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Page 64 Editorial Correction	OPAC (University of Maryland)	OPAC (University of Massachusetts Lowell)

FHWA Research and Technology Evaluation

Adaptive Signal Control

Final Report
June 2018

Publication No. FHWA-HRT-17-007

U.S. Department of Transportation
Federal Highway Administration

Forewords

The Federal Highway Administration (FHWA) Research and Technology (R&T) Program furthers the FHWA Office of Research, Development, and Technology's goal of ensuring transparency, accessibility, and responsiveness of R&T for all stakeholders.

This report examines how FHWA's investment in adaptive signal control (ASC) research and increasing awareness of ASC technologies has affected the development and deployment of these technologies. This report should be of interest to engineers, practitioners, researchers, and decisionmakers involved with the research, design, performance, and management of traffic signals.

Hari Kalla, P.E.
Associate Administrator, Office of Research, Development, and Technology

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16. Abstract
As part of the Federal Highway Administration's (FHWA) Research and Technology Program evaluation, this report documents the findings of a summative evaluation of various adaptive signal control technology (ASCT) research and outreach activities conducted by FHWA over the course of more than 20 yr. The evaluation considers the ways in which FHWA's investment in ASCT research and related outreach activities have influenced the development and deployment of these technologies. The evaluation also addresses the short-term impacts of ASCT deployments, including reduced traffic congestion and delays. Due to the extended timeline of the program, the research and outreach activities were chronologically categorized into three distinct phases, and each was evaluated on its influence on ASCT development and deployment. This report also identifies challenges and lessons learned that may be applied to further intelligent transportation systems research.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Definition
ACDSS	Adaptive Control Decision Support System
ACS	adaptive control software
ASC	adaptive signal control
ASCT	adaptive signal control technology
CMAQ	Congestion Mitigation and Air Quality Improvement
CRADA	cooperative research and development agreement
EDC	Every Day Counts
FHWA	Federal Highway Administration
HOP	Office of Operations
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LA-ATCS	Los Angeles Department of Transportation's Adaptive Traffic Control System
MPO	metropolitan planning organization
MSE	model systems engineering
NEMA	National Electrical Manufacturers Association
OPAC	Optimized Policy for Adaptive Control
R&D	Research and Development
RD&T	Research, Development, and Technology
R&T	Research and Technology
RC	Resource Center
RFP	request for proposal
RHODES	Real-Time Hierarchical Optimization Distributed Effective System
RTACL	Real-Time Traffic Adaptive Control Logic
RT-TRACS	Real-Time Traffic Adaptive Control System
SCATS	Sydney Coordinated Adaptive Traffic System
SE	systems engineering
SCOOT	Split Cycle Offset Optimization Technique
TFHRC	Turner-Fairbank Highway Research Center
TOD	time of day
TRB	Transportation Research Board
USDOT	U.S. Department of Transportation

Executive Summary

Purpose of Evaluation

The Federal Highway Administration (FHWA) has initiated an effort to evaluate its Research and Technology (R&T) Program. As part of being accountable to funders and policymakers, leaders of governmental transportation R&T programs need to be able to effectively communicate the full range of benefits of their programs. The R&T Evaluation Program was created to help FHWA assess how effectively it is meeting its goals and objectives and to provide useful data to inform future project selections. For each evaluation, FHWA employed the use of its FHWA R&T Evaluation Program Evaluation Team (referred to as the "evaluation team" throughout this report), which was made up of non-FHWA, third-party evaluators not involved in the research programs and projects being evaluated. FHWA's Office of Operations selected the Adaptive Signal Control (ASC) Program to be evaluated under the R&T Evaluation Program. The purpose of the ASC Program evaluation is to assess the effects of FHWA's efforts related to developing ASC technologies (ASCTs), which is a term coined by FHWA to describe the entire body of ASC systems, and support the adoption of technology by State and local agencies.

ASC Program Description

Conventional traffic signal systems use preprogrammed daily signal timing schedules that do not automatically adjust to traffic conditions and, thus, can contribute to traffic congestion and delays. ASC improves on these systems by adjusting signal timing parameters to accommodate variability in demand using current traffic data. FHWA's ASC Program supported both the development and deployment of ASCs in the United States. This research program spanned over 20 yr and can be divided into the following three major phases:

- **Phase 1 (1992–2002)**: R&T ASC Research and Development's Real-Time Traffic Adaptive Control System (RT-TRACS) Program, which produced two viable systems: Real-Time Hierarchical Optimization Distributed Effective System (RHODES) and Optimized Policy for Adaptive Control (OPAC) algorithms.

- **Phase 2 (2002–2009):** Adaptive Control Software (ACS) (known as ACS Lite) development and outreach.

- **Phase 3 (2009–2012)**: Every Day Counts (EDC) ASCT Outreach Program (referred to as the "EDC Program" throughout this report).

The first two phases focused on technology development. FHWA funded two iterations of ASC development, managed pilot deployments, and developed informational materials to introduce the technology to State transportation departments. When development activities were complete, the program switched gears in the third phase to focus on fostering ASC adoption by expanding outreach activities, developing guidance documents and materials, conducting training sessions, and providing technical assistance to agencies interested in pursuing the technology.

ASC and ASCT are distinct and unique unto themselves. "ASC" refers broadly to the process of updating traffic signal timing-based algorithmic processing of traffic flows through traffic signals, while "ASCT" refers to technologies that perform these updates. There is no industry standard way of discussing these technologies, and ASC and ASCT were chosen by FHWA for EDC activities.

Methodology

As a first step in designing this evaluation, the evaluation team constructed three primary hypotheses about how the program was intended to work. The evaluation discusses the hypotheses in the context of three distinct phases of FHWA research and outreach activities. The hypotheses include the following:

- **Hypothesis 1**: FHWA R&T ASC activities accelerated the development of ASCTs.
- **Hypothesis 2**: FHWA R&T ASC activities accelerated the deployment of ASCTs.
- **Hypothesis 3**: FHWA R&T ASC activities improved mobility and reduced emissions.

To test these hypotheses, the evaluation team conducted various data collection activities. First, the team reviewed research and documentation on the development, deployment, and impact of ASC to identify stakeholders; examined the timing of relevant development activities, outputs, and short-term outcomes; and refined the evaluation hypotheses. Data sources reviewed in the literature search included FHWA program documents, websites of vendors and adopters, relevant research on ASC, and literature on technology diffusion models. The evaluation team then conducted 19 interviews with ASC developers, vendors, local agencies, and FHWA program staff to gather information that could provide context for the literature review. The evaluation team transcribed each interview and analyzed the notes in two different ways. First, the evaluation team used the notes to fill in gaps and provide context for the timeline analysis. Next, the team identified findings for each phase of FHWA research. As a final step, the evaluation team designed and fielded an online survey with State transportation departments to connect what was learned from the indepth interviews and timeline analysis to the direct experiences of the ASCT market. The survey collected information from local, regional, and State transportation departments about their exposure to and use of ASCTs and their recent experience with EDC ASCT outreach and other FHWA resources. Survey findings helped bring the research on ASCT up to the present day and informed the hypothesis related to FHWA's impact on ASCT deployment.

Findings

The findings for the evaluation of the ASC Program highlight evidence from each of the three program phases by evaluation hypothesis.

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Evidence from the three phases shows that FHWA had both a direct and indirect effect on ASCT development. In phase 1, FHWA directly funded the development and pilot testing of ASC algorithms through RT-TRACS.(2) Of the four algorithms funded for development, three were pilot tested, and two eventually came to market: OPAC and RHODES. The impact of RT-TRACS, however, went far beyond these two systems. By the end of this phase, the FHWA R&T Program brought the OPAC and RHODES algorithms to market and introduced several signal control vendors and technology firms to the potential of ASCT in the United States.

In phase 2, FHWA used lessons learned from RT-TRACS to develop a new algorithm—ACS Lite—that was less costly and easier for agencies to purchase and maintain. A private contractor developed the algorithm, and four National Electrical Manufacturers Association (NEMA) signal control vendors partnered with FHWA to adapt their signal control equipment to run the technology. Two of the NEMA vendors went on to develop their own algorithms, one of which was based on ACS Lite. Outside FHWA, the cumulative effect of RT-TRACS and ACS Lite was noted to have a significant impact on the ASC market. Several vendors and technology firms learned from these programs as they developed or improved ASC products, including two products directly derived from FHWA research—ACS Lite in 2006 and Centracs™ in 2010.

In phase 3, FHWA moved away from technology development to supporting ASCT adoption. During this phase, eight additional ASCTs were launched or were being developed. The lessons learned from ACS Lite and RT-TRACS, along with the market support (i.e., education, training, and guidance documents) provided by FHWA's EDC Program, fostered investment in both FHWA-funded and independent technologies during this time.

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

In the development-heavy phases (i.e., RT-TRACS in phase 1 and ACS Lite in phase 2), pilot tests and demonstration sites represented the majority of the FHWA-influenced ASCT deployments. Additionally, less than 30 agencies deployed technologies developed independently of FHWA through 2009. Generally, the impact of these two phases was that FHWA development, testing, and outreach resulted in increased awareness of ASC among State and local transportation departments. Interviews, document reviews, and timeline analysis suggest that without FHWA's programs, it is unlikely that many agencies would have been aware that ASCTs were being developed and deployed in the United States at that time.

In phase 3, FHWA's EDC Program shifted efforts from ASCT development to supporting the growth of the ASCT industry. The program reached State and local transportation departments in 42 States and provided general information on ASCT through internally unpublished workshops, presentations, and meetings. To further support ASCT deployment, EDC developed a model systems engineering process and provided direct support for this process. Evidence from the interviews and the online survey confirms that actions performed by FHWA (and specifically the EDC Program) have affected the ASCT market at all stages of the adoption process. EDC outreach and guidance materials are associated with increased ASCT awareness and acceptance among agencies.(3) Half of ASCT adopters reported use of EDC's SE process (e.g., training, documents) and direct FHWA support to guide them as they navigated the complicated ASCT deployment process. (Refer to section 3.3 of this report for more detailed interview information.) The evaluation team determined that since 2009, over 176 cities have implemented ASCT systems, and many others are considering implementation. This a comprehensive finding that utilizes sources noted throughout this report as well as the researchers' observations and experiences. Both adopters and those considering ASCT indicated via interviews and the online survey that there is room for continued FHWA support in the future, particularly in overcoming purchase barriers that still hamper deployment and expansion in many agencies. (Refer to chapter 3 of this report for more detailed interview and online survey information.)

