Technical Memorandum

Advanced Signal Control Technology

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Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

ACS .... Adaptive Control Software
ASCT .... Adaptive Signal Control Technology
ATM .... Advanced Traffic Management
BI .... Buffer Index
CDOT .... Colorado Department of Transportation
MOE .... Measures of Effectiveness
FDOT .... Florida Department of Transportation
FHWA .... Federal Highway Administration
GUI .... Graphical User Interface
NCHRP .... National Cooperative Highway Research Program
OPAC .... Optimization Policies for Adaptive Control
PTI .... Planning Time Index
RHODES .... Real-Time Hierarchical Optimized Distributed and Effective System
SCOOT .... Split Cycle Offset Optimization Technique
SCATS .... Sidney Coordinated Adaptive Traffic System
TSM&O .... Transportation Systems Management and Operations
TTI .... Travel Time Index

1 Executive Summary

The purpose of this document is to provide an analysis for adaptive signal control technologies (ASCT) to move traffic more efficiently on the Florida Department of Transportation's (FDOT) Strategic Intermodal System while considering the impact to cross streets and interaction with the local agencies. Once complete, the intent of this document is to provide guidance to the districts and local agencies that may be considering ASCT as a solution to improve efficiency and safety on their arterials. In addition to a literature review, guidance and recommendations were developed based on practitioners' experiences provided by agencies located in Florida as well as throughout the United States.

The methodology used to create this report consisted of conducting a comprehensive review of literature of published research, online resources, before-and-after studies, and vender literature. Additional information was obtained by conducting surveys and interviews with agencies around the country that have had experience with ASCT systems. Surveys that asked quantitative and qualitative questions regarding an agency's experience with ASCT systems were sent to 20 agencies throughout the country, with the majority in Florida. After surveys were returned and follow-up phone interviews were conducted with each agency in order to ask follow up questions and obtain clarification. Finally, guidelines for ASCT deployment were developed based on the literature review, the agency experience surveys and interviews, as well as an in-depth analysis of existing ASCT systems in operation.

As with all technology, the state ASCT is continuously changing. Existing ASCT system vendors will improve their algorithms and add new features; new ASCT systems will be developed. It is recommended that an updated study be performed every two years to review new and updated ASCT systems/options. Additionally, it is the intent of this report to provide an unbiased summary; the information in this report is intended to provide guidance and objective information to agencies considering ASCT, help determine if ASCT is appropriate for them, and if so, which system is the best fit for their needs.

2 Introduction

ASCT refers to technologies that capture current traffic demand data and use it to optimize signal operations (timing, phasing, servicing, etc.) in order to optimize traffic flow in coordinated traffic signal systems. Adaptive signal control systems emerged in the early 1980s as an alternative to the inherent inefficiencies of traffic-responsive pattern selection systems. The first two ASCT systems were the Sydney Coordinated Adaptive Traffic System (SCATS) and the Split Cycle Offset Optimization Technique (SCOOT), both still in use today. During this time, most developments were taking place in Europe and Australia; however, around this time FHWA initialized a research project that resulted in the development of several ASCT systems, two of which were successfully tested and implemented in the field: a modified version of OPAC (Optimization Policies for Adaptive Control) and RHODES (Real-Time Hierarchical Optimized Distributed and Effective System).

While these systems showed significant benefits over fixed-time and actuated-coordinated systems, these earliest ASCT systems were not widely accepted or deployed due to their complexity and increased costs of operation and maintenance. In response to these issues, FHWA initiated the development of an ASCT system that would be simpler, more user-friendly, and compatible with existing infrastructure; the result was a system called ACS Lite, which is available today from a number of vendors. Several privately developed ASCT systems were developed at the same time as the FHWA programs. Today, there are many systems in operation throughout the country, operating with varying levels of success. The most commonly used systems presently in operation are discussed in this document.

ASCT systems should be installed in locations with both physical and operational characteristics agreeable for an ASCT deployment. Additionally, since all ASCT systems do not function in the same way, different systems will likely differ in their results. A successful deployment can be measured in different ways based on the needs and expectations of the maintaining agency. As examples, success can be measured by less frequent signal retiming, lower operating cost, reduced delay, improved flow, or fewer customer complaints.

Even a successful ASCT deployment can have limitations. Adaptive signal control is not a cure-all for traffic congestion nor is it a “hands-free” or “set-it-and-forget-it” system. There are numerous ASCT options on today’s market, each with different system requirements and means of operation. Differences between ASCT systems include their detection requirements, communications requirements, controller compatibility, system optimization algorithms, system architecture, system interface, and operational requirements. While all ASCT systems are similar with their end goal of operating a more efficient traffic signal system, some systems may be better suited for the unique characteristics of a particular signal system, roadway, or agency.

Costs of an ASCT system can also vary significantly, depending on which system is selected and how much existing infrastructure can be reused. Additionally, ongoing operations and maintenance costs can differ from a non-adaptive system, often shifting cost from operations to maintenance (usually of detection). Finally, traffic operations and maintenance staff will require proper training, as an ASCT system interface and features will differ from the previous non-adaptive system.

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3 Methodology

The methodology used to develop this document was based on real world user feedback that can provide agencies with the following guidance:

1. When to select ASCT;
2. Which system may be best suited to meet their needs; and
3. Awareness of challenges and recommendations to minimize or avoid having similar results.

The approach taken was to:

1. Review existing documentation on the subject (literature review);
2. Develop and distribute agency questionnaires;
3. Conduct agency interviews;
4. Analyze the date; and
5. Provide recommendations.

4 State of ASCT

4.1 Definition

ASCT is used to adjust traffic signal timing parameters in real time in response to current traffic conditions. While different systems differ in the details of their operation, infrastructure requirements, system architecture, and level of responsiveness, they all contain the same general components and goals. All systems collect and process vehicle detector data to optimize different parameters of the traffic signal system timing (cycle length, split, offset, and phase sequence depending on the system). The goals that each adaptive system attempts to achieve are determined by inherent characteristics of the ASCT's algorithms and configuration by the system operator. These include maximizing mainline throughput, minimizing side street delay, providing larger green bands, and having an equitable distribution of green time, among others.

ASCT differs from traffic responsive signal control technology, which selects a signal-timing plan most similar to the "observed" current traffic conditions from a set of timing plans developed for specific periods of the day. Instead, ASCT specifically optimizes each component of the traffic signal timing, typically splits, offsets, and/or cycle lengths based on the current detected traffic conditions. Additionally, some systems use predictive algorithms that supplement the current traffic data with historical traffic data, such as average link speed, that the ASCT system has observed during similar times of day.

4.2 Benefits

Successful ASCT deployments can improve a traffic signal system in the form of improved measures of effectiveness (MOE), cost savings, and other intangibles. While ASCT has the potential to improve aspects of a traffic signal system, in order to fully realize these benefits it is essential that the ASCT is deployed at a location that meets certain physical and traffic characteristics, as detailed in Section 5 Guidance for ASCT Deployment.

Numerous studies of ASCT deployments have quantified MOEs of ASCT deployments in before-and-after studies. While results vary greatly, in general, the greatest observed improvements associated with the deployment of an ASCT system are shown when compared to:

- Previously uncoordinated systems,
- Coordinated systems with outdated timings, and,
- Systems with variable non-recurring congestion.

Successful ASCT systems can provide quantitative benefits seen in the form of improved MOEs, which include:

- Travel time,
- Fewer stops,

- Average speed,
- Reduced fuel consumption/emissions,
- Side street delay,
- Reduced time of saturated conditions, and
- Reduced accidents.

The benefits achieved with a successful ASCT deployment vary due to the unique nature of each deployment. Every deployment has different existing conditions, levels of existing timing optimization, and traffic and geometric characteristics at different levels of suitability for ASCT. It is important to note that ASCT can also have different levels of improvement / degradation on MOEs throughout different periods of the day and different directions of travel.

