A SURVEY OF EXPERIENCES WITH ADAPTIVE TRAFFIC CONTROL SYSTEMS IN NORTH AMERICA

Miloš N. Mladenović, MSc
Virginia Tech, milosm@vt.edu

Montasir M. Abbas, PhD
Virginia Tech, abbas@vt.edu

Review paper

Abstract: *Adaptive Traffic Control Systems (ATCS) have multitude of features, with a lack of transparency in their description, and a lack of comprehensive information on agencies' experiences in operation. These are the reasons transportation agencies face a decision-making problem when selecting a specific ATCS. The focus of this paper is on surveying previous ATCS installations across United States and Canada, providing information on their hardware/software features, and experiences from operation.*

Keywords: *SCOOT, SCATS, RHODES, OPAC, ACS Lite*

ISKUSTVA SA ADAPTIVNIM SISTEMIMA UPRAVLJANJA SVETLOSNIM SIGNALIMA U SEVERNOJ AMERICI

Miloš N. Mladenović, MSc
Virginia Tech, milosm@vt.edu

Montasir M. Abbas, PhD
Virginia Tech, abbas@vt.edu

Pregledni rad

Rezime: *Adaptivni sistemi upravljanja svetlosnim signalima (ASUSS), pored velikog broj parametara, odlikuju se nedostatkom transparentnosti u njihovom opisu, i nedostatakom sveobuhvatnih informacija o operativnim iskustvima.Ovo su ključni razlozi zašto saobraćajne organizacije imaju problema prilikom odlučivanja o odabiru određenog ASUSS. Fokus ovog rada je na pregledu dosadašnjih instalacija ASUSS u Sjedinjenim Američkim Državama i Kanadi, predstavljajući informacije o hardverskim i softverskim osobinama, i dosadašnjih operativnih iskustava.*

Ključne reči: *SCOOT, SCATS, RHODES, OPAC, ACS Lite*

1. INTRODUCTION

Adaptive Traffic Control System (ATCS) is a system that continuously makes small adjustments of signal-timing parameters in response to changing traffic demand and patterns. They are primarily intended for implementation on coordinated signalized intersections [1]. Typical ATCS bases on the highly developed control algorithms, traffic model, different detector configuration, and centralized or decentralized architecture. In general, ATCS are excellent in handling undersaturated and unpredictable traffic conditions by dealing with cycle length, split, offset, and phase sequence adjustment [2]. However, ATCS frequently have issues in dealing with some traffic control users (e.g., emergency vehicles, pedestrians, etc.) [3].

Nowadays, ATCS are not just research projects, but are implemented as products with multiple features, developed by different companies [2]. Most of ATCS have significant number of special features. However, due to the market competition, they are delivered as vendor-specific "black box", due to the proprietary modeling and optimization algorithms [4]. This is the main reason why Virginia Department of Transportation (VDOT), just as any other transportation agency faced a decision problem when deciding which ATCS to purchase. In the case this was a single criterion problem, decision making would be intuitive [5]. However, considering multiple features, and lack of details on these features, this became a decision problem with multiple selection criteria.

Considering that the focus of previous research on ATCS was primarily on their optimization or modeling algorithms, in order to provide complete overview of ATCS, the focus of this research was on providing information on the ATCS as an integrated software and hardware systems, and providing lessons learned from practical implementations. This would essentially help VDOT in developing their functional requirements for selecting ATCS. The geographical focus of this paper is on United States and Canada, considering the similarity of traffic signal control practice. As a part of this project, research team conducted a survey and direct interviews with personnel at agencies that are/were using ATCS, throughout the United States and Canada. The survey in this study consisted of 16 questions, identifying information on the system under agency's purview and information on ATCS installation and operation. Interviews with some agencies were conducted after the survey, for obtaining in-depth details on the ATCS operation.

