	1%
Detroit, Ann Arbor	MI	701	5109	14%
Grand Rapids	MI	2	760	<0.2%
Greensboro, Winston-Salem, High Point	NC	28	959	3%
Hampton Roads	VA	29	1432	2%
Houston, Galveston, Brazoria	TX	36	3877	1%
Jackson	MS	1	321	<0.4%
Little Rock, North Little Rock	AR	4	377	1%
Los Angeles, Anaheim, Riverside	CA	174	6137	3%
Milwaukee, Racine	WI	3	1508	<0.2%
Minneapolis, St. Paul	MN	6	3002	<0.2%
Modesto	CA	2	336	1%
New York, Northern New Jersey	NY	985	18349	5%
Orlando	FL	44	1527	3%
Philadelphia, Wilmington, Trenton	PA	178	4443	4%
Providence, Pawtucket, Fall River	RI	1	361	<0.2%
Raleigh-Durham	NC	7	906	1%
Richmond, Petersburg	VA	370	1088	34%
San Diego	CA	11	2885	<0.4%
San Francisco, Oakland, San Jose	CA	13	2885	<0.4%
Tampa, St. Petersburg, Clearwater	FL	76	2040	4%
Tucson	AZ	13	570	2%
Tulsa	OK	1	80	1%
Washington	DC	869	2457	35%
Total		**4883**	**80300**	**6%**

*Data Source: RITA of US DOT

Fig.1 Geographical Distribution of the ATCSs Deployments in the U.S.

A national survey conducted in 2002 revealed the following main reasons for the limited number of deployments in the U.S. [10,11]:

•Concerns on shortage of personnel with the required expertise; additional training requirements due to the complexity of the system; the need for management that fully supports the project; the need for a full commitment and willingness of operational and maintenance personnel to try new technologies;

•Concerns for actual system performance and benefits; uncertainties regarding system's performance for site specific conditions; preference for arterial progression rather than delay-based coordination; and

•Concerns for the deployment and maintenance costs.

Based on the limited number of deployments in the U.S., field tests and evaluation studies revealed mixed results. The majority of the studies indicated improvements over the traditional systems. For example, the City of Gresham, Oregon deployed SCATS in 2005 on a major 5-lane arterial of 11 traffic signals. A field evaluation showed that SCATS improved travel time and stops for both corridor and side streets over the optimized time-of-day timing plans[12]. However, a study on the deployment of SCATS on a 15-signal arterial in Cobb County, Georgia showed no improvement in either customer satisfaction or actual field travel time studies[13]. One of the conclusions from this study showed that adaptive traffic control systems cannot further improve system performance if the signals have already been operating under the optimized signal timing plans. It should be realized that adaptive signal-control systems are not the ultimate solutions to signal coordination. Their effectiveness heavily relies on traffic and network conditions. Nevertheless, such applicable conditions have not been fully studied, which create dilemmas for transportation agencies to determine where and when adaptive signal systems should be deployed. This proposed research specifically addresses such issues and agency needs.

Features of Adaptive Traffic Control Systems

This section of the literature review contains a detailed review of the functions and features of five major ATCSs. These systems include SCOOT, SCATS, OPAC, RHODES, and ACS Lite. It is important to note that, in some literature, OPAC is also called MIST, which stands for Management Information System for Transportation. In fact, OPAC is a core part of MIST which was developed by Telvent Farradyne. Table.2 is a summary of these systems with brief descriptions of their development dates and main functions and features.

Table.2 Summary of Commercial Adaptive Traffic Control Systems

System	Year and Place Developed	Features and Methodologies	Number of Deployments
SCOOT	1970 / UK	Optimizes Splits, Cycle and Offsets; real-time optimization of signal timing	More than 200 locations worldwide; around 10 locations in the U.S.
SCATS	1970 / Australia	Optimizes Splits, Cycle and Offsets; selects from a library of stored signal timing plans	More than 50 locations worldwide; more than 10 locations in the U.S.
OPAC	1990 / USA	The network is divided into independent sub-networks	4 locations in the U.S.
RHODES	1990 / USA	Mainly for diamond interchange locations	4 locations in the U.S.
ACS Lite	1990-2006 / USA	Operates with predetermined coordinated timing plans; automatically adjust splits and offsets accordingly	4 locations in the U.S.