ASCT deployments can have cost savings to the operating agency by reducing the frequency of regularly updating signal-timing plans, although, most ASCT systems will need backup time-of-day plans if the ASCT system goes off-line. Often, agencies with ASCT systems experience a shift of time and resources from developing signal timing to maintaining detection. Additionally, reduced fuel consumption, travel time, and accidents can provide cost savings to the community. Other benefits observed include fewer citizen complaint calls to agencies and special features the system offers, such as a robust traffic data archive, and operational benefits provided by the user interface.

4.3 Limitations

Even a successful ASCT deployment in an appropriate location with traffic conditions favorable for ASCT has its limitations. The following summarize:

ASCT is a tool to manage traffic

ASCT does not add capacity to the roadway nor eliminate oversaturated conditions. In fact, most agencies report that their ASCT systems perform the same or worse than actuated-coordinated signal timing when operated in oversaturated conditions.

ASCT systems require oversight

While ASCT systems can minimize the need to develop manually updated timing plans, all systems require oversight to verify efficient operation. Agency operators need to monitor the ASCT system to verify that algorithms are working to meet the system goals (e.g. serving protected turns and side streets). All ASCT systems give the operator some ability to configure the system to meet their goals, with some systems having a greater ability to customize. It is important that system operators receive sufficient training in all aspects of operating and maintaining the new system and its features as its operation can be significantly different from the agencies previous system. Not having sufficient training and understanding of how the system functions will often result in greater reliance on the system vendor or developer. These services can be part of the upfront capital expenditure for the system or provided under a standalone maintenance contract.

ASCT system infrastructure is complex

ASCT systems have more components than other traffic signal systems with each component playing a critical role in the operation of the system. The ASCT processor is the "brains" of the system and will require significant up front configuration, periodic tuning, and regular maintenance in order to maximize the benefits of the system. In addition, communications between controllers (or processors) must be uninterrupted, for both the coordination and conveyance of detector data. Typically, ASCT requires detection that is at a minimum as abundant as a fully actuated signal, with most systems also requiring advance upstream detection on the main street. Accurate and operational detection is **critical** and agencies must place maintenance of detection systems as a high priority to have the system operating at its fullest potential. Various ASCT systems handle detector failures differently (some rely on archived historical data), with most systems remaining operational with limited detector failures, although with reduced performance. Similarly, reliable communications infrastructure is also critical. Some systems can handle minor communications disruptions with minimal effect to the system. However, major communication failures will typically have the system revert to a pre-programmed actuated time-of-day plan.

ASCT systems react quickly, but not immediately

ASCT systems require several minutes of a problem to be present (such as high detector occupancy) before the system acts. This may be counterintuitive since ASCT has a reputation for being responsive to traffic conditions in real-time. Adaptive works much faster than the weeks it may require to develop new timing plan, but it still has its limitations. When the system senses a traffic condition that needs to be mitigated, the system often varies timing by a few seconds each cycle. It can take several minutes before the 'improved' timing is fully implemented. Depending on the variations adaptive implements, the trigger event may have dissipated by the time the newly optimized timing has been implemented. Further, ASCT systems are typically slow to return to off peak/normal conditions.

4.4 Summary of ASCT Options

Agencies, controller manufacturers, and private companies have developed systems with some having been in the market more than 40 years. The systems vary in their adaptive control logic, hardware and software requirements, system architecture, communications, detection requirements, and special features. This section summarizes the major ASCT systems currently deployed throughout Florida and the United States, and identifies key differences between the systems

Based on our experience, the following ASCT systems were reviewed:

- Adaptive Control System (ACS) Lite (Federal Highway Administration [FHWA]/Siemens)
- Centracs Adaptive (Econolite)
- InSync (Rhythm Engineering)
- Kadence (Kimley-Horn and Associates)
- Optimization Policies for Adaptive Control (OPAC) (University of Lowell / United States Department of Transportation)
- QuicTrac (McCain)
- Real-Time Hierarchical Optimized Distributed and Effective System (RHODES) (U. of Arizona, Tucson / Siemens ITS)
- Sidney Coordinated Adaptive Traffic System(SCATS) (Road Transit Authority, Sydney, Australia / TransCore)
- Split Cycle Offset Optimization Technique (SCOOT) (Transport Research Laboratory, UK / Siemens UK)
- SynchroGreen (Naztec)

System Architecture

There are two primary architectural configurations of ASCT systems: centralized and distributed. Centralized systems process the optimized signal system parameters for the ASCT system with a single processor or server and then distribute the optimized timing parameters to each local controller. In contrast, distributed systems process the optimized signal system at each local controller or local ASCT processor, which communicates directly with the adjacent local controllers or local ASCT processors.

ASCT systems with central system architecture include SCOOT, SCATS, SynchroGreen, Centracs Adaptive, and QuicTrac. Systems with distributed central system architecture include InSync, ACS Lite, OPAC, and RHODES. However, some centralized systems may have features that are determined at a local level (SCOOT uses features of local controllers to skip phases with no demand). ACS Lite is a distributed system, but the system’s master controller is replaced with an ACS Lite field processor, which communicates with the local controllers.

Table 4-1: ASCT System Architecture

Central Systems	Distributed Systems
• Centracs Adaptive • QuicTrac • SCATS • SCOOT • SynchroGreen	• ACS Lite • InSync • Kadence • OPAC • RHODES

Communications

All ASCT systems require communications infrastructure to share data in real-time between signal controllers or ASCT processors in a distributed system architecture or to a central server in a centralized system architecture. Systems can be configured to use different types of communications media commonly used for traffic signal systems based on the system requirements: twisted pair copper, fiber optic cable, or wireless, although systems with higher bandwidth requirements and/or latency requirements will likely require fiber optic cable (e.g. if the system is capable of sharing real-time video from video vehicle detectors).

Agencies considering an ASCT should be fully aware that each ASCT vendor's product might be compatible with only certain communication media. As a result, agencies without funding to modify existing communications infrastructure may be limited to only those ASCT compatible with their legacy communication media.

Unlike non-adaptive signal control systems that typically use communications to synchronize the controllers' clocks for coordination and to update or modify existing timing plans remotely, the communications infrastructure of an ASCT system plays a much more critical role since it is used continuously for the operation of the system. An ASCT system uses the communications infrastructure so that it can optimize the system as a whole, and in the case of centralized ASCT systems, communicate with the central server to send detection data and receive system timings.

It is critical for the communications network of an ASCT system to be reliable and have minimal downtime. Unlike non-ASCT systems, where a communications failure typically does not critically affect the operation of the system, a communications failure in an ASCT system will prevent the system from operating adaptively; although, many systems have measures to keep the system operational, such as reverting to time of day actuated-coordinated plans or using historical data to predict the current traffic.

Controllers

A factor in selecting which ASCT system to implement is the system's controller compatibility—can the system work with the existing controllers and firmware? Purchasing new controllers can be a significant cost in implementing a new system, and takes time to train new field technicians and get them proficient with the new controllers or firmware. While some systems claim to be compatible with various controllers and firmware versions, many agencies find that they have issues when implementing systems on non-vendor preferred controllers. Some systems, such as InSync and ACS Lite, are controller-agnostic, which many agencies find to be a convenient feature to ease the upgrade to ASCT as well as provide flexibility for future controller upgrades. Other systems, such as Centracs Adaptive, work exclusively with Econolite controllers. While most systems are compatible with various National Electrical Manufacturers Association (NEMA), 170, and 2070 model controllers from multiple venders, it is essential that agencies check with ASCT vendors to verify compatibility, as system compatibility can be version- and model-specific and change as system versions are upgraded over time.