2. SPECIAL FEATURES OF ATCS

2.1. SCOOT

Split Cycle Offset Optimization Technique (SCOOT) is an ATCS originally created in the United Kingdom. SCOOT has a basic structure similar to the TRANSYT method of calculating fixed-time plans [6]. SCOOT makes use of the fully centralized physical architecture as well as a centralized timing algorithm.

SCOOT bases upon cyclic flow profiles that are a measure of the average one-way flow of vehicles past detection points. Cyclic flow profiles are used to estimate the number of vehicles that enter the links in 4-second increments.

In addition, SCOOT has a queue model, assuming steady flow discharge during green. SCOOT has signal optimizers for split, offset and cycle [7]. On start-up, the system will initially start with an offset, cycle, and green split that have been defined in the timetable for that time of day. Once the system has started, SCOOT will immediately start optimizing and moving the offsets, cycles, and green splits towards the minimum for stops and delay.

Basic calibration variables SCOOT uses are saturation occupancy, maximum queue, start-up loss time, main downstream link, and network's default offsets. SCOOT's fine-tuning control variables include split weighting, offset weighting, fixed or biased offsets, congestion offset, gating logic, and on-line saturation occupancy [8]. SCOOT has built in several special features for over-saturated conditions, such as, Congestion importance factors, Congestion offset per link, Variable Node Based Target Saturation, and Gating. SCOOT has Region, Link, Node, and Stage control level. Region level focuses on cycle length optimization, Link level primarily focuses on preventing queue spillback, Node level preforms fine adjustments of cycle length, offset, and split, while Stage level provides boundaries for minimum/maximum stage lengths. Optimizers of split, offset, and cycle can be turned on or off, depending on the needed level of optimization.

SCOOT collects 5 minute, 15 minute, Hourly, Daily and Weekly Total Volumes, Occupancy levels, Queue detection, aggregated peak hour flows, and Histograms of flows. Congestion detection is available directly from the SCOOT Model by means of SCOOT Event Driven Messages. INGRID (Integrated Incident Detection) is a system based on two algorithm types for incident detection. These algorithms operate by detecting sudden changes in detector flow and occupancy, and comparing those values among upstream/downstream detectors or their historical values [9].

SCOOT has built-in transit vehicle priority functions. SCOOT uses green time extension or early green, with or without using minimal green and using the normal stage sequence [10]. The extension can be central or local. The central extension uses the centralized SCOOT processing for priority determination. The local extension gives the extension on the local controller level. Recovery algorithms are different between transit and emergency vehicle prioritization, and can range from "do nothing" scenario to running stages based on their specified degree of saturation [8].

SCOOT's detectors are generally located at the upstream end of the links, and a second set of detector is placed some 50-300 meters before the stop-line. In the United States, SCOOT is operating on Siemens (NEMA/2070), Craig Gardner and Peek, Interval-based (TCT DM200T) and NOVAX (L7N2) controllers. However, SCOOT implementation can be achieved by controller firmware upgrade or the addition of a dedicated communication unit. The user interface for SCOOT software is Windows-based with its own command language. There are options of loading background graphical displays (e.g., .DXF, .NTF2) and integration with simulation sofrware (VISSIM, CORSIM, Paramics and Aimsun) [7]. SCOOT has several options for examining the operation, e.g., link validation or node fine-tuning display. In addition, SCOOT can log traffic events (signal plan implementations, faults, alarms), operator actions (login, data changes, commands), and system events. Finally, SCOOT has a specialized database called ASTRID (Automatic SCOOT Traffic Information Database) that is used to store and analyze data (e.g., link flows, stops, delays, saturation levels, detector occupancy, stage length, etc.).

