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A REVIEW ON ADAPTIVE TRAFFIC CONTROLS SYSTEMS

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Abstract: Adaptive traffic control systems continuously monitor traffic conditions on urban roads and adjust traffic signal timings to accommodate variation in traffic volume and minimize stops and delays. This paper describes currently practical adaptive control systems which have been used worldwide, which include Adaptive Control System-Lite (ACS-Lite), Optimization Policies for Adaptive Control (OPAC), Real-Time Hierarchical Optimized Distributed and Effective System (RHODES), Sydney Coordinated Adaptive Traffic System (SCATS) and Split Cycle Offset Optimization (SCOOT) and many. The comparisons of the benefits from past experiences will help the traffic engineers and decision makers to select the optimized adaptive control system based on research objectives.
Keywords: Adaptive Traffic Control Systems, Optimization, Signal, Traffic

I. INTRODUCTION

Traffic congestion in urban road networks is critical problem. Improper traffic signal timing contributes to traffic congestion and delay. Conventional signal systems use pre-programmed, daily signal timing schedules. Inefficiencies in traffic signal timing occurs from poor allocation of green time, inability to respond quickly to real-time conditions, and non coordination between adjacent intersections. Adaptive signal control technology adjusts the timing of red, yellow and green lights to accommodate changing traffic patterns and ease traffic congestion. The design of adaptive signal systems is generally recognized that traffic signal improvements offer high benefits for reducing congestion and increasing the capacity of existing road networks. With respect to the control of traffic signal networks, most practical success has been achieved using more centralized approaches that adjust the three fundamental parameters, cycle length, phase split, and offset, for traffic lights. Due to the rather strong restriction imposed on parametric adjustments, these systems are designed to effect changes to traffic signal timings on the order of minutes based on average flow predictions, which limits how effectively a system can respond to real time conditions. Benefits of adaptive traffic control systems are,

- Continuously distribute green light time equitably for all traffic movements
- Improve travel time reliability by progressively moving vehicles through green lights
- Reduce congestion by creating smoother flow
- Prolong the effectiveness of traffic signal timing
- Adaptive traffic control systems are eco – friendly clean technologies

II. ADAPTIVE TRAFFIC CONTROL SYSTEMS

2.1 TYPES OF ACTUATED CONTROL

2.1.1 Semi-Actuated Control

This type of controller is used at intersections where a major street having relatively uniform flow is crossed by a minor street with low volumes. Detectors are placed only on the minor street. The green is on the major street at all times unless a *call* on the side street is noted. The number and duration of side-street green is limited by the signal timing and can be restricted to times that do not interfere with progressive signal-timing patterns along the major street.

2.1.2 Full-Actuated Control

This type of controller is used at the intersections of streets or roads with relatively equal volumes, but where the traffic distribution is varying. In full actuated operation, all lanes of all approaches are monitored by detectors. The phase sequence, green allocations, and cycle length are all subjected to variation. This form of control is effective for both two-phase and multi-phase operations and can accommodate optional phases.

2.1.3 Volume-Density Control

Volume-density control is basically the same as full actuated control with additional demand-responsive features. It is designed for intersections of major traffic flows having considerable unpredictable fluctuations.

2.2 TYPES OF ADAPTIVE TRAFFIC CONTROL SYSTEMS

2.1.1 Split Cycle Offset Optimization Technique (SCOOT)

It is an adaptive system that responds automatically to fluctuations in traffic flow through the use of on-street detectors embedded in the road. SCOOT has proven to be a world leader in Urban Traffic Control that typically reduces traffic delay by an average of 20% in urban areas. SCOOT not only reduces delay and congestion but also contains other traffic management facilities such as bus priority, traffic gating, incident detection, on-line saturation occupancy measurement and vehicle emissions estimates. SCOOT is also having different versions to solve issues related to traffic such as Journey Time Reliability (JTR), controllable priority to pedestrians at stand alone pedestrian crossings so as to reduce their waiting times.