System	Compatible Controllers
ACS Lite	170, 2070, NEMA (Siemens, Econolite, Peek, McCain)
Centracs Adaptive	Econolite ASC/3 (version 2.49 or later) software running on ASC/3, ASC/3 2070, or ASC/3 Rack Mount controllers.
InSync	All major controllers
Kadence	170, 2070, NEMA (Siemens, Econolite, Peek, McCain)
OPAC	NEMA (TS-2), 170-ATC, 2070, 2070-Lite
QuicTrac	Program 233MC on Model 170 Program 2033 on Model 2070 Omni eX on both 2070 and NEMA form factors
RHODES	2070-ATC, ASC/2S
SCATS	170E with Interface Card 2070 with software ATC
SCOOT	Any Siemens: 2070 ATC or NEMA
SynchroGreen	2070 or ATC-type from multiple vendors

Detection

ASCT systems rely on vehicle detection as the source of data used to create optimized signal plans in real-time. It is critical that the vehicle detection systems are operational and accurately calibrated in order for the system to operate at its fullest potential. While ASCT systems have different requirements for preferred detection type and location, most systems are compatible with common detection systems, such as inductive loop, video, and radar; their location requirements do not typically differ significantly from a fully actuated signal. Most systems require stop-bar detection for each lane and/or advance detection for coordinated mainline phases, although there are systems that are exceptions.

Often, agencies can reuse much of their existing vehicle detection equipment for their adaptive system, but commonly will need to add mainline detection. All ASCT systems reviewed are compatible with inductive loops, video detection, and radar; although the InSync system ideally uses their proprietary video detection to detect and measure traffic demand at intersection approaches including vehicle queues. In order for the InSync system to use existing inductive loop detection, the InSync Fusion software must also be installed. The main differences between the detection requirements of different systems are their location requirements. Most commonly, both stop bar and advance detection are required (e.g. ACS Lite, OPAC, SynchroGreen, Centracs Adaptive, and RHODES). SCATS requires only stop bar detection, but additional advance detection is a preferred option. InSync requires only stop bar detection, but uses video to detect queue length, while SCOOT and QuicTrac require only midblock or advance detection on mainline and stop bar detection on side streets. Additionally, detection quantities can differ between systems. Most systems require one detector per lane. SCOOT requires only one loop / detection zone per two lanes; ACS Lite and RHODES require only one detector per phase.

Table 4-2: ASCT System Vehicle Detection Location Requirements

System	Detection Location
ACS Lite	Stop bar, one detector per phase, and at least one advance detector for each coordinated phase.
Centracs Adaptive	Stop bar and advance (250’-500' upstream).
InSync	Stop bar detector, queue detection.
Kadence	Stop bar, one detector per phase, and at least one advance detector for each coordinated phase.
OPAC	Stop bar detection, advance detection (10 sec upstream), and detection for each left turn bay as far upstream as possible.
QuicTrac	Midblock or existing advanced detection on mainline.
RHODES	Stop bar and upstream (250'-400' from stop bar). Requires one detector per movement - not per lane. Additional detectors can be considered (for large turn bays).

System	Detection Location
SCATS	Stop bar detector at all approaches of each intersection. Additional upstream detectors are preferred.
SCOOT	Located at upstream end of approach link (at least 7 sec upstream of stop bar). Requires one loop per two lanes. Stop bar detection on side streets.
SynchroGreen	Stop bar detection required for each lane on every intersection approach. Advance detectors for mainline through lanes, between 250'-500' upstream from stop bar.

Optimization and System Logic

Each ASCT manufacturer uses a unique set of algorithms to achieve the system goals. While the system algorithms can be complex and often proprietary, they all require accurate and plentiful detector data. ASCT systems process vehicle presence and speed data to determine a response to current traffic conditions. The location of the vehicle detection plays a major factor in the operation of the ASCT optimization logic. Systems that utilize upstream advance detection can model the flow approaching a signal and proactively respond to the approaching traffic. Systems that have stop bar detection can accurately measure the demand and queue length at the intersection and respond to this traffic.

The modified traffic signal timing components differ with each ASCT system, but are a combination of cycle length, split time, offset time, and phase sequence. SCOOT, SCATS, ACS Lite, OPAC, SynchroGreen, and QuicTrac modify cycle length, split time, and offsets, with SCOOT also providing the option to update phase sequence. Centracs Adaptive optimizes splits and offsets, but selects cycle length based on a time-of-day plan. InSync and RHODES are unique in that they do not have a set cycle length, but allocate green time to phase splits as needed and coordinate adjacent signals to optimize a green band through the corridor. The advantage of systems that do not have a set cycle length is that there are no negative effects associated with transitioning to a new cycle length, such as the offset becoming out of sync with the rest of the system; however this unpredictability can upset driver expectancy.

Ideally, an ASCT system improves traffic operations for side street movements as well as for mainline movements. However, some users of ASCT have cited a lack of side street attention as a downside to their system. Some ASCT systems, such as InSync, identify gaps in green bands of mainline progression and use this unused green time to serve the side movements. Users cite that side street delay is a configuration that needs to be dialed in over time.

Some systems, such as SCATS and SynchroGreen consider pedestrian traffic in the development of their system timing optimization plans.

Table 4-3: ASCT System Optimization Comparison

System	No Set Cycle Length	Optimizes Cycle Length	Optimizes Splits	Optimizes Offsets	Optimizes Phase Sequence
ACS Lite		X	X	X	
Centracs Adaptive			X	X	
InSync	X		X	X	X
Kadence		X	X	X	
OPAC		X	X	X	
QuicTrac		X	X	X	
RHODES	X		X	X	
SCATS		X	X	X	
SCOOT		X	X	X	X
SynchroGreen		X	X	X	

Table 4-3 source data obtained from system literature.

System Interface

ASCT systems have a variety of interfaces for system operators to configure and monitor. Many ASCT system interfaces are in the form of a graphical user interface (GUI). Some system GUIs, such as InSync and SynchroGreen, are web browser-based, while other systems, such as OPAC, are integrated into advance traffic management (ATM) software. Some agencies report that their staff are very happy with their ASCT user interface; however this seems to be dependent on the amount of training the agency received.

4.5 Cost Review

Agencies considering implementing an ASCT system will need to consider both the capital cost of installing the system as well as the ongoing maintenance and operation of the system.

The capital costs of implementing an ASCT system can vary widely and are dependent on several factors: type of ASCT system, existing infrastructure in place (such as detection, communications, compatible controllers, etc.), and the number of intersections included. According the National Cooperative Highway Research Program (NCHRP) *Synthesis 403 Adaptive Traffic Control*

Systems: Domestic and Foreign State of Practice, published in 2010, the average cost of installing ASCT is approximately $65,000 per intersection, however, this can vary widely. The capital costs for different components of different ASCT systems vary from system to system and a significant amount of cost can be attributed to software licenses.

Of the agencies surveyed, the average cost of installing an ASCT system was approximately $44,000 per intersection, ranging between $10,000 and $120,000. The wide range of cost per intersection can be attributed to the different needs of each unique ASCT installation. Differences between systems that can affect the cost of the system include the ASCT software selected, the amount of compatible infrastructure that can be reused, management of traffic for construction of new infrastructure, decision to use in-house staff or outside consultant to implement system, and economics of scale when implementing large systems compared to small systems.

Operation and maintenance costs of ASCT systems can also vary between different systems and from the previous non-adaptive system. The biggest change to operational costs that agencies observe is that they no longer need to spend resources continuously updating and optimizing signal timing plans for the signals in the ASCT network. As in a non-adaptive signal system, the installed infrastructure also requires continual maintenance; however, some ASCT systems have more detection, and accurate and operational detection plays an even more critical role in an ASCT system. Maintenance of ASCT system detection must be a top priority of the agency. The system processors often require upgrades and technical support at times.