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

FHWA-funded teams and FHWA-influenced technology firms developed effective ASCTs during the span of FHWA's ASC Program. The ASCTs all improved incrementally over the course of the program. Based on the most recent measures of effectiveness, it is clear that ASCTs can improve measures of travel time, delays, and number of stops in many situations, which will improve congestion on roadways.[4] Limited information, however, is available on the congestion impacts of ASCTs. The results speak primarily to the potential of the technology to affect congestion and travel time rather than its fully realized impact because the analysis is based on a relatively small number of performance evaluations.

Results from before and after studies of the phase 1 RT-TRACS pilots as well as the Split Cycle Offset Optimization Technique and the Sydney Coordinated Adaptive Traffic System (SCATS) algorithm show that the algorithms, with the exception of SCATS, had mixed results in their ability to reduce travel time and delay.[5,6] In phase 2, new entrant ACS Lite showed good performance in reducing travel time and delay, while OPAC and RHODES showed improvement on these measures. In the phase 3 timeframe, the majority of the ASCTs on the market, including all of those directly affected by FHWA, showed positive results in reducing travel time and delay.

Recommendations

FHWA's ASC Program unfolded over two decades and incorporated the development, testing, and outreach of ASCTs. It is typical for long-term efforts that are designed to develop and encourage adoption of emerging technologies to experience obstacles in adoption and development, such as those experienced by FHWA through its ASC Program. Future efforts could benefit from the following considerations:

Recommendation: While focusing on technical issues, there should be consideration of and planning for longer-term issues of market acceptance and deployment.

In the first phase of the ASC Program, FHWA initially focused on addressing issues, such as traffic congestion and delay, without fully considering and planning for the longer-term issues of the market's ability to deploy the complex and expensive ASCTs. It is important to understand both the needs (i.e., problems to address) and potential barriers to purchase (e.g., system costs, detection costs, complexity) up front and learn how those needs and barriers change over time. Interviews and/or surveys with a broader market audience can help at all phases of development and outreach.

Recommendation: Strategies and processes for transferring a technology from research to the market should be considered when conducting initial research.

For ASCTs that are developed by FHWA to be widely used, it is necessary for vendors to offer those technologies in the market. There are a variety of ways to accomplish this goal (e.g., FHWA contracts with a specific vendor, technology is open sourced), and different approaches may be appropriate at different times or in different markets. Before identifying a technology transfer strategy, it is important to understand how choices made in ASCT development and testing will facilitate or create barriers once the market is developed. When ACS Lite research was being completed in phase 2, there was miscommunication between FHWA and vendors about FHWA's technology transfer strategy, and this lengthened the amount of time it took for vendors to offer ASCTs or prevented them from doing so altogether.

Recommendation: Communication about the technology itself and its related outreach program should be communicated throughout FHWA.

There were instances during EDC's outreach when FHWA staff did not fully understand the ASC Program and its applications, and this affected agencies' ability to pursue ASC. FHWA should make sure that all staff who are responsible for a certain topic or product are aware of its applications and are able to communicate its uses and requirements to potential adopters.

Recommendation: Research programs should anticipate evaluation of and coordination with their strategic plan from the outset.

When designing a research effort, program managers should consider future evaluation needs (e.g., data, performance measures) and incorporate them into the research design. There were certain ASC performance measures that were difficult to evaluate (e.g., congestion, attendance at FHWA ASC workshops) due to limited data. Considering evaluation during research design would improve the quality and usefulness of future evaluations.

Conclusion

Based on the available data and interview findings, it is clear that FHWA's ASC Program and EDC Program's outreach had a significant positive impact on ASCT development and adoption in the United States. It is also likely that the ASC Program produced positive impacts in terms of time and congestion savings; however, data are too limited to make any definitive conclusions. Because the program had such a long duration, it is not surprising that FHWA faced obstacles along the way. Nonetheless, the program was successful because of the way FHWA adapted to those challenges and made interim improvements to the program. Findings from this evaluation suggest several opportunities that FHWA had to anticipate and certain issues that needed to be mitigated before they arose. In future research, FHWA should consider the findings and recommendations from this evaluation to eliminate similar hurdles before they arise.

1. Introduction

This chapter details the purpose of the evaluation, the report organization, and program background.

1.1 Evaluation Purpose

The Federal Highway Administration (FHWA) has initiated an effort to evaluate its Research and Technology (R&T) Program, as leaders of governmental transportation R&T programs need to be able to effectively communicate to its stakeholders about the impacts of their programs. FHWA's R&T Evaluation Program helps FHWA assess how effectively it is meeting its goals and objectives and provides useful data to inform future project selections. In 2014, the program worked with 9 FHWA offices to identify 17 projects for evaluation. For each evaluation, FHWA employed the use of its FHWA R&T Evaluation Program Evaluation Team (referred to as the "evaluation team" throughout this report), which was made up of non-FHWA, third-party evaluators not involved in the research programs and projects being evaluated. FHWA's Office of Operations (HOP) identified the Adaptive Signal Control (ASC) Program, which concluded in 2012, as one of the efforts that should be evaluated. This evaluation addresses FHWA's efforts related to developing ASCs and supporting the adoption of ASC technologies (ASCTs) by State and local transportation departments.

FHWA's HOP agenda has the following three primary objectives:

- Manage congestion by improving reliability and operating adaptive control software (ACS) at peak performance.
- Build a strong foundation for proactive operations.
- Improve the reliability of truck routes through efficient movement of freight.

The purpose of the ASC Program was to address the first objective, managing congestion by improving reliability and operating the system at peak performance. The evaluation team identified several hypotheses for how the ASC Program may have achieved these impacts (e.g., reduced congestion, improved travel time, reduced delays). The three hypotheses are summarized in table 1.

Table 1. Hypotheses by outcome type.

Hypothesis	Outcome Type	Description
1: FHWA R&T ASC activities accelerated the development of ASCTs.	Short term	The extent to which the number of ASCTs in the United States grew and the extent to which FHWA research and outreach contributed to this growth.
2: FHWA R&T ASC activities accelerated the deployment of ASCTs.	Short term	FHWA's contribution to the availability of information and support for ASC adoption. This includes evidence of benefits and information about ASCT and its uses.
3: FHWA ASC activities improved mobility and reduced emissions.	Long term	The extent to which the growth in the number of ASC deployments in the United States contributed to operational, environmental, and economic impacts, such as reduced congestion and travel time savings.

1.2 Report Organization

This report is organized as follows:

- Chapter 1 provides an overview of the purpose of the evaluation as well as a high-level description of the ASC Program's history. Section 1.3, ASC Program Background, is broken down into the three phases of FHWA's research and outreach activities.
- Chapter 2 describes the evaluation methodology, including data sources, data collection methods, and data analysis methods. Most evaluation methodologies collected data across the full ASC research time period from 1992–2012, informing multiple phases. This chapter details the three-phase breakdown of the program that the evaluation team used to organize the evaluation findings.
- Chapter 3 summarizes the findings of the evaluation. It discusses key activities, outputs, and outcomes that occurred in each of the three phases through all aspects of the market (e.g., technology development and supply, technology adoption, and technology effectiveness).
- Chapter 4 describes the evaluation team's recommendations for FHWA based on the findings of the evaluation. The recommendations are proposals that the evaluation team developed to address certain findings about the program.
- Chapter 5 contains general conclusions that the evaluation team drew from the evaluation. It discusses overarching findings about the ASC Program that cut across the three phases of research.
- Appendix A details the interview methodology used in this evaluation.
- Appendix B describes detailed findings about the ASC program that were uncovered through the literature review and interviews. The evaluation team used the information presented in this appendix to draw conclusions about the outcomes and impacts of FHWA's activities.
- Appendix C describes the methodology and shows tabulated results for the online survey conducted with a representative cross section of traffic signal decisionmakers from local, regional, and State agencies.

1.3 ASC Program Background

Those in the traffic operations industry acknowledge that poor traffic signal timing contributes to traffic congestion and delay; however, State and local transportation agencies' capabilities and resource limitations constrain the frequency of traffic signal retiming. Conventional signal systems use daily signal timing schedules that are programmed on the basis of engineering analysis of traffic demand. These systems do not adjust to accommodate variability in demand and remain fixed until they are manually adjusted. Substantial amounts of historical traffic data and labor hours are required to conduct traffic and engineering analysis.

ASC uses current traffic data to recognize when signal timing does not accommodate traffic demand and improves on conventional signal systems by adjusting signal timing parameters that control the duration of red and green intervals to accommodate variability in traffic flows, alleviating congestion and delay.[7] FHWA coined the term "ASCT" during the Every Day Counts (EDC) Program to reflect the entire body of ASC systems. This report uses the term "ASC" when referring to FHWA's activities that occurred prior to the EDC Program and "ASCT" in all other instances.

ASC was first used in the 1970s when Australia adopted the Sydney Coordinated Adaptive Traffic System (SCATS).(8) Soon after, the United Kingdom Transport Research Laboratory developed and implemented a new system, the Split Cycle Offset Optimization Technique (SCOOT). Although popular in Europe, these systems were not consistent with U.S. traffic signal system infrastructure, thus making them expensive to implement and hindering their acceptance in the United States.

Phase 1: Real-Time Traffic Adaptive Control System (RT-TRACS)

In 1992, the Turner-Fairbank Highway Research Center (TFHRC) initiated research on ASC to better understand the potential of this technology to reduce traffic congestion and travel time delay in the United States.(2) In the first phase of this research, TFHRC solicited proposals for the development of ASC systems through the RT-TRACS Program and supported the selected academic and technology teams as they developed and tested their systems. Three viable algorithms emerged from the program: Optimized Policy for Adaptive Control (OPAC), Real-Time Hierarchical Optimization Distributed Effective System (RHODES), and Real-Time Traffic Adaptive Control Logic (RTACL). In 1996, TFHRC initiated a series of four field tests in Reston, VA; Chicago, IL; Seattle, WA; and Tucson, AZ, to demonstrate the costs and benefits of operating these three new algorithms in real-life situations.(9–13)

The field tests showed mixed results; none of the systems consistently improved travel time and delay. There were some successes, such as how the RHODES was able to maintain traffic conditions on very congested corridors, which was considered an achievement by the test administrators. Although the algorithms were not perfect, some showed promise and areas for improvement. RTACL was not considered successful, and the recommendation was to continue developing the algorithm before deploying it again.(9)

As these field tests ended, TFHRC conducted a survey with the Institute of Transportation Engineers (ITE), asking users about their attitudes toward ASC systems.(14) The results of the survey showed that most respondents believed ASC systems were too costly (approximately $100,000 per intersection on top of the cost of typical traffic signal controller, communication, and detection systems). Additionally, nearly half were unconvinced of the benefits of ASC over time of day (TOD) and traffic responsive plan selection signal control strategies, and many believed that the technology was difficult to understand, configure, and maintain.