When running on the PC workstations, the standard SCOOT software is capable of controlling up to 300 intersections. There is the ability to expand the controlled network up to 3000 intersections (using multiple computers for operation), but this number depends on the actual number of intersections running in fixed time and adaptive control. SCOOT allows creation of user accounts, with up to 16 levels of password access. Only the fully privileged user can access any level and make modifications to system and user data. Literature suggest that the average cost for implementation of SCOOT is $49,300 per intersection, with the average number of hours of training for SCOOT being 38 [11]. From the user survey performed in this research, the capital costs for the system (per intersection) are ranged between $16,000 and $70,000. Annual operating and maintenance costs per intersection ranged from $3,500 to $25,000. Additional infrastructure costs are ranged from $3,500 to $12,000 per intersection.

2.2. SCATS

The Sydney Coordinated Adaptive Traffic System (SCATS) was originally developed in Australia but it is also used in the United States [12, 13]. SCATS is two-level hierarchical heuristic feedback system that adjusts signal timing based on the changes in traffic flows during previous cycle(s) [14]. Distribution is on central and tactical level. On the strategic level, regional computers compute cycle length, splits, and offsets. Controllers on the tactical level determine upon the green termination or phase omitting. The point to emphasize here is that SCATS is not model but it is algorithm based, thus behaving as reactive system. Being a partially centralized system, SCATS adjusts signal plans based on traffic conditions at critical intersections.

These critical intersections control coordination within subsystems, and subsystems coordinate with other subsystems as traffic demands fluctuate. Subsystems can include from up to 10 intersections operating on the same cycle length.

SCATS makes incremental adjustment to signal timing based on the vehicle count and gap measurement at stop bar. SCATS calculates degree of saturation (the ratio between demand and discharge flow at stop bar), and consequently adjusts cycle length every cycle (in increments from 6 to 21 seconds) [15]. The cycle length can be set between 20 and 240 seconds. The increments of green time are in the range of 4 to 7 seconds. Split weighting is used for favoring the main intersection approaches, in order to reduce main road stops and give more scope for offsets. In addition, SCATS has a library of internal offset values driven by cycle values (up to four distinct offset plans), with weighting for favoring specific progression directions. Grouping of coordinated intersection is dynamical, based on real-time flows.

The main (adaptive) control mode of operation is Masterlink. Besides Masterlink, SCATS has several additional operating modes. These modes of operation allow SCATS to operate intersections on Time-of-day basis, as isolated, to allow preemption, or various manual modes for control by police. SCATS software is able to display region, subsystem, and intersection data along with time-space diagrams. SCATS has several special control features (e.g., Actions Sets, Variation Routines, Specialized Configurable Controller, etc.). For example, Voting Biases is the ability to allow certain movements a higher priority in cycle length and phase split optimizations. Another example is Booster Voting, which is the ability to allow upstream detectors to vote for cycle length and split time at the bottleneck movement on the downstream intersection. SCATS can implement special control features for bikes and pedestrians. In the case of bicycle traffic, green times can be shortened. In the case of high pedestrian volume, walk recalls and longer green times can be implemented during specific parts of the day.

For recurrent oversaturation, SCATS can prepare operational actions in advance (e.g., set Cycle length to 80 seconds at 8:00 AM). SCATS is also able to recognize unexpected oversaturation and provide a quick response (e.g., trend flags for Cycle length growth). SCATS cannot respond to non-recurrent congestion in the case of queue spillback. The only option in this situation, an alarm is signaled if the detectors are covered by traffic for certain period.

Specially defined priority phases can be called to either clear the queue ahead of the vehicle or to provide a phase extension for priority or preemption. Priority can be defined on the controller level, but if it is defined on the system level it can provide automatic emergency route control. The control decisions depend on the time of day, tidal flow determination based on traffic flows, or on the level of congestion at the intersection approaches.

SCATS relies primarily on stop-bar detection (5m x 2m), with queue or strategic detectors placed sporadically. SCATS can be integrated with McCain and Safetran 170E, Delta 3, Siemens NEMA TS2, or 2070 Econolite, Siemens, Naztec and McCain 2070 controllers. SCATS can be integrated into a 170 controller, with an upgrade to a central processing unit board. Simulation software integrated with SCATS are VISSIM, S-Paramics and AimSun.