The operation of the SCOOT model [1] is summarized in figure 1. SCOOT obtains information on traffic flows from detectors. As an adaptive system, SCOOT depends on good traffic data so that it can respond to changes in flow. Detectors are normally required on every link. Their location is important and they are usually positioned at the upstream end of the approach link. When vehicles pass the detector, SCOOT receives the information and converts the data into its internal units and uses them to construct "Cyclic flow profiles" for each link. The sample profile shown in the diagram is colour coded green and red according to the state of the traffic signals when the vehicles will arrive at the stop line at normal cruise speed. Vehicles are modeled down the link at cruise speed and join the back of the queue. During the green, vehicles discharge from the stop line at the validated saturation flow rate.

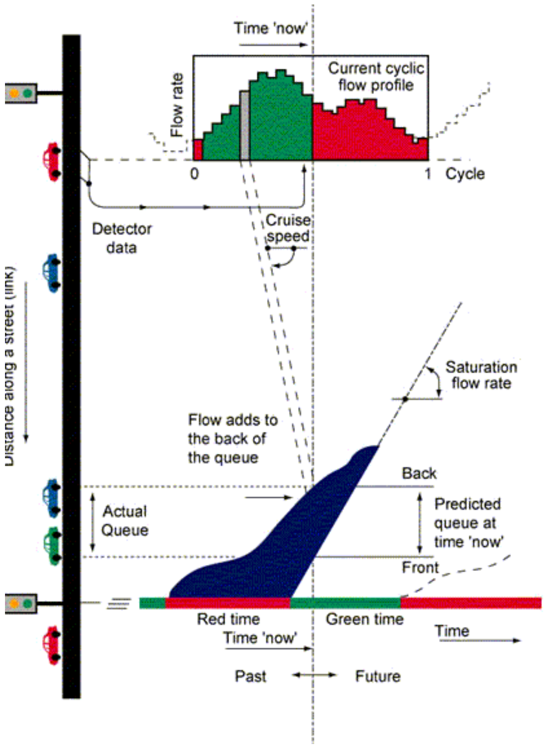

Figure 1 Operational Diagram of SCOOT model

The data from the model is then used by SCOOT in three optimizers which are continuously adapting three key traffic control parameters - the amount of green for each approach (Split), the time between adjacent signals (Offset) and the time allowed for all approaches to a signaled intersection (Cycle time). These three optimizers are used to continuously adapt these parameters for all intersections in the SCOOT controlled area, minimizing wasted green time at intersections and reducing stops and delays by synchronizing adjacent sets of signals. This means that signal timings evolve as the traffic situation changes without any of the harmful disruption caused by changing fixed time plans on more traditional urban traffic control systems. Early results showed that SCOOT achieved an average saving in delay of about 12% when compared with fixed time plans.

2.2.2 ACS Lite

ACS Lite is designed to provide adaptive technologies to arterial applications. Where other systems such as SCOOT adaptive control are applicable only for complicated grid networks, ACS Lite calculates slight adjustments to timing patterns to optimize traffic through arterial flows. ACS Lite is on-street master adaptive control software designed to adapt the splits and offsets of signal control patterns in a closed-loop system, with changes to cycle time handled on a time-of-day schedule like traditional traffic control systems. At each optimization step, which occurs about every 10 minutes, the system changes the splits and offsets a small amount to accommodate changes in traffic flows. During each cycle, the local controller software manages the duration of each split using gap-out and coordination logic, as designed by the traffic engineer [2].If communication is interrupted, the local controller still maintains full operation of the intersection. Currently, each ACS Lite installation can manage up to 16 intersections in a loop. Initial field testing of ACS Lite with Siemens control equipment in Houston, TX has shown 5-25% improvement in arterial travel times, significant reduction in stops, and 5%-50% improvements in delays at side streets and left turns. The ACS Lite approach to adaptive control has been designed to provide a significant amount of benefit for a minimum amount of agency investment in additional infrastructure, training, and maintenance by using stop bar detection and advanced loops commonly used for intersection control.