Phase 2: ACS Lite Development and Outreach

Based on feedback from the four RT-TRACS field tests and survey conducted in phase 1, TFHRC decisionmakers decided through an internal phone call with FHWA officials that the best course of action was to move from creating the best technical solution to developing a more affordable technology that is easier to install and maintain. TFHRC determined that by making a technology compatible with existing infrastructure, it would remove the barriers of affordability and complexity, making it easier for States and local agencies to deploy such systems.

FHWA's Office of Research, Development, and Technology (RD&T) hired a private contractor to develop an algorithm that was easier to use and less costly to implement. This algorithm, which was released in 2004, became known as "ACS Lite." While developing ACS Lite, the Office of RD&T reached out to leading vendors in the signal control industry for help in supporting and promoting the product. The office encouraged the original vendor partners to make their equipment compatible with ACS Lite so it would be easier and cheaper for State transportation departments to deploy. In return, FHWA offered these vendors exclusive licenses to the architecture and central algorithms for ACS Lite.

TFHRC engaged with FHWA's Division Offices to select local agencies that would work alongside vendor partners to pilot test ACS Lite. FHWA selected four pilot test sites: Gahanna, OH; Houston, TX; Bradenton, FL; and El Cajon, CA.[15–18] All four of the field tests demonstrated that ACS Lite was successful in reducing traffic delays and costs to society. From 2006 to 2008, FHWA contributed funding to three additional implementations of ACS Lite.[19] (Refer to appendix B in this report for more information on funding.)

As the pilot tests were being conducted in the mid to late 2000s, FHWA transferred the ASC project from TFHRC to FHWA's HOP to further market and promote the technology. The FHWA Resource Center (RC) developed a marketing plan for the technology, hosted workshops with traffic operators and vendors, and produced informational resources on the product.[7] Even after the transition of the ASC Program to HOP, many State and local agencies and vendors still saw ASC as a research project rather than a market-ready technology. This was not helped by the state of the market, as partner vendors continued to advance their technologies but did not aggressively market their systems because they had yet to see much demand for ASC among State and local transportation departments.

Phase 3: EDC Program ASCT Outreach

FHWA sought to improve the perception of ASC by broadening the outreach efforts for the program in 2009 and incorporating it into the EDC Program. The goal of ASC's incorporation into this program was to mainstream the technology, including ACS Lite as well as other ASC products on the market. During this transition, FHWA coined the term "ASCT" to represent the growing family of systems that update signal timing using a systematic process of traffic data collection via sensors, evaluate signal timing based on the system's functional objective, and update signal timing and repetition of the process on some stated frequency. The hallmark of the EDC Program-supported ASC Program was its development of a systems engineering (SE) process for implementing ASCTs, an approach that provided guidance to State and local agencies considering ASCTs. Such an approach had not been used in the traffic signal community before. Since the inception of EDC deployment activity has increased considerably. The outset of EDC coincided with aggressive marketing of the newly completed InSync™, a proprietary ASC system.[20] Vendors on the sideline for years as well as new entrants became more active in marketing and distributing their ASCT systems. As of 2015, at least 227 ASC systems have been deployed across the United States, 19 of which are ACS Lite systems. (Refer to the Bibliography section for a full list of data sources.)

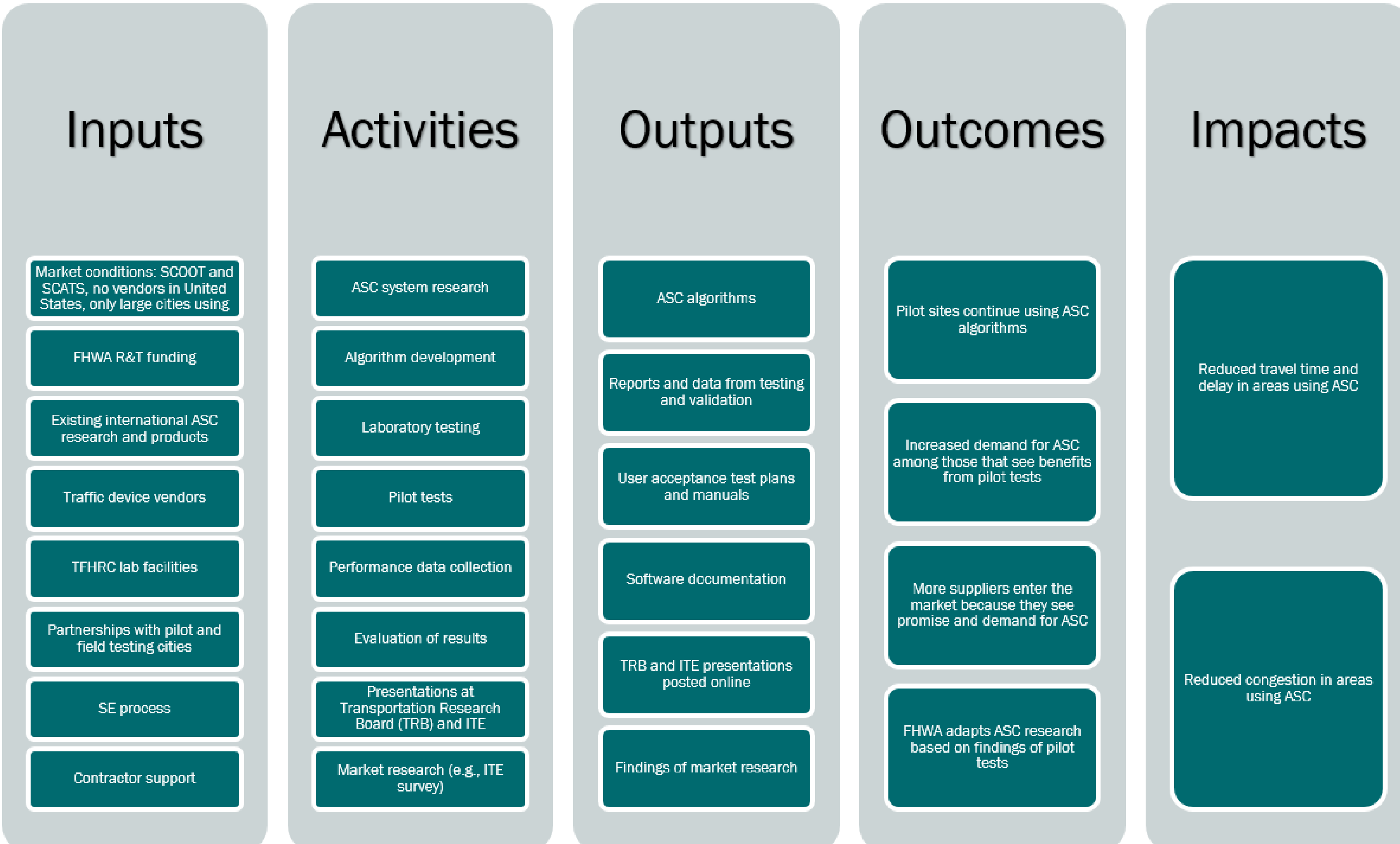
2. Evaluation Design

The evaluation team met with FHWA's R&T Program Manager as well as FHWA's ASC Program Manager to define core evaluation hypotheses and gain a basic understanding of the ASC Program. In particular, the team sought to understand the program's goals, refine the program activities and timeframe that would be assessed, gather available resources, and identify key stakeholders who should be included in the evaluation process. After gathering and reviewing this information, the evaluation team was able to select appropriate evaluation methodologies to answer the three evaluation hypotheses that were defined in chapter 1.

2.1 Logic Model

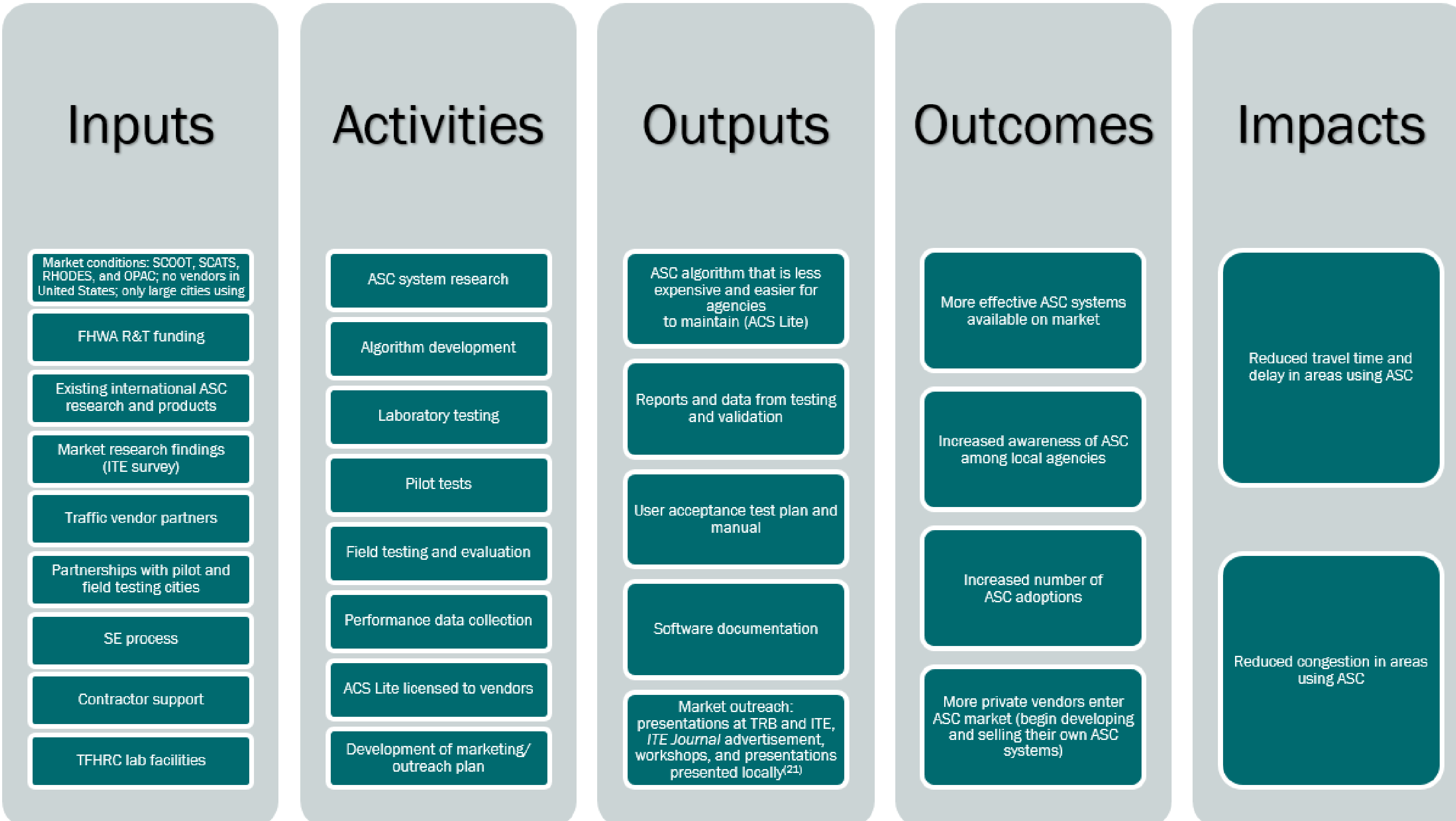
To understand program theory and design, the evaluation team constructed an initial logic model of the ASC Program. As the evaluation progressed, however, three distinct phases of the ASC Program were identified, and it was determined that each phase needed its own logic model to accommodate its unique outcomes and impacts. Figure 1 through figure 3 show the logic models for each of the three ASC Program phases. The separate logic models break out the inputs, activities, outcomes, and impacts for each phase to enable a better understanding of how the program functioned. Because the phases were chronological, the outcomes from each phase affected the inputs and activities in the next phase.