SCATS is available on a Windows-based PC platform, with up to 32 regional computers under a central management system. Each regional computer can coordinate up to 250 controllers and there can be up to 64 regions. SCATS uses two types of servers. Regional SCATS server is for traffic control on the large area and communication with maximum 250 controllers. Central SCATS manager is for enabling central access, database entry and settings priorities in different SCATS regions [16]. SCATS software can also provide reports on volume, alerts, alarms, and data recording. From the literature, the average cost for implementation of SCATS is $60,000 per intersection [11]. The average hours of training for SCATS is 60 hours. SCATS has shorter installation and fine-tuning times, along with fewer maintenance hours required, in comparison to other adaptive systems. From the agency survey, capital costs range between $27,000 and $120,000. Operation and maintenance costs are from $1,000 to $27,000.

2.3. RHODES

RHODES is the abbreviation for Real Time Hierarchical Optimized Distributed Effective System. This control software is decentralized (computational power located at intersection) with link-by-link short time prediction of traffic demand [17]. RHODES uses decomposition of traffic network, by modules that individually deal with sub-problems [18].

RHODES focuses on proactive control, through short-term estimation and prediction of individual vehicles, platoons, emergency vehicles, turning probabilities, and queues. This traffic flow prediction model is assuming constant free-flow speeds [19]. The timing plan is not defined with parameters such as cycle time, split, or offset but it is based on the phase duration for any given phase sequence. Dynamic programming is used for the optimization on the intersection level and decision trees are used for the optimization on the network-flow control level. In addition, there are link flow prediction logic, platoon flow prediction logic, and parameter and state estimation logic. Each of these modules relates to a control level with a different perspective on the traffic flow.

At the intersection level, appropriate timing is selected based upon prediction and observation of individual vehicles. At the middle level, RHODES adjusts green times based upon macro characteristics of the traffic flow, taking into consideration platoons and their speeds. On the highest level, dynamic network loading captures characteristics of traffic that change slowly over time. This level determines the prior green times for different demand and phase based upon network geometry, capacities, overall travel demand, travel times, and typical routes used on the network. Each link receives an estimated load in terms of vehicles per hour. For transit priority in RHODES, a weighting technique is implemented using the data on delay and number of passengers for transit vehicles (Automatic Vehicle Location). For the emergency preemption, RHODES assigns a path to an emergency vehicle.

The RHODES architecture is designed around a simple flat database and an executive event controller [18]. The database contains dynamic data (vehicle detector information, past or planned signal states, traffic flow predictions), model parameters (turning percentages, queue discharge rate, average link travel speeds), and static data (e.g., network geometry). The executive event controller schedules control events such as updating surveillance information, setting signal control at a designated intersection, or running network, intersection coordination, or traffic flow prediction algorithms.

Detectors have to be placed on each lane of the approaches, typically 30 to 40 m upstream of the intersection. RHODES is operating on NEMA TS 2 and 2070 controllers (Siemens Next Phase and Econolite ASC/2), although a modular processor for housing the RHODES software has to be installed. Using a larger time horizon, (20 – 40s for the intersection level and 200 – 400s for the network control level) approximately nine intersections might be controlled with one RHODES processor. RHODES is integrated with CORSIM and Q-Paramics. Estimates of the marginal cost for a new RHODES installation range from $30,000 - $65,000.

2.4. OPAC

Optimized Policies for Adaptive Control (OPAC) is a ATCS that is not providing optimization for some predefined time period, but is constantly optimizing the control parameters, without a rigid cycle structure [20]. Control is decentralized, based on the dynamic optimization algorithm that calculates signal timing with respect to minimizing total delay and stops performance function. The algorithm itself uses actual and modeled demand in a combination, trying to optimize phase duration restricted by minimum and maximum green time, offset, and virtual cycle length (if operating in coordinated mode).