SCOOT

SCOOT is perhaps the most widely-used adaptive traffic control system with over 200 implementations throughout the world[2]. The SCOOT system divides a network into “regions”, each containing a number of “nodes” (signalized intersections and pedestrian crossings which run at the same cycle time to allow coordination). Nodes may be “double cycled” (i.e. operate at half of the system cycle length) at pedestrian crossings of under-saturated intersections. Regional boundaries are located at long links where coordination may not be feasible[5]. The performance of SCOOT significantly relies on traffic flow data obtained from the detectors. The system requires a large number of detectors located at pre-determined locations on every link. The location of detectors is critical, typically placed at the upstream end of the approach link.

SCOOT has three optimization procedures: the Split Optimizer, the Offset Optimizer, and the Cycle Time Optimizer[5]. The algorithm predicts vehicle delays and stops on each link, and calculates the system’s performance index based on these measures. From the overall performance of the network, SCOOT incrementally changes the pre-determined signal timing plans. Before making changes to the phase splits, the Split Optimizer evaluates the current red and green splits to determine whether the splits should be extended, shortened or remain the same. The Split Optimizer works in increments of one to four seconds.

With the above described optimizers, SCOOT can actually change signal timing plans according to traffic flow fluctuations in different time periods. It can also follow daily traffic flow trends over time and maintain a constant coordination of the signal network[5].

SCATS

SCATS is probably the most advanced and widely used adaptive traffic control system. SCATS was developed by the Roads and Traffic Authority of New South Wales, Australia[15,16]. As a real-time adaptive signal control system, SCATS can adjust signal timing in response to fluctuations in traffic flow and system capacity.

SCATS is designed with three control levels: central, regional and local. For each intersection, SCATS distributes computations between a regional computer at the traffic operations center and the field controller. The central level is operated by the central computer, which communicates with other levels in the hierarchy, primarily for monitoring purposes.

SCATS combines adaptive traffic signal control with conventional control strategies to provide users with a system that can meet various operational needs. Control strategies include: adaptive operation, time of day and day of week coordination, and isolated signal operation. With real-time reporting tools, the system allows traffic engineers to monitor system operations. Continuous intersection monitoring quickly alerts operators of any unusual conditions or equipment failures.

OPAC

OPAC is a distributed control strategy featured by a dynamic optimization algorithm that calculates signal timings to minimize total intersection delays and stops. OPAC was developed at the University of Massachusetts at Lowell under the sponsorship of the U.S. Department of Transportation in the early 80s [6,17].

OPAC distinguishes itself from traditional cycle-split signal control strategies by dropping the concept of cycle[6]. In OPAC, the signal control algorithm consists of a sequence of switching decisions made at fixed time intervals. A decision is made at each decision point on whether to extend or terminate a current phase. Dynamic programming techniques are used to calculate optimal solutions.

The latest version of OPAC is RT-TRACS, which is the network version of OPAC. This generation of the OPAC system has the following features[18]:

- Full intersection simulation with platoon identification and modeling algorithm.
- Split optimization for up to eight phases in a dual-ring configuration.
- Configurable performance functions of total intersection delay or stops, or both.
- 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.

RHODES

RHODES, which was developed by the University of Arizona in 1990[7], is a real-time traffic adaptive control system with a hierarchical structure. RHODES can take input from different types of detectors and, based on what future traffic conditions are predicted, generate optimized signal control plans.

Three major system features were noted by the development team that makes RHODES a viable and effective adaptive signal control system[7]. First, recent new technologies and methods are well adopted in RHODES to make sure the system has high performance in transferring, processing, predicting traffic data and signal control. Second, RHODES takes into consideration the stochastic nature of traffic flow variations. Third, explicit prediction of individual vehicle arrivals, platoon arrivals and traffic flow rates are fully considered in RHODES[19].

ACS Lite

In the mid-1990s, a collection of prototype adaptive control systems (ACS) was developed by FHWA. ACS Lite, a reduced-scale version of the ACS, was developed by FHWA in partnership with Siemens ITS, the University of Arizona and Purdue University[20,21]. The system offers small and medium-sized communities a low-cost traffic control system that operates in real time, adjusts signal timing to accommodate changing traffic patterns, and eases traffic congestion. ACS Lite can be used with new signals or to retrofit existing traffic signals[22]. It is designed for providing cycle-by-cycle control to closed-loop systems, which represents 90% of the traffic signal systems in the United States.

The effectiveness of two offset settings at upstream and downstream intersections is measured or quantified by calculating the progressed flow or captured flow. This performance measure is a surrogate for vehicle stops and delay, which cannot be directly measured in the field from point detectors. Specifically, the captured or progressed vehicular flow is the amount of flow (in units of vehicle-seconds of occupancy) arriving at the stop line at a given point in the cycle multiplied by the percent of time the progression phase is green at that time during the cycle. The algorithm evaluates different offsets by calculating the captured flow on each approach and selecting the offset that maximizes the total amount of captured flow[23].