Additional costs of an ASCT system include consulting costs and the cost of training personnel to operate ASCT hardware and software. NCHRP *Synthesis 403* estimated that the cost of maintaining "optimal" signal timings under ASCT account for only 75 percent of what is spent to maintain comparable signal timings under non-adaptive signals (note that this estimate was published in 2010).

4.6 Staffing

According to survey data from NCHRP *Synthesis 403,* there are three major obstacles in expanding ASCT systems: high cost, lack of traffic signal operations staff, and operational inefficiency. NCHRP *Synthesis 403* reports that many agencies with ASCT systems that are understaffed and lack qualified personnel report this as one of the major problems for potential performance issues of their deployments. ASCT requires a commitment to staffing for both operations and maintenance; the capabilities and resources within the agency should be considered before deploying an ASCT corridor within the agency. Staff turnover can be an issue for an agency since the new staff will need to be trained on the system.

Agencies should not consider ASCT as a way to reduce staff. Most agencies report about the same time requirements for operations, although their focus shifts to looking for malfunctions and configuring periodic tweaks based on the data that the system produces. Most agencies report more time required to maintain detection. Because detection is critical to the success of the ASCT system, repairing broken detection needs to be a top priority. Agency staff need to be properly trained in the operation and maintenance of the ASCT system for it to perform at its fullest potential.

Proper training from the vendor on both operations and maintenance is necessary to the success of the system. Agencies that stated their ASCT systems were unsuccessful also typically stated that the training they received from the vendor was inadequate. Agencies with training that was "about right" to "very good" were typically very happy with their ASCT system. Some agencies that are dissatisfied with their ASCT system also report that they have not set up some special features of their ASCT system, such as setting up alarm triggers for malfunctions, which may decrease the system's operational efficiency.

4.7 Recommendations

An agency considering implementing ASCT should first determine if their traffic meets criteria where this can be successful, see Section 5, Guidelines for ASCT Deployment. Agencies should deploy an ASCT system that is a good fit in both its cost and operational features. If an agency has limited budget for an ASCT system, they should consider one that is compatible with their existing controllers and detection. The ASCT system software license is typically the largest cost of deploying this system. An agency should consider the size of their ASCT deployment, as the cost per intersection may decrease if deployed throughout a larger system due to economies of scale.

The unique characteristics of the traffic signal system where ASCT will be deployed should also be considered. While ASCT can be deployed on grid networks (SCOOT is known for its ASCT operation in grid networks), nearly all current ASCT systems are developed on arterial (single corridor) networks. Agencies that have locations that have large directional variability throughout the day may consider a system that supports optimizing phase sequences throughout the day, such as InSync or SCOOT. Some features of an ASCT interface might appeal to an agency, such as InSync's closed-circuit television camera detection monitoring, or access to the interface through a web-browser, such as InSync, ASC Lite, or SynchroGreen. Interoperability with existing ATM or traffic monitoring software may also be a major factor when considering system options.

4.8 Summary of Deployments and Agency Experience

ASCT is increasing in popularity throughout the United States, especially where traditional time-of-day plans cannot accommodate variable traffic patterns. Since the emergence of ASCT in the 1970s and 1980s, ASCT signal timing has been widely implemented internationally, but has been slow to grow in the United States only recently gaining favour with a greater number of agencies.

Agencies deploying ASCT all have unique characteristics in their staffing, technical skills, funding, existing infrastructure, expectations for what ASCT can accomplish, etc. Thus, agencies' individual experiences with ASCT deployments can vary widely. Two agencies deploying the same ASCT system can experience very different levels of success. One of the biggest commonalities reported by agencies that deem their ASCT systems a success is receiving sufficient training for both operations and maintenance of their system. Additionally, agencies should have realistic expectations of an ASCT system and be careful not to be oversold an ASCT's capabilities. Note that agency experience conclusions will be heavily based on the characteristics of the corridor, its traffic conditions, and the unique characteristics of the agency itself.

The following are agency recommendations to others considering deployment of an ASCT.

Managing Expectations

- Establish the needs/issues (use system engineering process) prior to procurement of a system.
- Agencies need to go into it with their eyes wide open. It is not a one size fits all solution. You cannot set it and forget it. It takes work and you have to want it.
- Define your objectives very clearly; determine what you are trying to accomplish with adaptive and select the appropriate system to address these objectives.
- ASCT doesn't mean install, forget, and eliminate staff. The system requires maintenance on the detection, reliable communications, and periodic adjustments to intersection thresholds.
- Understand what you are trying to accomplish with an adaptive system. Are you filling a specific need that only adaptive can fill? It is not a cure-all.
- Check with other agencies and ask a lot of questions.
- When the product is being sold, the buyer may not be made aware of all of the requirements. Understand that adaptive has its place; understand the limitations of the system and where the system works well and does not work well.

Staffing

- Make sure you have the staff to make ASCT work. You need to be willing to put the time in to make it operate as expected.
- Think through your staff expertise and impacts it will have on the current system.
- Maintenance technicians need to be prepared. It is different than what they have seen before; they need to be on-board and trained.
- Consider how much time you are going to put into the system and how experienced your agency is with traffic signal operations. You need to be willing to put time into it and have the relevant signal operations experience to make ASCT successful. Venders can provide turn-key systems, but you are going to pay extra for it.

Operations

- Signal operations can hop around and violate driver expectations. If you want the most for your expenditure, operate toward lead/lag and consider use of flashing yellow.
- Assume the installation of an ASCT system will not decrease the time it takes to operate the system.
- Good detection is the heart of a successful adaptive system.

Traffic Conditions

- Need to make sure there is sufficient traffic demand to justify adaptive.
- Know your corridor; don't just pick a system and deploy. Know what you are trying to achieve; let the roadway pick the system and not vice-versa.
- If it's saturated, adaptive will not work. If it is not saturated, then varying traffic is the determining factor.
- Do not assume that adaptive is a one-size-fits-all application; it is not a good solution for every corridor.

The following are general summaries of agency experiences with ASCT systems gathered from questionnaires and interviews.

4.8.1 Centracs

Econolite's Centracs is an ASCT system that uses centralized system architecture. An agency interviewed gave the system positive reviews and would use it again. The agency selected Centracs after going through the systems engineering workbook by FHWA, which resulted in a performance spec that addressed exactly what they needed based on operational needs. Additionally, their existing controllers were Econolite, which are compatible with the Centracs system they selected. They reported that the implementation experience was simple and they used existing loops for detection. The signal controllers required a data key to unlock the software that was already resident on their Econolite ASC-3 controllers and then Econolite completed minor system configuration remotely.

The agency reported that they have received good local product support from the vendor. They received formalized training provided to the corridor manager and field techs; however, they stated that they could always use more training since it's different than regular signal timing. One key to the agency's successful deployment of Centracs was their realistic expectations; they were cautious of being oversold.

The agency found that the system works well during off-peak times with left turn movements. They report that the system originally provided too much time to side streets, which they were able to dial back. They noted that the system struggles during oversaturated periods to adjust offsets correctly, but they seem optimistic that with time they will be able to fine tune this.

The agency stated that their Centracs system takes less time than their previous system (traffic responsive) to operate. They said it was a lot of work to get the system configured at the start, but once it was operating they generally don't deal with it much. The Centracs system provides malfunctioning detector alerts and the agency commented that it is critical to fix malfunctioning detectors quickly. Their maintenance staff has shifted their activities from maintaining signals to maintaining detection. They noted that if a controller needs to be replaced, it needs to be replaced with the appropriate controller—ASC-3 or 1C model. To expedite replacement, the agency requires their maintenance contractor to have appropriate training.

The agency likes that the system is easy to use and flexible; they can select different features to use. They stated that they would select Centracs again, but recommend that agencies should understand what they are trying to accomplish with an adaptive system and that it should fill a specific need that only ASCT can fill.