The control strategy is defined as a rolling horizon consisting of the series of projection horizons whose usual length is around the average cycle length. The stage, which is considered the projection horizon, consists of *n* intervals and this is the period over which the calculation of phase changes is obtained. For the beginning of the horizon, the optimization is done on the basis of the actual arrival data, and after certain number of intervals, flow data are obtained from the model, taking into consideration the average of the past arrivals. The optimization is done for the whole projection horizon (typically ranging between 50 and 100s, divided in 5-second intervals) [21], but the only changes that are implemented are those in the beginning of the projection horizon, based on the actual data. After that, the new projection horizon starts at the end of the initial part of the previous projection horizon.

The OPAC architecture is formed as a distributed system based on individual controllers. There are three layers in the structure of OPAC. Layer 1 is the local control layer, which directly implements the rolling horizon control logic. Layer 2 is the coordination layer which optimizes the offset of each intersection, once per cycle. Layer 3 calculates Virtual Fixed Cycle (VFC), once every few minutes, as specified by the user. VFC can be calculated separately for groups of intersections, if desired. There is a direct connection between layer 1 and layer 3, because the projection horizon is under VFC constraints. Local cycle reference points are allowed to fluctuate between fixed yield points determined by VFC bounds and offsets. The advantage of introducing VFC is that it allows phases in synchronization to terminate or start earlier for better response to changes in traffic conditions. OPAC uses an additional constraint that no more than three phase changes are allowed during a planning horizon. In split optimization, green time extends or terminates in the steps of 1 or 2 seconds. Phase sequence is initially based on TOD plans.

Among additional features, OPAC includes [20] intersection simulation with platoon identification and modeling algorithm, split optimization for up to eight phases, configurable performance function of total intersection delay or stops (or both), optional cycle length and offset optimization, phase skipping in the absence of demand, etc. OPAC currently does not have any special features for priority or preemption on the system level. Preemption/priority is handled by local controller and will always take priority over OPAC control. Furthermore, OPAC does not have explicit features for pedestrians or oversaturation conditions. Installation in New Jersey indicates that OPAC was effective during oversaturation conditions [22], while the installation in Vancouver had opposite conclusions [23].

OPAC detectors are typically placed 8 to 15 seconds upstream from the intersection (120 – 200 m upstream of stop bar) but there are some field implementations where detectors were placed at stop bars. In addition, left turn count detector should be placed as far as possible. OPAC has proven to work on 170, NEMA TS2 and 2070 controllers. OPAC has interface with CORSIM. Our interviews have not found the cost associated with OPAC installation. The literature suggests that the average cost for implementation of OPAC is estimated to be $68,100 per intersection [11].

2.5. ACS Lite

The recent development of ACS Lite was initiated by the Federal Highway Administration (FHWA). The project received support from several traffic control vendors - Econolite, Eagle, Peek, and McCain. The original idea was to create a system for automatic monitoring and adjusting of traffic signal operational parameters but with smaller investment costs than traditional ATCS. The core idea of ACS Lite is that it is an adaptive closed-loop system, where a supervisory computer monitors and coordinates the signal timing of several signal controllers (typically 8 to 12 local controllers) [24]. One of the main advantages of ACS Lite is that it tries to utilize existing infrastructure (controllers, detectors, twisted-pair communication media, etc.) without any unnecessary additional hardware installation or operational costs [25]. ACS Lite is not designed to optimize traffic signals on the second-by-second basis. The focus of ACS Lite is primarily on arterials, not on networks of intersections.

ACS Lite has built-in split and offset optimization logic [25]. Splits are adjusted based on the degree of saturation for each phase, calculated from traffic volume and occupancy data. Green duration can be increased or decreased between minimum or maximum limit values. Offset adjustments are made in small increments (few seconds), based on the cycle flow profiles obtained from advanced detectors. Incremental adjustments of the split or offset value are done after a certain amount of time (usually 5 to 15 minutes).