For instance, an outcome of phase 1 (see figure 1) is "more suppliers enter the market because they see promise and demand for ASC." This was due to a lack of suppliers in the existing ASC market. This outcome influenced the activity in phase 2 (see figure 2) of "ACS Lite licensed to vendors." Although the outcome from phase 1 was not an intended outcome of the program in general, it was an important outcome that influenced the direction of subsequent ASC research (e.g., ACS Lite).



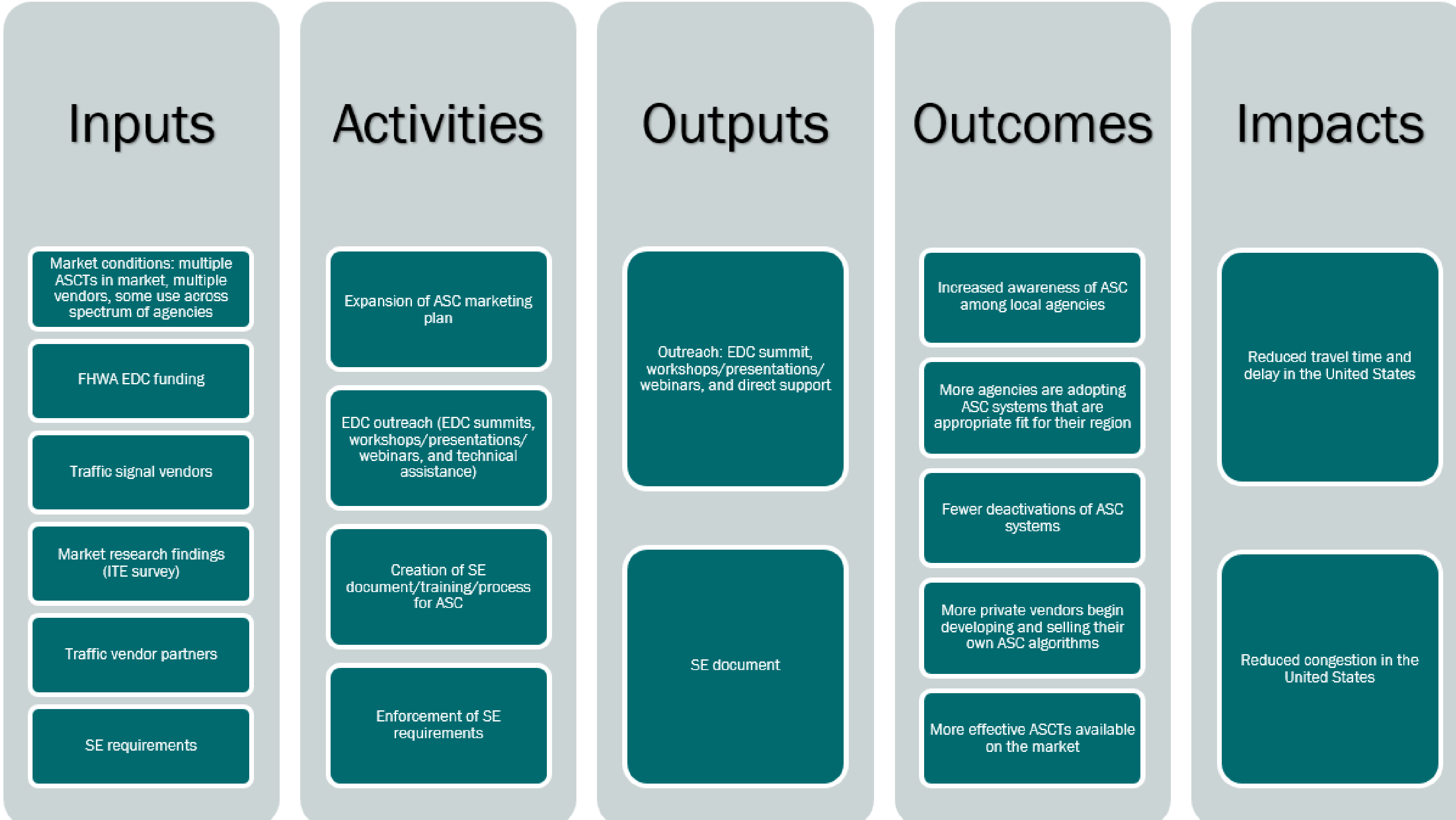
Source: FHWA.

Figure 1. Illustration. Phase 1—R&T technology development and testing.



Source: FHWA.

Figure 2. Illustration. Phase 2—R&T ACS Lite development, testing, and outreach.



Source: FHWA.

Figure 3. Illustration. Phase 3—EDC outreach on ASCT.

2.2 Hypotheses

The evaluation team developed the following three primary hypotheses for how the program inputs and activities achieved their intended impacts:

- **Hypothesis 1**: FHWA R&T ASC activities accelerated the development of ASCTs.
- **Hypothesis 2**: FHWA R&T ASC activities accelerated the deployment of ASCTs.
- **Hypothesis 3**: FHWA R&T ASC activities improved mobility and reduced emissions.

These hypotheses cross the three phases of the ASC Program, although some may not show measurable outcomes until later phases. The evaluation team developed a set of secondary hypotheses that sought to explain how the program worked on a more detailed level. Several of these hypotheses are focused on individual phases of the ASC Program. A list of all primary and secondary hypotheses and performance measures is shown in table 2.

Table 2. Primary and secondary evaluation hypotheses and performance measures.

Primary Hypotheses	Secondary Hypotheses	Key Performance Measures
1: FHWA R&T activities accelerated the development of ASCTs.	FHWA invested in ASCT Research and Development (R&D), accelerated development of ASCTs, and grew the ASCT market (phases 1 and 2).	Development of ASCT products that can be associated with FHWA-sponsored R&D, including the following: Direct development (OPAC, RHODES, and ACS Lite). FHWA direct influence on ASCTs. FHWA Indirect influence on ASCTs (qualitative assessment).
1: FHWA R&T activities accelerated the development of ASCTs.	EDC efforts supported developers, vendors, and distributors, advancing ASCT development (phase 3).	Developer/vendor participation in EDC activities/events. Qualitative assessment of EDC influence on vendors/market.
2: FHWA R&T activities accelerated the deployment of ASCTs.	The R&T Program outreach led to increased adoption and deployment of all ASCTs (phases 1 and 2).	Timeline of deployment of FHWA-supported technologies pre-EDC (direct and indirect). Qualitative assessment of types of outreach of the R&T and RC ASCT outreach to early deployments.
2: FHWA R&T activities accelerated the deployment of ASCTs.	EDC outreach efforts had an impact on moving State transportation departments toward adoption of ASCT (phase 3). Despite EDC efforts, there are still barriers to overcome in achieving widespread adoption of ASCT systems (phase 3).	Timeline of deployment of FHWA-supported technologies since EDC incorporation (direct and indirect). Qualitative assessment of EDC outreach/awareness efforts on deployments. Qualitative assessment of EDC SE outreach/training efforts and deployments. Assessment of ASCT market adoption, including adoption funnel, adoption influencers, and barriers to adoption. Quantitative assessment of use of FHWA outreach/training/SE materials.

Primary Hypotheses	Secondary Hypotheses	Key Performance Measures
2: FHWA R&T activities accelerated the deployment of ASCTs.	Initial test sites for FHWA-funded ASC algorithms influenced the perceptions of the technology by serving as a model of their use and potential benefits (phases 1 and 2).	Qualitative assessment of RT-TRACS and ACS Lite testing/demonstration impact on deployments.
3: FHWA R&T ASC activities improved mobility and reduced emissions.	The implemented ASCTs affected by the R&T Program yielded measurable improvements in time savings for travelers (phases 1–3). The implemented ASC technologies affected by the R&T Program yielded measurable reductions in emissions from vehicles (phases 1–3).	Change in travel time in the corridor where ASCTs were applied. Measure of criteria air pollutants emitted. Measure of greenhouse gases emitted.

2.3 Evaluation Methodology

The evaluation conducted by the evaluation team was a summative evaluation, meaning that it focused on the impact of FHWA's ASC activities on ASC development and deployment in the United States as well as impacts on travel time and congestion to the fullest extent possible. The evaluation team used the following four primary data collection methodologies to inform this evaluation:

- Literature and document review.
- Timeline analysis.
- Stakeholder interviews.
- Online survey.