4.8.2 InSync

Rhythm's InSync ASCT system has the largest number of deployments in recent years and has consistently positive reviews from agencies. The system has a distributed system architecture that places a processor in each cabinet that is compatible with nearly all signal controllers in use. While the additional cabinet space requirements are minimal, some agencies reported that they had to upgrade their cabinets in order to accommodate the added equipment. Rhythm strongly urges the use of flashing yellow arrow signal heads so that the system can take advantage of dynamically optimizing protected/permitted left turn phase sequences, which may be an additional cost to an agency during implementation. Most agencies reported no major issues implementing InSync and some reported that implementing InSync was quicker and had fewer issues than their experience implementing other ASCT systems, although there is still a learning curve. While the InSync adaptive system is up and running quickly, agencies reported that it still takes additional time to fine-tune.

Rhythm provides training for both operations and maintenance that most agencies found to be about right or even excellent. Rhythm's support is part of the InSync product and is widely reported to be very good with support staff that is responsive and available to make adjustments when necessary. Rhythm provides 24-hour phone support and can remotely monitor and adjust the system; however, this requires agencies to rely heavily on Rhythm for support. Agencies refer to the system as a "black box" that Rhythm remotely adjusts in order to fine-tune the system; the agency may not necessarily know the exact changes that Rhythm makes, which can be frustrating to agency operators that are used to identifying and resolving specific issues themselves.

InSync can use either their proprietary video detection only or a combination of video detection and other detection, a version they call InSync Fusion. InSync Fusion might be used when loops or other vehicle detection are needed to augment the video detection due to occlusions, such as power lines, or an agency will use existing non-video detection to save on the cost of installing some new InSync cameras. Agencies reported no serious issues with the detection portion of the system, and often found the InSync camera detection system requires less time to maintain than a loop detection system; however, agencies report fewer issues with corridors using video detection exclusively compared to the Fusion corridors. A unique feature of the InSync video detection is that agency operators and Rhythm support can view the camera feed for all cameras remotely to monitor operation of the corridor.

Nearly all agencies deploying InSync reported that they would use InSync again; however, the heavy reliance on Rhythm for support and configuration of the system should not be interpreted such that agency staff can spend less time operating and maintaining the ASCT system compared to a non-adaptive system. Agencies reported that InSync maintains its performance well over time with regular monitoring and maintenance.

4.8.3 OPAC

OPAC is an ASCT system with a distributed system architecture. The system requires an OPAC Box in each signal cabinet that controls the ASCT system. One agency refers to the OPAC Box as a “black box,” saying it made it difficult to understand how the system functioned in order to address citizen questions. The OPAC interface is integrated into the MIST ATM software, which is a commonly cited reason for selecting the system over other ASCT. Agencies gave OPAC mixed reviews; one agency removed its OPAC system because they saw better improvements with fine-tuned traditional signal timing, and another agency only had about half of their original OPAC deployment currently active.

Agencies that have deployed OPAC stated that the implementation process was time consuming and required a lot of setup and fine tuning. They stated that the training and support that OPAC provided was good and included phone and on-site report.

OPAC received mixed reviews about in what conditions it works well. One agency stated that OPAC works well in oversaturated conditions with wide spacing of intersections (mile spacing), while another agency stated that OPAC didn’t do well in saturated conditions. Agencies report that OPAC caused an increase in side street delay because it puts more emphasis on optimizing the main street and gives less priority to side streets and left turns.

Agencies reported that the time spent on operations was relatively unchanged compared to a traditional system, but that they spend more time to maintain detection, sometimes doubling efforts.

One agency with an OPAC system stated that they think ASCT is beneficial, but would consider using a different system in the future. Another agency stated that ASCT has its purpose, but found that a traditional time-of-day actuated system was more relevant for their needs.

4.8.4 QuicTrac

McCain's QuicTrac is an ASCT system that uses a centralized system architecture. An agency interviewed gave the system positive reviews and has expanded its original deployment to four systems currently; all systems are deployed on arterials and contain between 6-8 signals per corridor. The agency said that implementation went smoothly; the system uses their existing equipment and they only had to add mainline detection (microwave). They have had no issues with communications, which is a mix of fiber and Digital Subscriber Line (DSL).

The agency stated that the training they received from vendors was about right. The technical support they received was very positive despite some back and forth on some items. Their technicians love the system and they stated that citizen complaints have dropped dramatically. They have not made any staffing changes, but report that overall they spend less time operating and maintain the system.

The operators gave the user interface (BiTran QuicNet) good reviews and have decided to use it for their non-ASCT signals as well. They find that the system performs well in various situations, except in one location where there are low volumes so they don't see much benefit. Overall, they said the QuicTrac system was low-cost and provides them with a high benefit-cost ratio (they did not provided a measured ratio). They stated that they would use the same system again, but recommend agencies make sure that there is sufficient demand to justify an ASCT system.

4.8.5 SCATS

SCATS is one of the original ASCT systems utilizing a centralized system architecture. Agencies had mixed experiences with implementation, some stating that it was difficult to configure the detection, while other agencies stated that they had a smooth implementation done by a contractor. Overall, though, agencies provided consistently positive reviews.

Agencies reported that the training they received was about right and that they can get more training as needed. They reported that they have had no issues with technical support. Agencies reported no serious issues with the required stop bar detection, although one agency stated that overall their Wavetronix detection worked best and that cameras on the far side of the intersection generally worked better than nearside cameras. If the communications fail, the system reverts to pre-programed time-of-day operation. One agency reported that when their adaptive system went off-line due to construction disrupting communications, the system ran time-of-day plans and the MOE worsened significantly compared to the functioning SCATS system.

During saturated conditions, agencies reported that SCATS works no better or worse than a well-timed traditional system; however, some agencies believe SCATS may shorten the duration of saturated condition impacts. SCATS performs well during shoulders of peak periods and off-peak periods with less predictable traffic.

The SCATS system interface received mixed reviews from agencies. One agency reported that the "point and click" aspects are good, but other features need to be written in code, which sometimes must be provided by Transcore. They reported that it takes years to understand all the capabilities.

Some agencies deploying SCATS reported that their adaptive systems require more staff and time to maintain than their non-adaptive systems and have added both operations and maintenance staff. If detection goes down, it must be fixed immediately. One agency stated, "Maintenance technicians need to be prepared - it is different than what they have seen before, they need to be on-board and be trained." The agencies states that SCATS is a powerful system that includes diagnostics, a helpful system reporting log system, and the capability to set up triggers for different actions. Overall, agencies with SCATS systems would use SCATS again.

4.8.6 SCOOT

SCOOT is one of the original ASCT systems and uses a centralized system architecture. Agencies gave SCOOT mixed reviews — one agency removed SCOOT from a number of its signals due to poor performance in areas with predictable traffic flow. Another agency found that the system worked well and met their operational objectives; they have expanded their SCOOT system to include additional signals. One agency interviewed has deployed SCOOT on a grid network with crossing major arterials and has had positive results.

Agencies reported that SCOOT implementation requires a lot of time to set up and fine tune to get the system up running. Part of the difficulty of implementation is related to the very rigid detection and communications requirements. SCOOT needs specific controllers and communication to the server online at all times. With SCOOT, the system tuning must happen in the field, unlike other systems that can be tuned remotely. One agency noted that they had some challenges with familiarity with software and region configuration.

One agency deploying SCOOT reported that they received training from the vendor for one week of hands on training for staff. The agency warned, "The system is complex and not easy to use, so if you don't use it on a daily basis, you tend to lose expertise." They reported that more training would have helped, but overall the system is "very complicated for engineers, technicians, and TMC operators and should be more user friendly and intuitive to use." One agency reported that their training was good, but their trainer was from the UK (where SCOOT was developed), and they wished that the trainer was more familiar with US traffic operations and traffic control. They also stated that it would have been beneficial to have additional training after the system was deployed when they had some experience working with the system. They noted that because SCOOT is a very mature system that can address just about any situation, they would like some advanced training on system features that are more complex and a better understanding of "why the system is doing what it is doing." One agency stated that SCOOT "requires more time during first deployment to set the initial parameters, but the operational requirements step down gradually with experience."