2.2.3 BALANCE

BALANCE is the traffic-adaptive network control by GEVAS software. Network control searches for the best possible signal control in an entire traffic network and for all road users. This aims at balancing optimal green waves, less fuel consumption and less air pollution. Effective light signal control means that a whole road network is used with optimal capacity, during quiet times as well as in peak times with competing traffic demands. If the existing traffic potential is used in such a good way, the negative aspects of stop-and-go will decrease resulting in less waiting times at stop lights, easy traffic flow, less fuel consumption. BALANCE allows flexible reactions on changing amounts of traffic and a comprehensive view on the traffic situation over the whole network. The facilities for local control and public transport prioritization remain fully serviceable. Projects in Hamburg, Ingolstadt and other cities with a total of more than 100 light signals have shown that BALANCE improves the traffic flow significantly. BALANCE runs every 5 minutes and calculates optimized signal plans for the following 5 minutes period. BALANCE is an open system and thus not bound to equipment and detectors by particular manufacturers. The mathematical algorithms in BALANCE search a complex solution space in a very efficient way. For optimization, Genetic Algorithms are used instead of other methods. Therefore, BALANCE is very stable and easy to calibrate.

2.2.4 InSync ATCS

The InSync adaptive traffic control system, developed by Rhythm Engineering is a plug-and-play system that works with existing traffic control cabinets and controllers. Its two main hardware components are IP video cameras and a processor, sometimes referred to as "the eyes" and "the brain" of the system, respectively. Mounted video cameras determine the number of vehicles and delay. Local Optimization InSync uses integrated digital sensors to count the exact number of cars demanding service at an intersection and the delay experienced. Approaches are given phasing priority based on this queue and delay data. InSync's dynamic phasing and dynamic green splits enable the traffic signals to use green time efficiently. Global Optimization InSync creates progression along an entire corridor by using "green tunnels." Platoons of vehicles gather and are then released through the corridor. By communicating with each other, the signals anticipate the green tunnel's arrival so vehicles pass through without slowing down or stopping. The green tunnels' duration and frequency can vary to best support traffic conditions. Between green tunnels, the local optimization serves the side streets and left turns.

2.2.5 SCATS Ramp Metering System

SCATS Ramp Metering System (SRMS) is a SCATS subsystem and controls traffic signals at the entries of motorways and integrates with SCATS intersection control for promoting integrated real-time management of the traffic corridor as a whole. The objective of SRMS, based on current traffic conditions, is to efficiently determine the metering flow rates of the operating ramp metering signals. It will also monitor which actions shall be taken to signalized intersections of the corridor to promote network-wide benefits.

SRMS achieves these objectives by implementing a collection of pre-configured adaptive intelligent strategies either automatically or manually. In manual mode, the SRMS operator can create new or manipulate existing rules in order to adjust the ramp metering system for effective operation during any planned or unplanned events. SRMS is a distributed control system that operates on a central control server and road-side traffic controllers. The central control server is a component of SCATS and inherently provides integrated motorway and arterial real-time management. Metering rates are determined by the local traffic signal controller or by the central control server in two ways such as adaptive operation or time-of-day-based operation. SCATS can be simulated in-the-loop (SCATSIM) using third party traffic simulation tools [3]. The adaptive operation optimizes mainline traffic state by using real-time data from vehicle detector stations installed at several mainline locations, ramps and optionally at arterial roads. The adaptive operation determines control actions at 10 seconds

2.2.6 LA ATCS

The Los Angeles Adaptive Traffic Control System (LA ATCS) is a personal computer based traffic signal control program which provides fully automated traffic responsive signal control based on prevailing real-time traffic conditions. ATCS automatically adjusts all three critical components of traffic signal timing (cycle, offset, and phase split) in response to current traffic demands. Any long-term traffic pattern changes and short-term variations of traffic conditions are automatically accommodated by ATCS. The results are fewer stops and less delay for motorists, along with improved traffic signal coordination throughout the traffic network. ATCS was fully developed by City of Los Angeles Transportation Engineers with over 50 years cumulative traffic operations experience. ATCS currently manages traffic in over 3000 intersections in the City of Los Angeles.