The ACS Lite has been field demonstrated in Gahanna, Ohio; Houston, Texas; and Bradenton, Florida. The latest field test is planned for El Cajon, California. All of the test sites showed improvement in traffic flow[21]. The widely accepted benefits of using ACS Lite are as follows:

- Low cost.
- Compatible with closed loop systems.
- Operates in real time.
- Easily configured and calibrated, does not require periodical calibration.
- Proven the ability to ease traffic congestion.

Comparison of System Features

Based on the above descriptions of the major ATCSs, comparisons are made among system functions and features, as shown in Table.3.

Table.3 Main Features of Various ATCSs

ATCSs	SCOOT	SCATS	OPAC	RHODES	ACS Lite
Goal	Minimize Performance Index	Minimize Delay and Stops or Maximize Throughput	Minimize Stops and Delays	Minimize Cumulative Delay	Maximize Total Amount of Captured Flow
Detector Layout	Upstream[1]	Stop bar	Both[4]	Both[4]	Both
Hierarchical Organization	Central	Central Regional Local	Synchronization Coordination LocalBoth	Network Loading Network Control	Intersection Regional Local
Arrival Prediction	√	×	√	√	×
Queue Estimation	√	×	√	√	×
Split Optimization	√[2]	√	√	√	√
Offset Optimization	√	√	Optional	√	√
Cycle Optimization	√[3]	√	Optional	√	×
Phase Sequence Optimization	N.A.	×	×	N.A.	N.A.
Saturated Condition	Poor	Good	N.A.	Poor	N.A.

[1] Detectors deployed at least 300 ft upstream from stop bar.
[2] One third of total split is affected by optimization.
[3] Constraint by sub-area, not affected by congestion.
[4]Upstream detectors deployed at 400-600 ft from stop bar.
[5] Upstream detectors suggested at 325 ft from stop bar.

Benefit and Cost Comparison

The Table.4 shows that ACS Lite has the minimal cost among all the systems and it requires less maintenance; however, there are some major limitations of the current software version. One limitation is that it does not provide cycle optimization, but only selects from a set of pre-defined time-of-day plans. Another limitation is that it requires upstream detectors on coordinated approaches for offset optimization. Other systems are much more expensive and need skilled staff to operate and maintain the systems. SCOOT, OPAC, and RHODES rely heavily on presence of upstream detectors for making signal timing adjustments; however, SCATS only uses stop-bar detectors.

Table.4 Benefit and Cost Comparison

ATCSs	Benefit (Percent Change in)			Initial Capital Cost (Per Intersection)
	Travel Time	Delays	Stops	
SCOOT	-29% to -5%	-28% to -2%	-32% to -17%	$30,000 to $60,000
SCATS	-20% to 0%	-19% to +3%	-24% to +5%	$20,000 to $30,000
OPAC	-26% to +10%	-	-55% to 0%	$20,000 to $50,000
RHODES	-7% to +4%	-19% to -2%	-	$30,000 to $50,000
ACS Lite	-12% to +7%	-38% to +2%	-35% to -28%	$6,000 to $10,000

* Data Source: Lecture Slide[24]
Note: "-" means reduction; "+" means increase.

Conclusions

This overview of adaptive system control system provides detailed reviews of several adaptive traffic control systems that have been deployed both in the U.S. The system features, number of deployments, and system performances based on field tests are documented. Major findings from this review are summarized below:

- Compared to other countries, the number of adaptive system deployments in the U.S. is relatively small, with only about 4% of the total signalized intersections under adaptive control.
- There are various factors that have affected the low number of adaptive system deployments. These factors include: (1) concerns for the shortage of personnel with the required expertise; (2) concerns for actual system performance and benefits; (3) concerns for the initial and maintenance costs.
- According to the published literature, the majority of system deployments resulted in significantly improved traffic operations compared to traditional time-of-day coordination plans. The improvements are based on reduced stops, delays, and fuel consumption. Only one published document was found to report unsuccessful adaptive system implementations.
- Regarding number of system deployments, SCOOT has the largest world-wide deployments, while SCATS has the largest U.S. deployments. The number of deployments for OPAC and RHODES is limited to very few locations. Although ACS Lite also has a small number of deployments due to its short history, the number of deployments is expected to grow due to its low cost and compatibility with existing closed-loop systems.
- Regarding deployment costs, ACS Lite was the lowest, while SCOOT was the highest. The actual costs will vary significantly depending on the level of detection needed. The high cost for SCOOT is probably due to the large number of detectors required.

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