SCOOT uses advance detection that is normally located at least 7 seconds upstream from the stop bar; one agency was able to re-use existing loops that were only 5-6 seconds upstream from the stop bar. To minimize cost, loops are sometimes tied to the upstream controller rather than the downstream controller to reduce the distance between the controller and loop.

An agency deploying SCOOT reported that it works well in areas that have unpredictable traffic fluctuations, but does not work well in areas with predictable traffic. In some areas with predictable traffic, they removed SCOOT from those intersections and saw improved performance using traditional actuated-coordinated operations. SCOOT is reported to work well for ingress and egress of traffic for side streets and overall travel time and delays in most unsaturated conditions. Like other ASCT systems, SCOOT does not work well in oversaturated conditions, but one agency stated that it works well up to saturation. The agency reported that they experienced the greatest improvements during the off-peak. They stated, “There is a big payback on side streets in reduction of delay.” Another agency stated that SCOOT works well when there are unplanned lane closures (e.g., lane closures due to incidents or maintenance of traffic). The agency likes that SCOOT works well in a dynamic environment, and once they got the system tuned it worked well. Agencies like that SCOOT provides “really good and relevant reports.” In order for the system to maintain its performance over time, adjustment/fine tuning is required at least once a year.

4.8.7 SynchroGreen

Trafficware’s SynchroGreen ASCT system has positive reviews from most agencies; however, one agency interviewed reports having a poor experience leading to removal of the system. This negative experience was related to the system’s incompatibility with the existing detection and roadway configuration; the installation did not include SynchroGreen detection pods, which were later determined to be necessary. All agencies stated that the implementation of SynchroGreen was time consuming and required a lot of support from the vendor; however, they stated that after the initial implementation, subsequent deployment on other corridors were easier.

SynchroGreen has a central system architecture that typically requires only a controller firmware upgrade and no additional modules or devices added to the signal cabinets, with the exception of additional detection devices. Agencies deploying SynchroGreen commonly stated that among the main reasons they selected SynchroGreen over other ASCT systems is its compatibility with existing devices and with ATMS.now, the current ATMS software they are using. Operators of SynchroGreen can select from four different modes of adaptive operation: balanced, progressive, critical movement, and isolated adaptive. The different settings optimize the adaptive signal timings to meet different goals (e.g. maximum mainline throughput, minimize side street delay, etc.). The agencies with successful deployments reported that the system works well in non-saturated peak periods and shoulders of peak periods. They reported that the system works very well during special events and that it handles side street delay well depending on which of the four modes the system is operating in.

Agencies with SynchroGreen ASCT systems stated that compared to non-adaptive systems, more effort is required to keep detection and communications up and running. However, with SynchroGreen, many controller functions are available for an operator to adjust remotely in less time than it would take a field signal technician to accomplish. In general, there is a shift from field signal technicians to traffic operations. Agencies stated that it is important that the system operators are experienced and knowledgeable in order to obtain the applications full functionality. The operators must make periodic adjustments to intersection thresholds in order for the system to run as efficiently as possible and maintain its performance over time.

Most agencies deploying SynchroGreen reported that they would use SynchroGreen again. They stated that adaptive systems must be deployed on a corridor with the right conditions, chiefly highly variable traffic, that it is not oversaturated, and that the agencies operators are skilled.

5 Guidelines for ASCT Deployment

According to FWHA's Every Day Counts Program, ASCT signal timing operation is best suited for arterials that experience highly variable or unpredictable traffic demand. Traffic conditions can change rapidly due to new or changing land uses, incidents, crashes, pre-emption, weather, or other special events (non-recurring congestion). ASCT signal timing can address issues as they occur instead of waiting for staff to analyse, create, and implement new timing plans. Corridors with multiple phases or high pedestrian volumes could be too demanding for ASCT systems to adapt green time to varying conditions. Since ASCT is often devoted to supplying green time to the major direction traffic flow, the benefits of ASCT signal time are more clearly seen on corridors with multiple signals.

Installing ASCT technology is intended to improve system operations by continually evaluating and implementing timing improvements that address varying traffic conditions. ASCT can continuously distribute green light time equitably for all traffic movements, improve travel time reliability by progressively moving vehicles through green signals, reduce congestion by creating smoother flow, and prolong the effectiveness of traffic signal timing.

5.1 System Engineering for Project Management

As noted throughout the by nearly every agency that has deployed an ASTC, it is important to understand the needs and issues being experienced on roadway corridor before considering methods to mitigate. ASCT cannot address all traffic conditions. As such, it is important that agencies following a system engineering process so that all issues/needs can be considered and functional requirements can be developed based on those issues/needs. In addition to the initial capital costs associated with the deployment of ASCT, agencies should also use the system engineering process to understand the long term implications of deploying ASCT and the effect it will have on operational costs, staffing, training, and maintenance. This type of information will typically be included as part of the concept of operations.

5.2 Guidance for deployment

The following three guidelines are intended to provide quantitative and qualitative consideration to agencies when considering ASCT to improve arterial operations. The guidelines are meant to be sequential, if the first guideline is met, then the next should be considered; however, if one is not met then ASCT may not be appropriate the appropriate tool to meet the needs of the agency.

5.2.1 Currency of Timing Plans

Background: Signal timing that is outdated or does not take advantage of modern signal controller functions can lead to congestion as the signals may not be effectively addressing traffic demand. Existing traffic signals should be identified as congested before a mitigation approach is pursued.

Guidance: If signal timing has not been updated in the past three years, traffic volume data should be collected and compared to volumes used to time the traffic signal to determine if traffic demands have substantially changed (10 percent up or down for any movement), then retiming should be considered. If the intersection is congested and timing is current, then adaptive may be considered.

Note: *With the importance of maintaining both detection and communication to operate an ASCT, many systems will require agencies to develop current time-of-day back up plans that the system can revert to when these failures occur (InSync uses historical data). Per* ***NCHRP Synthesis 403 on Adaptive Signal Control Systems: Domestic and Foreign State of Practice*** *agencies report average percentage of downtime of systems to be between 2%-9% per year.*

5.2.2 Corridor length, density of signals, and character of the arterial

Background: ASCT requires that signals communicate with each other to optimize signal timing parameters (e.g., adjust green bands to improve flow). Therefore, there must be enough signals in the system within a close enough proximity (typically ¾ mile or less) to facilitate coordination. The locations must also exhibit characteristics that typical signal controller operations, such as full-actuation and fully-actuated coordination are not capable of adapting to traffic demand.

Guidance: Based on an evaluation of existing adaptive systems nationwide, the minimum number of signals typically included in an ASCT system is three signals. In addition, spacing should be approximately ¾ mile or less to facilitate coordination. If a corridor or signal system has less than three signals or many signals are spaced more than ¾ mile, traditional timing methods are generally acceptable. If a corridor or signal system contains more than three signals and signal are generally densely spaced at ¾ mile or less, then ASCT may be an appropriate solution.