In order to update signal plans, ACS Lite utilizes three levels of optimization and control: TOD Tuner, Run-time Refiner, and Transition Management. The TOD Tuner updates timing plans by incorporating measured traffic conditions into the existing database of TOD signal timing plans. The Run-time Refiner changes the parameters of the actual signal plans and determines the best time for transitioning from the current to the next signal plan. The Transition Manager determines transition method in order to balance time spent out of coordination during plan transition, ensuring timely and coordinated transition. ACS Lite does not have any in-built special features for handling priority/preemption or oversaturation conditions [24].

ACS-Lite software consists of several modules: System Manager, Controller Manager, Web Server, Run-Time Refiner, Analysis Engine, and Transition Manager. ACS Lite has several operational modes, in addition to adaptive control mode. For example, in Configuration mode, user can change configuration parameters, and in monitoring mode, ACS Lite allows data polling and management. ACS Lite may be used as a replacement for a field master providing features as lock synchronization and command of patterns according to a time-of-day schedule. On the other hand, ACS Lite can be used along with the master controller in the operation. Furthermore, ACS Lite software may be installed on the server in the traffic management center or in the dedicated processor in the field.

ACS Lite tries to utilize existing detector infrastructure. ACS Lite can use stop bar detectors in each lane (5 to 6 m long for through lanes, and 10 to 15 m long for left turn lanes). However, the length of detector can even be up to 25 m. ACS Lite also uses advanced detectors in separate lanes for measuring platoons (75 to 150 m upstream). ACS Lite performs optimization on a single processor for a specific arterial. This way, lower-cost and older generations of controllers (such as 170) can still be kept in the operation. Therefore, the reduction is not just in the retention of the existing equipment but it is also in the absence of the new operational procedures and training because there is no new equipment [25]. Therefore, ACS Lite is not requiring special hardware and can work on different types of controllers. ACS Lite is licensed with four traffic controller manufacturers: Siemens, Econolite, McCain and Peek. From the agency survey, it was confirmed that ACS Lite is operational on 170 BiTrans 233, Econolite ASC/3 Peek 3000E and Siemens M50 (TS2) and SEPAC controllers. ACS Lite has been integrated with CORSIM and VISSIM. Costs associated with capital investment for ACS Lite are in the range from $38,000 to $62,000 per intersection. Operating, maintenance, and unpredicted costs are usually much smaller, with values of $600 to $15,000 per intersection.

3. ADDITIONAL LESSONS LEARNED FROM FIELD IMPLEMENTATIONS

Some of the survey questions, and follow-up interviews focused on the associated costs, hardware compatibility, and experiences in operation. Considering that information on costs per intersection and compatible controllers were presented in the previous section, here we will present the key points from installation experiences.

Total number of surveyed agencies was 11. Most of the agencies surveyed were city or county jurisdictions.

This is logical, since ATCS are primarily intended for networks of intersections, that can are primarily located in urban environments. SCOOT and SCATS had the greatest number of installations, with OPAC having the smallest. Some systems were installed as early as 1992, and as recently as 2009, showing that ATCS are systems used for over two decades. Systems were installed primarily on arterials, but sometimes these arterials are close or intersecting, with flows interacting among them. Installation size starts from 5 up to 334 (Toronto) and 650 intersections (Oakland County). In addition, agencies' estimated maintenance requirements were as expected or even higher.

The following Table 1 presents the responses of surveyed agencies with their estimation how ATCS perform in certain areas. As it can be observed, ATCS have good performance in general traffic operation, data archiving needs, and real-time performance measures. On the opposite, they are evaluated with lower performance in handling oversaturation, pedestrians and bikes, in the areas of maintenance, and system communications. These results are in accordance with the vision for ATCS, that are usually designed to operate on under-saturated networks with high fluctuations of traffic patterns and do have good supporting databases. ATCS do not usually perform well in oversaturated networks since their algorithms were designed for undersaturated conditions, where traffic patterns are more predictable. In addition, ATCS require high maintenance efforts for detector and communication infrastructure, since they depend on the correct detector data and continuous communication between intersections or control center. The adequate operation depends on detector/communication downtime and efforts required for repair.