Literature and Document Review

The evaluation team conducted a review of available literature to gain an understanding of FHWA's ASC Program, supply and demand for related technologies, and the impacts of the technologies in operation. The evaluation team reviewed multiple types of literature, including key FHWA documents (e.g., workshop presentations, marketing plans, technical reports), industry resources (e.g., TRB presentations, *ITE Journal*), academic journals, and agency and news websites.(21) Reference information regarding the aforementioned resources can be located in comprehensive detail throughout chapter 3. Findings from the literature review were the foundation for developing guides for indepth interviews and the quantitative survey instrument. They informed the timeline analysis as well as the analysis of the effectiveness of ASCTs. The literature review informed all of the hypotheses being tested.

In addition to the background and contextual information on the ASC Program and ASCT marketplace garnered from the literature review, the evaluation team also used the review as primary sources of information for the timeline analysis and analysis of the effectiveness of ASCTs. ASCT development and deployment data were the foundation of the timeline analysis. The evaluation team sourced data for this analysis from several additional sources, including Florida Atlantic University's Laboratory for Adaptive Traffic Operations and Management (FHWA adoption records), Intelligent Transportation Systems (ITS) deployment tracking survey, ASCT vendor websites, and Internet searches.(22,23) These records were provided internally through coordination between the FHWA team and the evaluation team staff. These records were used to develop the findings in chapter 3 and are cited throughout. Additionally, a references list showing sources directly used in this report and a bibliography listing all sources reviewed can be found at the end of this report.

The analysis of the effectiveness of ASCTs relied on data from technology evaluations and interviews to provide an understanding of how the quality and impact of ASCTs changed over time. Knowing the effectiveness of the actual products allowed the evaluation team to gain insight on the impacts that ASCTs have had (e.g., reduced travel time and delays).

Timeline Analysis

The evaluation team used findings from the literature review to develop a comprehensive timeline of FHWA and technology developer, supplier, and adopter activities from the early 1990s to the present. The timeline served as a visual framework for exploring which FHWA activities might have affected the development and offering of ASCTs. In this report, the timeline analysis is presented in several graphs showing the adoption levels of ASCTs along with key FHWA and industry activities (e.g., see figure 4 through figure 6 in chapter 3). The evaluation team used the timeline as a tool for testing the first two primary hypotheses previously presented.

The technology developers' and suppliers' version of the timeline describes which technologies were offered, when they entered the market, and who supplied them for each year of the analysis period. It also shows FHWA activities that occurred during that time, including pilot projects, major meetings, and workshops with their target audience. The technology adoption version of the timeline focuses on activities among State and local agencies that adopted ASCTs, including which systems were deployed as well as when and where they were deployed.

The evaluation team then compared the chronology of FHWA's program activities with the market history of ASCT offerings and deployments, looking for points where preliminary conclusions about causality could be drawn. The evaluation team further tested these hypotheses by asking questions related to the activities of interest in the stakeholder interviews, which are described in the following section. The evaluation team used the findings from these interviews to verify the activities listed in the timeline as well as refine the hypotheses made about causal connections between FHWA activities and ASCT adoption.

Stakeholder Interviews

The evaluation team originally contacted 31 stakeholders through help from FHWA's HOP to develop the interviewee list and gather contact information; however, only 19 responded to one of several contact attempts via email and/or phone. As such, the evaluation team conducted 19 indepth, semi-structured interviews with stakeholders from FHWA, traffic industry consultants, ASCT adopters, and ASCT developers and suppliers. The evaluation team used the interviews to better understand the extent to which the ASC Program influenced ASCT development and adoption. The interviews helped fill in gaps in the timeline analysis and provided contextual details about what signal vendors and technology developers were experiencing with the R&T Research Program and the traffic signal control market during the analysis period. To address the intricacies in R&T evaluation, the evaluation team interviewed many stakeholders. The team ensured all interviewees that their identities would remain confidential to achieve more unbiased answers to questions they may be asked. To do so, interviewee names throughout the report were redacted. However, to maintain continuity and comparability between interviewee responses, a generic title was attributed to each interviewee. (Note that this information is presented throughout the footnotes of this report.) The interviews helped the evaluation team understand which factors affected agencies' decisions to adopt ASCT and their attitudes toward ASCT in general. They also helped address the three primary hypotheses previously described. A list of all interviewees is located in table 21 in appendix A.

Online Survey

The evaluation team designed and fielded an online survey with State and local transportation departments to connect what was learned from the indepth interviews and timeline analysis to the direct experiences of the ASCT market. The survey collected information from local, regional, and State transportation departments about their exposure to ASCTs and their experience with EDC ASCT outreach and other FHWA resources. The survey responses were used to develop an understanding of how much interest in ASCT there is today and the role FHWA and EDC played in bringing this technology to the State transportation departments. The online survey specifically helped address the first hypothesis, "FHWA R&T ASC activities accelerated the development of ASCTs."

Invitations with links to the online survey were emailed to a representative cross section of 1,137 traffic control decisionmakers from local, regional, and State agencies. An additional 105 invitations were sent to previously identified ASCT adopters to allow for more indepth analysis of adopters. In total, 212 agencies completed the survey (183 agencies comprised the cross-section sample, and 29 agencies comprised the adopter oversample).

Survey questions captured how far the agencies had moved toward adopting ASCT (e.g., unaware of ASCT, aware, considered, or purchased) and identified various sources informing the adoption process. The survey also collected information on traffic control objectives that led to ASCT purchase and ASCT satisfaction among purchasers and identified issues/barriers that prevented agencies from adopting ASCT systems for their jurisdictions. The survey findings inform the hypothesis stated in this subsection and also provide additional information that could help shape further ASCT outreach and support activities. Detailed information on the ASCT survey methodology can be found in appendix C.

3. Evaluation Findings

This chapter is divided into three subsections that highlight the chronological phases of FHWA's ASC Program. Each subsection contains an overview that summarizes the findings for that research phase at a high level. There is also an indepth discussion of findings categorized by the three primary hypotheses. These specific findings seek to address the evaluation team's secondary hypotheses and are supported by evidence collected through the evaluation methods described in chapter 2. As part of the evaluation effort, the evaluation team established a baseline state of the industry at the beginning of the phase, identified all FHWA and industry activities that took place during that phase, and then used data collected to draw logical conclusions about FHWA's influence on the outcomes. A detailed discussion of the baseline state of the industry and FHWA activities for each phase is provided in appendix B.

3.1 Phase 1: RT-TRACS Findings

Overview

In phase 1, FHWA directly funded the development and pilot testing of ASC algorithms through RT-TRACS. Of the four algorithms funded for development, three were pilot tested, and two (i.e., OPAC and RHODES) eventually came to market. The impact of RT-TRACS, however, went far beyond these two systems. The program made several signal control vendors and technology firms aware of the potential of ASCT in the United States. Several of the firms interviewed for this evaluation—some who were part of RT-TRACS and some who applied but were not selected for RT-TRACS—said that this program encouraged them to begin or continue ASC research programs. By the end of this phase, the FHWA R&T Program brought two technologies to market and increased the interest of many firms who were in the traffic signal control market.

The adoption side of the market, on the other hand, made slower progress during this phase. Agencies outside of the pilot program showed reluctance to purchase ASCT because they were either not aware of the technology or unconvinced of its benefits. During RT-TRACS, pilot tests represented the majority of FHWA-influenced technology deployments (i.e., OPAC and RHODES). A handful of agencies deployed ASCTs that were developed independently of FHWA (e.g., SCATS and SCOOT).

The technologies developed with the support of FHWA during this phase showed mixed results. Some tests showed slight improvements in travel time and reduced congestion, but others showed no change or worsening conditions. Because of this, there were no significant measurable impacts on the transportation system as a result of FHWA activities in this phase. Still, the pilots showed that some of the algorithms had promise and provided many lessons learned to researchers, which helped FHWA adapt their future activities and research to be more effective.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Finding: FHWA found that investment in ASC R&D accelerated the development of ASCTs among private vendors.

As a direct result of FHWA activities, two ASC algorithms (OPAC and RHODES) were developed that became available commercially, although the only actual deployments at the end of this period were field tests. In addition, there is some evidence that exposure to RT-TRACS generated supplier interest in the market that sparked research and the eventual development (or marketing) of ASC products. For example, in response to FHWA's request for proposal (RFP) for RT-TRACS, one manufacturer developed a plan for a prototype algorithm. Although its proposal was not funded, this manufacturer continued conducting research on ASC and began incorporating adaptive characteristics into its traffic controllers.[1] They also pursued the deal to market SCATS in the United States around this time.

An interview with an ASC system developer expressed the impact of RT-TRACS on his company. He stated the following:

> *"RT-TRACS was the key initiator to us getting involved in ASC research."*[2]

Other interviews with signal control industry leaders described RT-TRACS as pivotal to the growth and improvement of the ASC market in the United States. Excerpts from the interviews are as follows:

> *"RT-TRACS was where the [developer and vendor side of the] industry started to be aware of adaptive technology."*[3]

> *"Other programs that exist now would not have taken off without RT-TRACS."*[4]

> *"[We] took lessons from RT-TRACS and ACS Lite to make a better product [that we have currently]."*[5]

Table 3 shows the ASC systems available in the United States during this phase that were and were not affected by FHWA activities. FHWA R&T funding directly influenced the development of three out of the five systems on the market.

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[1]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[2]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[3]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[4]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

[5]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

Table 3. ASC systems introduced during phase 1 in the United States from 1992–2001.

System	Year Introduced in United States	Phase Developed	FHWA Technology Development	Explanation of FHWA Activity
SCATS	1992	1	No	N/A
OPAC	1995	1	Yes	Funded additional development and testing
SCOOT	1999	1	No	N/A
RHODES	2001	1	Yes	Funded additional development and testing
RTACL	2001	1	Yes	Funded additional development and testing

N/A = not applicable.

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

Finding: The R&T Program outreach increased awareness of all ASCTs but resulted in limited adoption and deployment of the technology.