Note: *Agencies should pay special attention to uncontrolled movements/access points between signalized intersections. If large traffic generators or sinks are located outside the ability of the system to detect traffic entering/exiting the arterial, the systems will be unaware of their affect and will have difficulty optimizing flow. Additional detection may be necessary to accommodate these conditions.*

5.2.3 Non-recurring congestion

Background: ASCT is most effective when traffic conditions fluctuate often and/or unpredictably (non-recurring congestion) and when there are demanding traffic conditions. Travel time reliability measures can be used to identify corridors and networks that experience demanding conditions and non-recurring congestion. Travel time index (TTI), planning time index (PTI), and buffer index (BI) are travel time reliability measures that can be used to evaluate congestion and non-recurring congestion. TTI is a measure of how the average travel time compares to free-flow travel time. PTI is a measure that identifies the time a driver would need to allocate to arrive on-time 95 percent of the time. BI is the difference between TTI and PTI. Therefore, BI measures the variability of congestion, a small BI indicates more recurring congestion, while a larger BI indicates non-recurring congestion, as described below.

Figure 5-1 shows the relationship between TTI, PTI, and BI. During the PM peak in this example, the TTI is approximately 1.45 or 45 percent longer than free flow traffic. The PTI is approximately 2.05 or 105 percent longer than free flow traffic. Therefore, the BI is about 0.60 or in order to arrive on time 95 percent of the time; a driver would need to plan to allocate 105 percent more time than free flow conditions and 60 percent more time than during average congestion.

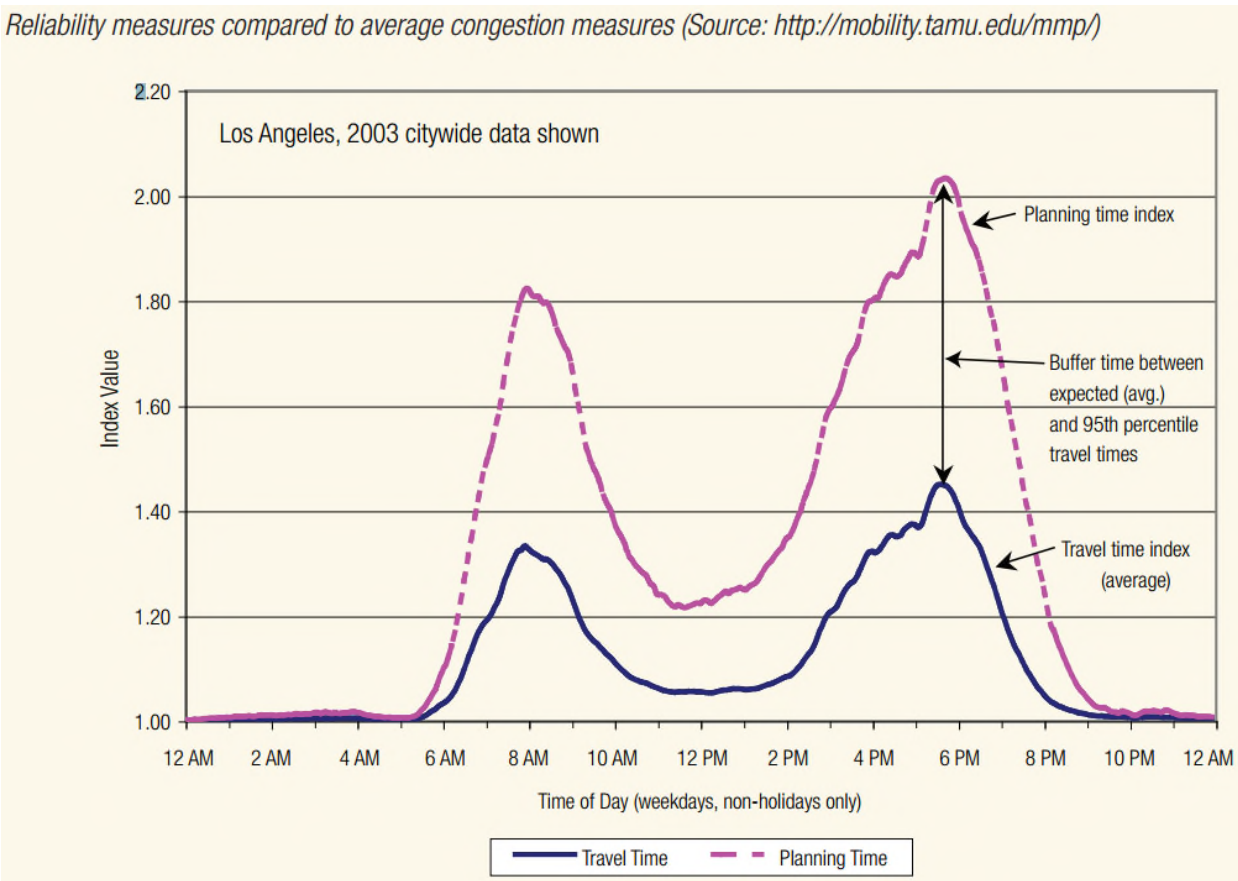

Figure 5-1: Reliability Measures Compared to Average Congestion Measures

Figure 5-2 shows the TI and TTI for two separate corridors in Colorado. For SH 392 the BI is relatively small, around 0.1-0.15. This means that there is relatively minimal variability between the TTI and PTI and that congestion is fairly consistent or recurring. For SH 66 the BI is much larger, between 0.4-0.6, which indicates congestion is less consistent or is non-recurring. As noted above, ASCT tends to have the greatest benefit along corridors with non-recurring congestion.