Table 1. Performance rating for ATCS features in different areas

Performance rating for features	Excellent	Very good	Good	Poor
General operation	4	4	2	1
Signal preemption	3	2	5	0
Oversaturation	2	2	5	2
Pedestrian/bike	1	3	4	1
Data archiving	4	4	2	0
Maintenance	1	4	4	2
Real time measurement	2	4	3	1
Communication	**2**	**3**	**4**	**2**

In the cases these systems were shut down that was due to underachievement in peak hours, hardware compatibility problems, or the fact that the agency is not able to handle the system properly – due to the lack of technical or human resources. Further problems appeared in serving left-turning vehicles. Agencies have stated that detection requirements are slightly higher than with conventional systems. On the other hand, most of the systems can successfully handle minor detector and communication failure.

ATCSs are rarely implemented on the significant number of intersections (N>100) and implementation is usually on the arterials instead of on the grid networks. Some of the systems have proven to operate better for arterial implementations (ACS Lite and SCATS), while some proved better for grid network implementation (SCOOT). Speed limits on the intersections where ATCS were implemented range from 30 to 45 mph. Average time for system installation is 18 months with average costs of $65,000 per intersection. Installation costs can increase depending if ATCS needs to be integrated with Traffic Management System (TMS) in traffic control center, the complexity of the installation (e.g., pavement repair after installation of new detectors), and requirements for any non-standard feature, (e.g., additional traffic monitoring or communications capabilities). Finally, ATCS require a lot of fine-tuning, training, and ongoing support. In this way, suppliers create a strong relationship of dependence.

Lessons learned point out numerous details that should be taken into consideration when selecting ATCS. Functional requirements for selection should include the assessment of control algorithms in relation to network size and configuration, traffic patterns, special users (e.g., public transportation vehicles, emergency vehicles, pedestrians, etc.), special control options (e.g., oversaturation, incident detection), software features (e.g., data displays, reports, archiving, access levels, user interface), compatibility (e.g., controllers, TMS), etc.

Some of the positive aspects of ATCS are:

- Effective dealing with changes in traffic conditions
- Short system response time to fluctuating demand
- Large traffic data stored
- Efficient dealing with special effects
- Spillback on Interstate reduced

Some of the negative aspects are:

- Black box – difficult to understand operation
- Lot of maintenance and operational effort to maintain system in the optimal performance
- Steep learning curve
- Lack of support
- Initial set-up time and costs

Lessons learned from all the previous and current implementations can be categorized as:

1. The need for better support from local vendor,
2. The need for better planning for in-house support,
3. Good assessment of existing infrastructure (detection and communication), and
4. Detailed pre-installation functional requirements and evaluation is necessary for estimation of costs and benefits.

4. CONCLUSION

Market ATCS are currently delivered by multiple vendors, with a multitude of features, most of them unknown. In addition, ATCS frequently have uncertain benefits, due to the uncertain adaptability to site-specific problems and quality of operation of the system before ATCS [4]. This research has been initiated by the Virginia Department of Transportation, for improving the knowledgebase on features and experiences in operation of ATCS, and consequently aiding decision-making for ATCS selection. Considering that previous research focused primarily on describing control algorithms, or individual evaluation of ATCS, the intention of this research was a provision of comprehensive survey of ATCS software/hardware features and experiences from installations across United States and Canada. The survey and interview of these agencies has provided in-depth insights on ATCS installation, operation, and maintenance. Finally, ATCSs as complex systems, heavily rely upon human factor, thus requiring adequate additional training, and a deeper understating of operation concepts and features, to achieve desired results.

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