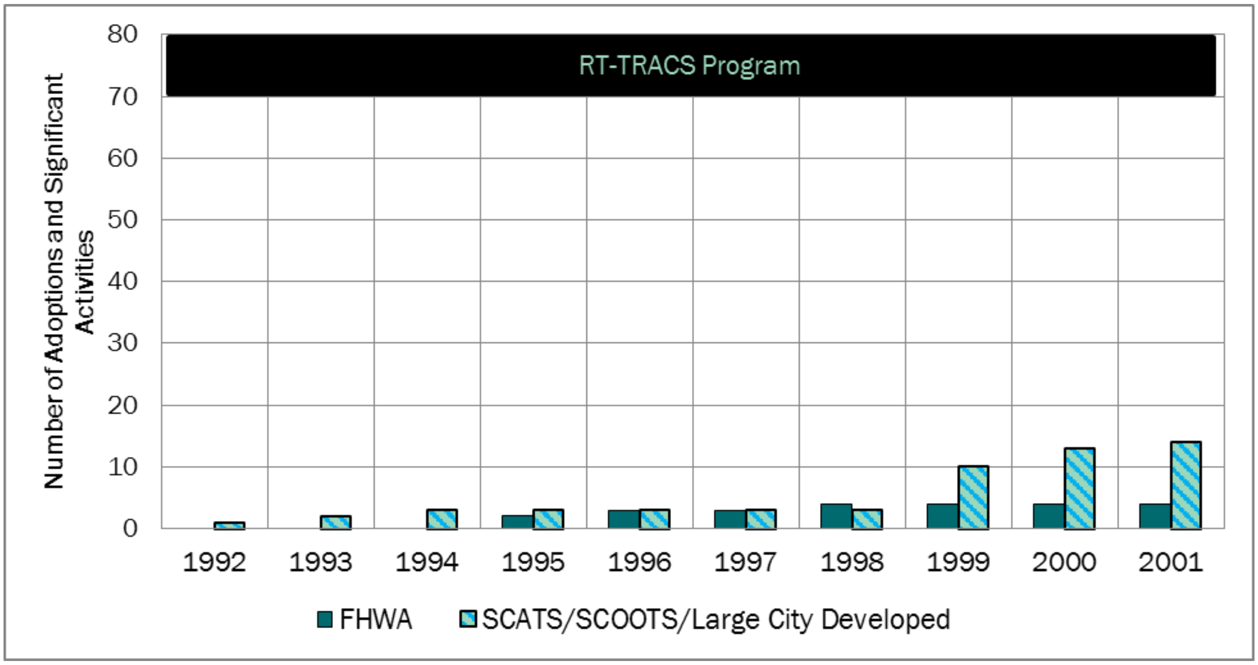
ASC adoption during phase 1 was primarily limited to the FHWA-sponsored pilot tests. It is easy to draw the conclusion that without the funding and support provided by FHWA through RT-TRACS, the four pilot agencies would not have deployed ASC as early as they did. There is no evidence suggesting that they were planning to deploy ASC systems on their own at the time. Despite short-term interest in ASC, the evidence does not support the idea that RT-TRACS increased the sites' acceptance of ASC in the long term. All of the pilot sites eventually abandoned their ASC systems after FHWA support ended, indicating that the technology was difficult to install and could not be maintained with current staff. One interviewee, who was an ASC researcher involved with RT-TRACS, suggested that the "sites found the system to be overly complex and dismantled it after the test."[6]

FHWA's market research during this time revealed some reasons why there was little interest in ASC after the RT-TRACS Program. The survey found that 40 percent of respondents were unconvinced of ASC's benefits and that many agencies viewed ASC as too expensive and too complex to implement. This evidence, along with the fact that there were few adoptions by the end of this phase, indicates that the R&T Program did not have a significant effect on increasing deployments during the early 2000s. It did, however, help move agencies in the direction of adoption by making them aware of the technology and its potential benefits. RT-TRACS helped make customers aware of adaptive technologies as they became exposed to the RT-TRACS research, testing, and results.
One interviewee noted that they "shared research and results [of the RT-TRACS pilot tests] with customers which helped them learn what adaptive systems could help address."[7]

Figure 4 and table 4 show that the adoption of ASC slowly increased during this period, with adoptions more steeply increasing around the time that FHWA was doing its pilot tests while SCATS was deploying in larger U.S. cities. The dates represented by figure 4 and table 4 show when the

[6]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.
[7]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

technology was introduced at a given location. Figure 4 shows that adoptions of FHWA-influenced ASC systems during this phase were limited to the pilot tests and did not increase beyond this.



Source: FHWA.

Figure 4. Graph. Phase 1 timeline of adoptions and significant activities from 1992–2001.

Table 4. Phase 1 timeline of adoptions and significant activities from 1992–2001.

Description of Activities	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Number of FHWA systems deployed	0	0	0	2	3	3	4	4	4	4
Number of SCATS/ SCOOT/large city developed systems deployed	1	2	3	3	3	3	3	10	13	14
Activity occurring	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS	RT-TRACS

Finding: Initial test sites for FHWA-funded ASC algorithms revealed challenges with the technology that influenced future research.

As described in the logic model, FHWA intended for the RT-TRACS test sites to serve as models for future adopters. However, there is little evidence suggesting the pilot deployments from this phase of research were used as positive models by future adopters. Although the tests may have raised awareness of the technology among industry members, they also revealed that there were many barriers for agencies to deploy ASCT.(9)

The newly developed algorithms were not readily compatible with existing traffic signal controllers. This made the cost and complexity of deployment extremely high. FHWA determined that the system cost per intersection was approximately $100,000, which was too high for most small- and medium-sized local agencies to cover with their existing budgets. These costs were significantly higher than traditional manual signal phase retiming, which has been estimated to cost $2,500–$3,500 per intersection.(24) The value proposition for ASCT is that retiming occurs on an ongoing or instantaneous basis, so there is significant reduction in the time during which the quality or efficiency of a timing schedule could degrade and mobility benefits would be reduced. Retiming on an ASCT deployment occurs at a decreasing average cost. However, while these systems may have been the most cost-effective solution, budgetary constraints for small- to medium-sized agencies may have made $100,000 systems unattainable.

FHWA received initial feedback from the pilot agencies explaining that, based on the pilot tests, the technology was too difficult to install and maintain with their current staff and skill pool. Survey research conducted by FHWA after the pilot tests confirmed that the market shared these views on the available ASCT (FHWA and other).(14)

FHWA concluded that even though the algorithms held potential for meeting the goals of ASC, they were not necessarily the optimal solution. If local agencies could not purchase and maintain these solutions, then they would not be successful in the market.

Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Finding: ASCT implementation influenced by FHWA's R&T Program yielded some measurable improvements in time savings for travelers.

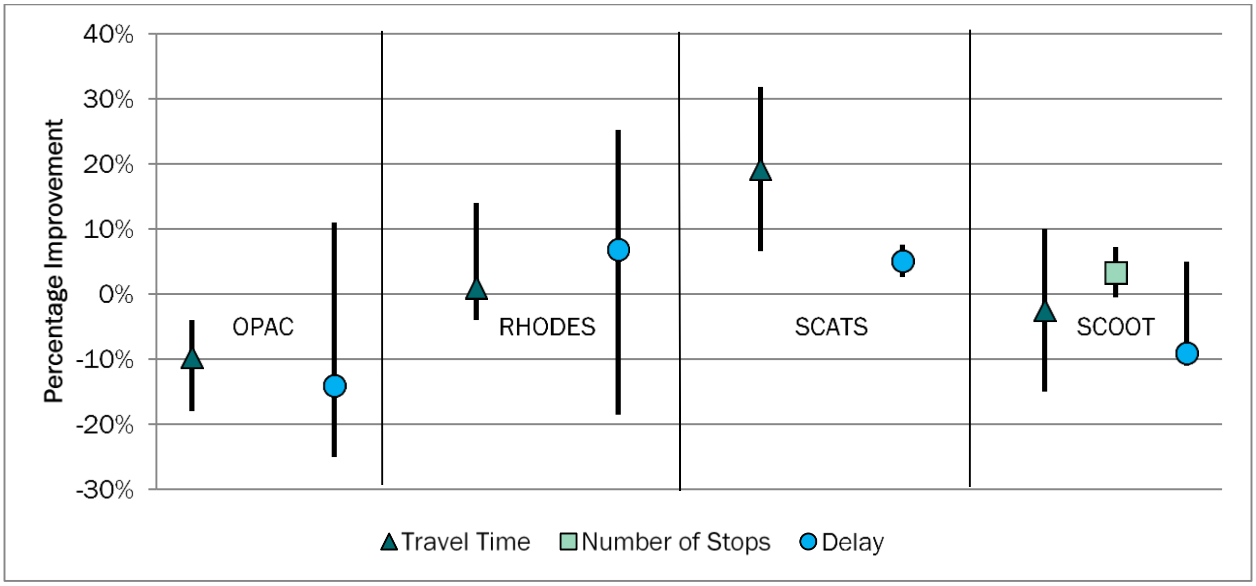
Results from tests of the algorithms developed by FHWA (OPAC and RHODES) showed mixed results.[8] OPAC significantly increased travel time and delays in most cases.(10) FHWA-contracted evaluators concluded that this was because OPAC timing plans were not optimal in determining cycle lengths, splits, and progression. RHODES, on the other hand, was able to reduce travel time and delays in many cases; however, there were still some tests in which the technology produced negative results. Although the RHODES test results were mixed, the evaluators considered it an achievement that RHODES was able to maintain conditions on certain corridors with high traffic volumes in the RT-TRACS pilot study conducted in Seattle, WA.(9,12) The evaluation report stated that "Being able to nearly match the performance of optimized timing plans indicates that RHODES performed almost optimally" (p. 6).(25) The researchers and FHWA recognized that some of the evaluations were conducted poorly (e.g., the evaluators only drove up and down the main street a few times at one TOD), which could have contributed to the negative results.

The algorithms that FHWA supported through RT-TRACS did not reduce travel time and delays as effectively as SCOOT and SCATS did in other countries. However, compared to the use of those technologies in the United States, the FHWA-developed technologies performed similarly. Because there were only four FHWA-sponsored deployments of ASC during this phase, any positive or negative effects were not significant.(9)

Figure 5 and table 5 show the effectiveness of ASCTs that were available at the end of phase 1. Four ASCTs were deployed in the United States during this phase: OPAC, RHODES, SCATS, and SCOOT. OPAC and RHODES were affected by FHWA research, while SCOOT and SCATS were developed independently. RTACL was not included in this analysis because the technology was

[8]This conclusion is based on phone interviews with numerous traffic signal stakeholders conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

abandoned by the pilot agency when the test ended, and it did not enter the market. Results from all before and after evaluations on ASCs during this phase are included. This includes all FHWA-funded RT-TRACS pilot tests, except for the RHODES test that was conducted in Tucson, AZ, where there were no data available. RHODES and OPAC showed mixed results; however, RHODES appears to be the most effective out of the two algorithms funded by FHWA.