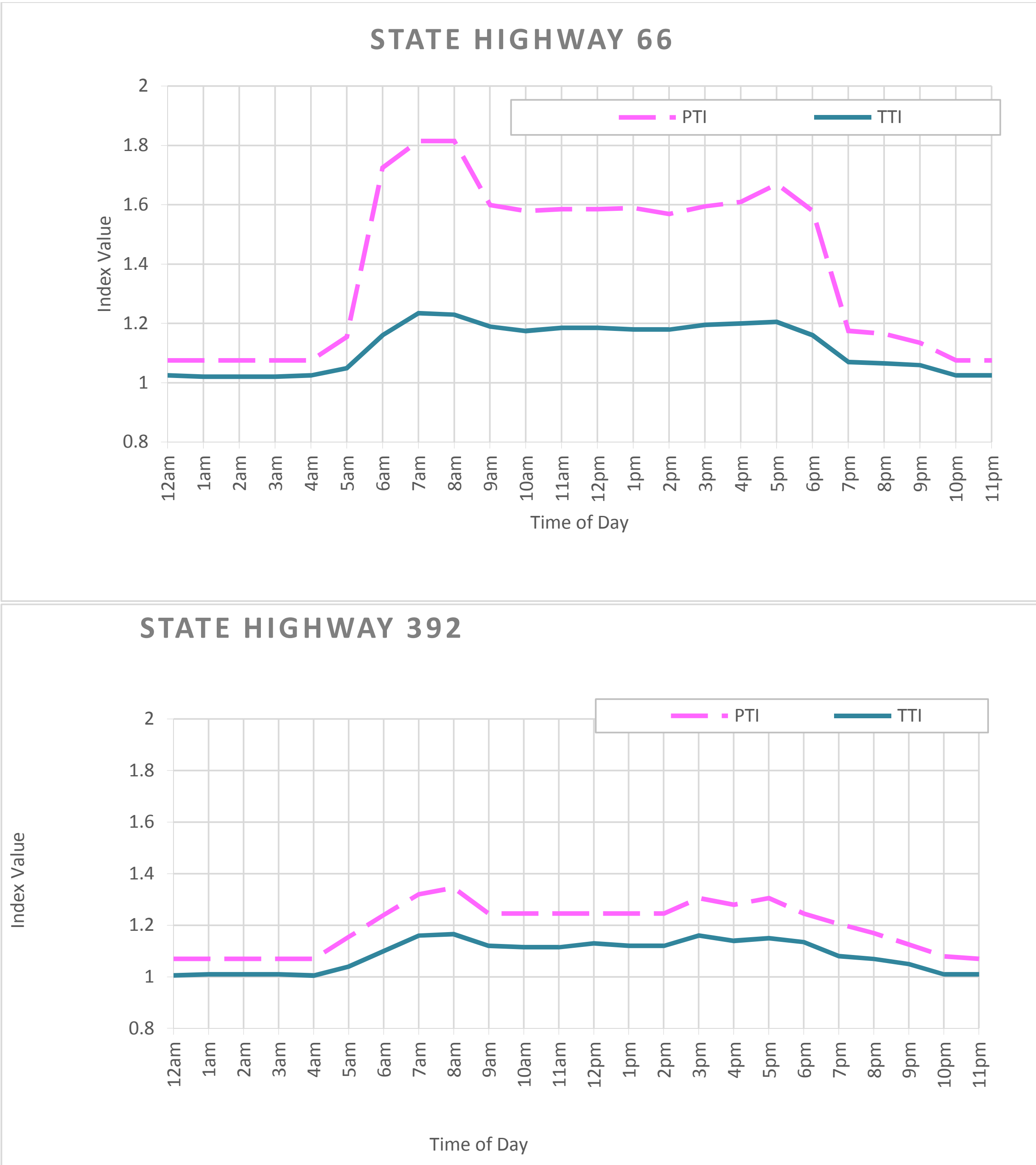

Figure 5-2: Travel Time Index and Planning Time Index throughout the Day

A literature review has been conducted to determine if there was a BI threshold to indicate non-recurring congestion. Results of the review were inconsistent with agencies that use this measure to identify non-recurring congestion using a variety of measures generally ranging from 0.25 to

0.5. Based on this information and initial work in Colorado to identify need for adaptive signal control, a BI of 0.3 appears to be a reasonable threshold to use to identify non-recurring congestion.

Guidance: Based on the understanding that ASCT is most beneficial in areas with non-recurring congestion, ASCT should be considered for locations that exhibit characteristics of non-recurring congestion. This can be identified by a BI of 0.3 or greater, long shoulder periods, or the proximity of land uses that create variable traffic flow, such as events and sporting venues, large shopping centers, etc. For locations that exhibit non-recurring congestion, ASCT may be considered.

Note: *While an ASCT may be able to delay the onset of saturation, once saturation occurs, ASCT performance generally degrades, or at best, functions as well as time-of-day plans.*

5.2.4 Operations, management and maintenance

Background: Changes in driver behavior, detection failures, communication failures, and geometric changes are a few examples of the need to actively operate ASCT systems. Successful systems are actively operated, managed, and maintained over time. Traffic engineering staff as well as senior management must understand this to allocate appropriate funding and staffing levels to the support the ASCT.

Guidance: Per NCHRP Synthesis 403, yearly operations and maintenance costs can vary from between $1,000 to $25,000 per intersection per year and may require weekly maintenance of 6 to 14 hours per week per intersection.

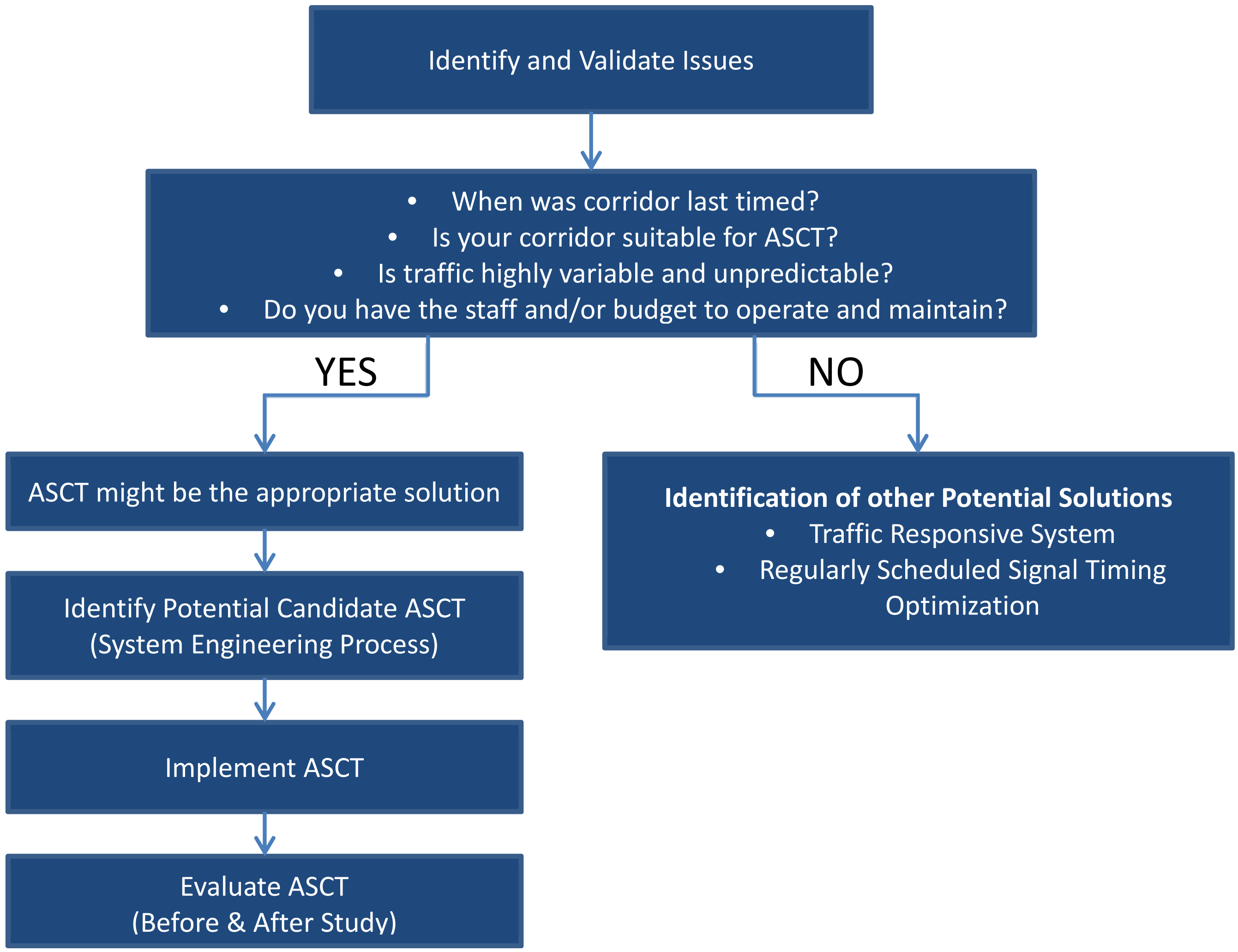

Figure 5-3: ASCT Decision Flow Chart

6 Evaluation Criteria

It is important to evaluate the effectiveness of ASCT on corridors where it is implemented in order to continue to learn which systems are better suited for certain conditions. Agencies indicated that ASCT is effective if it operates better than other traffic signal operations methods. ASCT systems can perform significantly differently as traffic conditions change throughout the day, so it is recommended that agencies evaluate their system during all periods of the day. The identification of evaluation criteria is based on criteria identified as important to agencies during the user interviews. The following criteria were identified as important:

- Travel time: agencies typically measure travel time benefits to gauge the effectiveness of ASCT. This is typically done through before/after travel time runs or using Bluetooth readers. Agencies indicated they typically evaluate travel times immediately before and after deployment of ASCT as well as at regular future intervals (such as annually) to evaluate effectiveness.
- Delay and number of stops: evaluated during travel time runs.
- Side street delay: measured through field observations.
- Number or rear-end crashes: evaluated by looking at crash patterns over time.
- User complaints: typically this is based on the agencies perception of the number of calls they receive, but it can be tracked if the agency maintains a log of citizen complaints.
- System Characteristics: number of signals in system, signal spacing, number of unsignalized side streets / driveways, residential or commercial, special event route, average daily traffic, number of lanes, etc.