2.2.7 MOTION

MOTION means Method for the Optimization of Traffic Signals In On-line controlled Networks. It is a new signal control method for urban road networks in central systems. The MOTlON system consists of a Workstation with the network control method and Controllers with detection equipment and local control methods. Motion MX, developed by Siemens uses a newly developed method for assessing traffic parameters, modeling traffic flows and optimizing the control routines for the connected traffic lights. This makes it the only adaptive network control system that is truly able to calculate optimally coordinated green phases for both travel directions across several signaled intersections. With higher versions of Sitraffic Motion MX we can even go a step further and select appropriate signal plans on the basis of traffic models. To this purpose, different optimization parameters such as minimum waiting times, maximum capacity and optimum coordination can be automatically balanced against each other during ongoing operation.

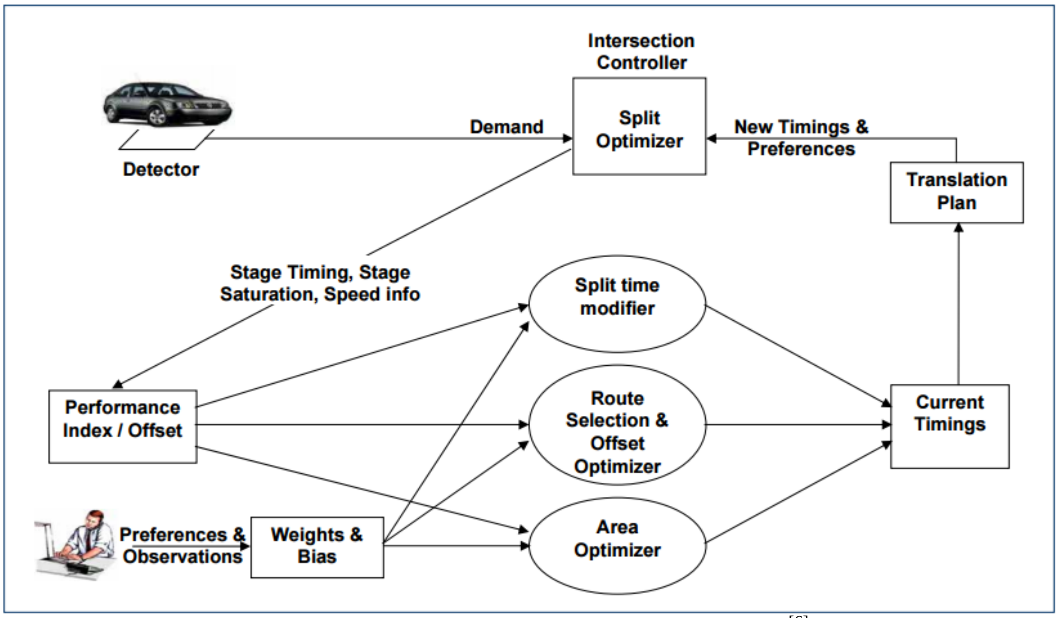

Figure 2 Operational Diagram of CoSiCoSt ATCS [6]

2.2.8 OPAC

Optimized Policies for Adaptive Control (OPAC) is a distributed real-time traffic signal control system which continuously adapts signal timings to minimize a performance function of total intersection delay and stops over a pre-specified horizon. It can operate as an independent smart controller, or as part of a coordinated system. The basic principle of its design is that it must provide better performance than off-line methods and it must be truly demand-responsive. The main aim is that it must not be restricted to arbitrary control periods, but capable of frequent or continuous updating of plans. OPAC model development includes the dynamic programming optimization, search procedure, first use of rolling horizon approach and real-time implementation.

2.2.9 RHODES

RHODES is Real-time Hierarchical Optimizing Distributed Effective System, developed by a research team at the University of Arizona. It uses three-level hierarchy for characterizing and managing traffic. It requires basic data such as lane traffic data, real-time communication to/from processors and PC-level computational capability. RHODES's logical Architecture has the highest level as a dynamic network loading model that captures the slow-varying characteristics, which pertain to the network geometry and the typical route selection of travelers. Then based on the traffic load on each particular link, RHODES allocates green time for each demand pattern and each phase. These decisions are made at the middle level of the hierarchy, referred as Network flow control. If given the approximate green times, the intersection control at the third level selects the appropriate phase change based on observed and predicted arrivals of individual vehicles at each intersection.