Source: FHWA.

Note: Pilot test data not were available for the RHODES test Tucson, AZ.

Figure 5. Graph. Effectiveness of ASCTs in phase 1.

Table 5. Effectiveness of ASCTs in phase 1.

System	Travel Time Minimum (Percent)	Travel Time Median (Percent)	Travel Time Maximum (Percent)	Number of Stops Minimum (Percent)	Number of Stops Median (Percent)	Number of Stops Maximum (Percent)	Delay Minimum (Percent)	Delay Median (Percent)	Delay Maximum (Percent)
OPAC	−18	−10	−4	—	—	—	−25	−14	11
RHODES	−4	1	14	—	—	—	−19	7	25
SCATS	7	19	32	—	—	—	3	5	8
SCOOT	−15	−3	10	−1	3	7	−11	−9	5

—No data were available. It is not clear whether the implemented ASCTs affected by FHWA's R&T Program yielded measurable reductions in emissions from vehicles because there were no data available to support this hypothesis.

3.2 Phase 2: ACS Lite Development and Outreach

Overview

The second phase of FHWA's ASC Program included all activities that occurred from 2002–2008 as well as some of the activities in the early months of 2009. In this phase, FHWA used lessons learned from RT-TRACS in phase 1 to develop a new algorithm—ACS Lite—that was less costly and complex for agencies to purchase and maintain. While a private contractor developed the algorithm, four

National Electrical Manufacturers Association (NEMA) signal control vendors partnered with FHWA and adapted their signal control equipment to run the technology. This agreement is an example of a cooperative R&D agreement (CRADA), which is a written agreement between a private company and a Government agency to work together on a project. It allows private companies and the Government to accelerate the technology transfer process by leveraging resources and sharing intellectual property.

Two of the NEMA vendors went on to develop their own algorithms, one of which was based on ACS Lite. Outside FHWA, the cumulative effect of RT-TRACS and ACS Lite was noted by ASCT developers interviewed to have a significant impact on the signal control market. Several vendors and technology firms developed or improved ASC products, often giving credit to the lessons learned from RT-TRACS and ACS Lite.[9] (Readers should refer to table 21 in appendix A for more information on interviewees.) During this phase, two products directly derived from FHWA research (i.e., ACS Lite and Centracs™) became available along with two independent products (InSync™ and the Los Angeles Department of Transportation's Adaptive Traffic Control System (LA-ATCS)).

Deployment of FHWA-developed and sponsored ASC systems also increased steadily during this phase. The number of deployments increased most dramatically around the time that FHWA conducted the ACS Lite pilot tests.(14) SCOOT and SCATS deployments increased steadily as well. There was limited deployment of InSync™ and LA-ATCS because InSync™ was a relatively new technology during this period, and LA-ATCS was developed solely for Los Angeles, CA. Deployments of ASCTs during this phase are displayed in table 6.

Table 6. ASC systems introduced in United States during phase 2 from 2002–2008.

System	Year Introduced in United States	Phase Developed	FHWA Technology Development	Explanation of FHWA Activities
SCATS	1992	1	No	N/A
OPAC	1995	1	Yes	Funded further development and testing
SCOOT	1999	1	No	N/A
RHODES	2001	1	Yes	Funded further development and testing
RTACL	2001	1	Yes	Funded further development and testing
LA-ATCS	2003	2	No	N/A
ACS Lite	2007	2	Yes	FHWA developed and tested
InSync™	2007	2	No	N/A
Centracs™	2008	2	Yes	Built on ACS Lite

N/A = not applicable.

The impact and effectiveness of all ASCTs during this phase increased from phase 1. Compared to phase 1, the FHWA-sponsored technologies developed in phase 2 (OPAC and RHODES) were much more effective in reducing travel time, delays, and number of stops. ACS Lite, which was new in phase 2, significantly reduced travel time, delays, and number of stops in most deployments.(26) Technologies developed by the private sector, such as SynchroGreen™, SCATS, and SCOOT, proved to be effective in most cases as well in terms of reducing travel time, delays, and number of

[9]ASCT Adopters; phone interviews conducted by evaluation team members Jonathan Badgley and Emily Futcher in April and May 2015.

stops.(27,8,28) There were still some instances where these technologies made conditions worse or resulted in no change.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Finding: FHWA's investment in ASC R&D likely accelerated development of ASCTs and growth of the ASCT market.

Traffic signal vendors and consultants reacted to ACS Lite by beginning to develop or acquire their own ASC products. Several interviewees provided evidence supporting this hypothesis as follows:

> *"[The pilot tests] created quite the buzz at the time. Since [the pilot tests] we've seen several systems come to light such as SynchroGreen™ and [InSync™]."*[10]

When asked how FHWA influenced one company's work on developing a new adaptive product, the interviewee answered as follows:

> *"I was working with Raj Gahman and attended [ASC] lectures and worked with a couple of other involved people at FHWA. I wanted someone to take the [my] concept and run with it, but it ultimately ended up that I started the company."*[11]

During this phase, three products entered the market: ACS Lite, InSync™, and Centracs™. A fourth product, LA-ATCS, was developed only for Los Angeles, CA, and was not available in the general market. Additionally, the SCATS and SCOOT algorithms had been made available to large U.S. cities. Two of the algorithms developed (ACS Lite and Centracs™) can be directly connected to FHWA's efforts. Additionally, the founder of new entrant InSync™, while not directly connected to FHWA, credits the efforts of FHWA in RT-TRACS and ACS Lite with influencing entry into this market. Table 6 shows all systems that were available by the end of phase 2.

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

Finding: FHWA's ACS Lite research and outreach led to increased awareness and adoption of ASCTs among local agencies.

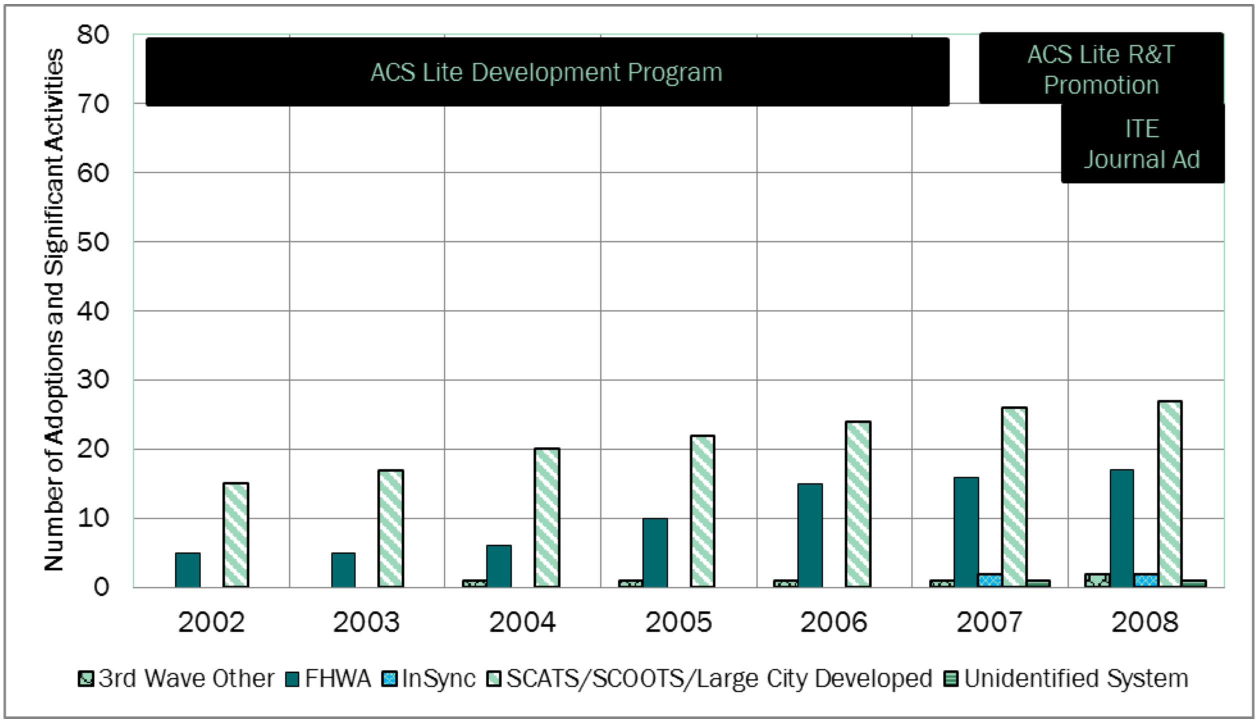
The FHWA-sponsored pilot and demonstration sites were instrumental in getting ACS Lite implemented in the seven funded locations where they were deployed. (Refer to appendix B for indepth details on FHWA funding on deployments.) The agencies involved with the initial four pilot sites in this phase were interested in the technology; however, at least two of the original sites did not maintain their systems. One interviewee noted the following:

[10]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in June 2015.

[11]Industry Professional; phone interview conducted by evaluation team members Sari Radin and Jonathan Badgley in June 2015.

> *"The staff in Gahanna were very cooperative with the process and interested. They did not continue operating ACS Lite once FHWA left because they did not have the staff to continue maintaining the system at the level required. They also believed that the benefits were not high enough to justify the budget changes necessary for additional staffing or training."*[12]

Despite the fact that some of the original test/demonstration sites deactivated the system, the demonstration tests of ACS Lite increased awareness and interest in the technology among those in the traffic signal industry. FHWA further increased awareness about ACS Lite and the pilot testing through a full-page advertisement in the *ITE Journal*.(21) Figure 6 and table 7 show the adoption of ASCTs during the period by type of technology as well as FHWA activities that were occurring at the time. Adoptions of FHWA-influenced ASCTs increased slightly around the time that FHWA conducted the ACS Lite field tests and continued to increase at a slow pace through 2008.



Source: FHWA.

Figure 6. Graph. Phase 2 timeline for ASCT adoptions and significant activities from 2002–2008.