2.2.10 CoSiCoSt

In CoSiCoSt, the split optimization is a two level strategy. The main one is that the Central Control (CC) suggests the stage timings to the intersection controller based on the demand trend analysis. This function is handled by the Split time modifier. Also the traffic signal controller is given further autonomy to modify the split time online (Online Split Optimizer), within the constraint of common cycle time, by preempting stages of low demand and provide early start for the succeeding stage. Sensor loops are provided for each approach at the stop-line. Wherever independent control is required for turning traffic, exit loops are provided. During red signal the detector will register a demand for a right of way. Towards the end of the initial green (mandatory minimum green), presence of the vehicle at the stop-line is verified by the traffic signal controller to decide for configurable extension or termination of the stage. For a presence, the green is extended for a programmable period. CoSiCoSt with its Online Split Optimizer module at the intersection controller efficiently manages this situation to reduce the green time wastage. Routes that have maximum volume of traffic at a given point of time are identified as priority routes by the Central Control (CC). Stages contributing to the priority route are identified as priority stages and intimated the intersection controller by the CC. CoSiCoSt is a traffic coordination system as shown in fig 2. It tries to identify arteries with maximum flow rate and provide coordinated traffic in these corridors. Coordination between the stages at different intersections is achieved by computing the ground speed of the platoon and displacing the stages with a definite offset. The task of network control is divided into local optimization by the intersection controller and network optimization by the central computer.

III. COMPARISON OF ADAPTIVE TRAFFIC CONTROL SYSTEMS

Adaptive traffic control systems are one of the solutions which are exactly opposite to fixed-time plans. Four different adaptive traffic control systems will be discussed. Each of them has unique characteristics that make it worthy to compare. The general architecture of these systems is based on a similar concept, but there is a great number of general and detailed differences that makes them interesting to compare. By making a deep comparison between these systems, which is one of the outputs of this research, governments and the authorities in charge can have an appropriate reference to look for their benefits and choose an adaptive traffic control system to apply to their networks.

Table 1 Operational Characteristics of various ATCS [6]

ATCS	Detection	Action	Time Frame	Model	Timings
ATC Lite	SL,MB,US	P & R	5-10 Mins	No	S.O
Balance	NSL	P & R	5 Mins	Yes	S.Cl.O.PS
InSync	NSL	P & R	Phase/Cycle/15 mins	Yes	S.Cl.O.PS
LA ATCS	SL,US	P & R	Cycle	Yes	S.Cl.O
MOTION	NSL	P & R	5-15 Mins	Yes	S.Cl.O.PS
OPAC	MB,SL	P	Phase/Cycle/5 mins	Yes	S.Cl.O
RHODES	MB,SL	P	Sec-by-Sec	Yes	S
SCATS	Sl,NSL,MB	R	Cycle	No	S.Cl.O
SCOOT	US,SL	P & R	Cycle / 5 Mins	Yes	S.Cl.O.PS
UTOPIA	US,SL	P	3Sec / 5 Mins	Yes	S.PS
CoSiCoSt	SL,NSL	R	Cycle	No	S.Cl.O

Most of the currently operational ATCS are Model based. Model Based ATCS use macroscopic, mesoscopic, or microscopic models to estimate the current state of traffic. The estimated value is further used as an input to adjust signal timings. Non-model based works on functional relationship between parameters that describe change of traffic conditions and uses feedback of the traffic measured during the previous interval.

IV. CONCLUSION

ATCS helps in improving the traffic conditions by Increasing the lane carrying capacity and travel speed. It aids in reducing delay, stops, queue, fuel consumption, emissions and drop in accident rate. Hence through ATCS Better Traffic Management is possible by introducing Green Wave Routes, Diversions and Incidents Detection. The reality is that some of ATCS perform some kind of optimization, which is usually constrained by its domain to conduct the optimization process. Optimizations use heuristic techniques, whereas others use extensive search techniques, to find solutions. Other ACTS do not formally optimize but they adjust signal timings by using some heuristic methods and common traffic engineering concepts. Some of the analytical models are constrained by inadequate input data such as low level of lane discipline, high mix of traffic, higher percentage of two wheeler populations and poor junction geometry. Constrains also exist in forms of lack of expertise, power and network connectivity interruptions.

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