[12]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

Table 7. Phase 2 timeline for ASCT adoptions and significant activities from 2002–2008.

Description of Activities	2002	2003	2004	2005	2006	2007	2008
Number of FHWA systems deployed	5	5	6	10	15	16	17
Number of SCATS/SCOOT/ large city developed systems deployed	15	17	20	22	24	26	27
Number of third-wave other systems deployed	0	0	1	1	1	1	2
Number of InSync™ systems deployed	0	0	0	0	0	2	2
Number of unidentified systems deployed	0	0	0	0	0	1	1
Activities occurring	ACS Lite development	ACS Lite development	ACS Lite development	ACS Lite development	ACS Lite development	ACS Lite development and promotion	ACS Lite promotion and *ITE Journal* advertisement(29,21)

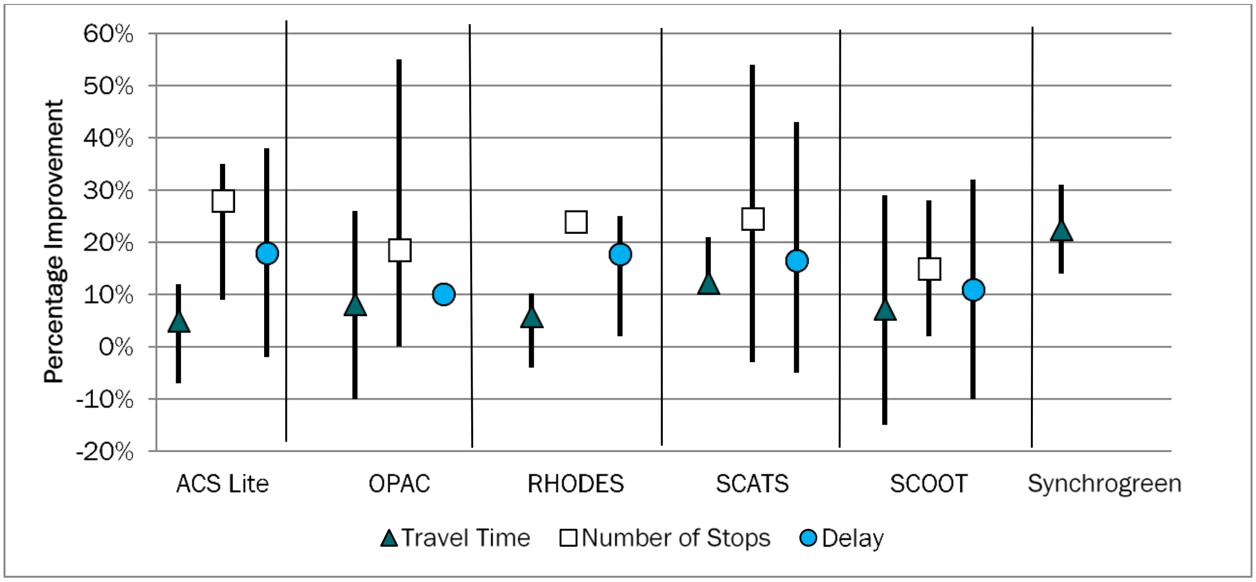
Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Finding: ASCT implementations influenced by FHWA's R&T ASC Program yielded measurable improvements in time savings for travelers.

All ACS Lite demonstration test sites yielded positive results of travel time savings, reduced delays, and reduced number of stops.(15–18) The ASC evaluation in El Cajon, CA, revealed that ACS Lite improved total delay significantly and travel time savings to a smaller extent.(18) The Bradenton, FL, and Houston, TX, studies indicated that ACS Lite significantly reduced delay and total number of stops during peak hours.(17,16) The ACS Lite deployment in Gahanna, OH, resulted in significant benefits, including number of stops and reduced delay per vehicle during peak hours.(15) Although there were many benefits, the Gahanna, OH, test also revealed some issues.(15) For instance, ACS Lite was very sensitive to good detection (i.e., if the detection did not function properly, then neither did the adaptive system), and communication was a challenge (i.e., if one link of the communications system did not function properly, then the adaptive system often made traffic worse).

Figure 7 and table 8 show the range of effectiveness of each of the ASCTs available in the market during phase 2. Five products were deployed in the market during this time: ACS Lite, OPAC, RHODES, SCATS, and SCOOT. ACS Lite, OPAC, and RHODES were affected by FHWA research, and SCOOT and SCATS were developed independently. Evaluations for these technologies measured their effectiveness in terms of travel time, number of stops, and delays. The graph shows the percent improvement in each of these categories with ASCT as compared to original TOD signal timing. Figure 7 and table 8 include data from all four FHWA-funded ACS Lite demonstration tests as well as independently funded before and after studies of all technologies.



Source: FHWA.

Figure 7. Graph. Effectiveness of ASCTs in phase 2.

Table 8. Percentage improvement of ASCTs in phase 2.

System	Travel Time Minimum (Percent)	Travel Time Median (Percent)	Travel Time Maximum (Percent)	Number of Stops Minimum (Percent)	Number of Stops Median (Percent)	Number of Stops Maximum (Percent)	Delay Minimum (Percent)	Delay Median (Percent)	Delay Maximum (Percent)
ACS Lite	−7	5	12	9	28	35	−2	18	38
OPAC	−10	8	26	—	19	55	10	10	10
RHODES	-4	6	10	24	24	24	2	18	25
SCATS	0	12	21	−3	25	54	−5	17	43
SCOOT	−15	7	29	2	15	28	−10	11	32
SynchroGreen™	14	23	31	—	—	—	—	—	—

—No data available.

Test results of all products showed an improvement in reducing the number of stops when compared to traditional TOD. In terms of travel time and delays, the results were mixed. Many of the tests (see appendix B) showed improvement, but there were many instances when a technology made conditions worse or kept them the same, as shown in table 8.(17) This suggests that although those technologies could improve travel time, they were not more effective than traditional signal timing in all situations. All technologies showed the potential to improve the number of delays, although in some situations, SCOOT, SCATS, and RHODES increased the number of delays. Technology effectiveness generally improved from phase 1.

Compared to phase 1, the FHWA-sponsored technologies developed in phase 2 were much more effective in reducing travel time, delays, and number of stops. Both RHODES and OPAC improved travel time, and OPAC significantly increased the ability to reduce delays. ACS Lite, which was new in phase 2, significantly reduced travel time, number of stops, and delays in most deployments.

It is unclear whether the implemented ASCTs affected by the R&T Program yielded measurable reductions in emissions from vehicles because there were no data available to support this hypothesis.

3.3 Phase 3: EDC Outreach

Overview

Phase 3 includes all FHWA ASC Program activities that occurred from 2009–2012, which are primarily related to the EDC Program initiative. During this phase, FHWA moved away from technology development to supporting ASCT in general. Eight additional ASCTs were launched or were being developed. The lessons learned from ACS Lite and RT-TRACS, along with the market support (e.g., education, training, and guidance documents) provided by the EDC Program fostered investment in both FHWA-funded and independent technologies during this time.(30)

This phase saw the largest increase in adoption of ASCT. The increase in adoption occurred after FHWA published an ad for ACS Lite in the *ITE Journal* and conducted extensive outreach activities (e.g., conducted workshops and webinars, produced resources) to State and local agencies.(29,21) The increase in adoption can also be tied to increased vendor activity and products available in the market.

Phase 3 also saw a dramatic increase in the effectiveness of ASCTs. Although FHWA did not fund the development or improvement of any ASCTs during this phase, their previously developed technologies (e.g., ACS Lite) showed improvements in reducing travel time delay. Furthermore, FHWA's EDC efforts likely encouraged more ASC vendors and developers to pursue research on ASCTs. Conclusive links cannot be drawn between EDC outreach and the impacts of these independently developed ASCTs, but it can be assumed that their outreach likely had some indirect effect on those impacts.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Finding: FHWA's EDC efforts encouraged technology developers, vendors, and distributors to advance their ASCT programs (e.g., via R&D).

Many ASCT products entered the market during phase 3. While few were directly tied to FHWA research, it is likely that FHWA's emphasis on ASCT through EDC encouraged developers to invest in ASC R&D. The most significant goal of EDC was to create interest in and increase use of ASCT. ASC developers and consultants noted the following through interviews:

> *"As the momentum built around adaptive, there were more vendors and products and people are pushing it more. There is more of an effort to market it."*[1]

[1]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

> *"There was a much greater knowledge and awareness of ASC after EDC. There wasn't much interest before 2010. EDC helped agencies recognize the benefit of adaptive, and competitors started entering marketplace."*[2]

Table 9 summarizes all ASCTs available in the market and that were being developed through 2015. The table shows which technologies were directly influenced by FHWA's activities. As of 2015, 6 out of 16 ASCTs that had been developed were directly affected by FHWA.

Table 9. ASCTs available in market or in development in the United States by 2015.

System	Year Introduced in United States	Phase Developed	FHWA Technology Development	Explanation	Currently Available
SCATS	1992	1	No	N/A	Yes
OPAC	1995	1	Yes	Funded further development and testing	Yes
SCOOT	1999	1	No	N/A	Yes
RHODES	2001	1	Yes	Funded further development and testing	Yes
RTACL	2001	1	Yes	Funded further development and testing	No
LA-ATCS	2003	2	No	N/A	No
ACS Lite	2007	2	Yes	FHWA developed and tested	Yes
InSync™	2007	2	No	N/A	Yes
Centracs™	2008	2	Yes	Built on ACS Lite	Yes
NWSVoyage	2009	3	No	N/A	Yes
QuicTrac™	2010	3	No	N/A	Yes
Adaptive Control Decision Support System (ACDSS)	2011	3	No	N/A	No
Meadowlands Adaptive Signal System for Traffic Reduction	2012	3	No	N/A	No
SynchroGreen™/ ATMS.now	2012	3	No	N/A	Yes
Kadence	2013	3	Yes	Built on ACS Lite	Yes
Surtrac	2014	3	No	N/A	Yes
Marlin*	2015	3	No	N/A	No

N/A = not applicable.
*Still under development at the time of writing of this report.

The SE process created both opportunities and challenges for vendors. It brought more vendors into traffic signal control RFPs as agencies completed the model systems engineering (MSE) documents, but it often made the process more complex.(30) Interviewees explained the following:

[2]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

> *"Systems approach helped level the playing field among vendors. Agencies started going out to more vendors. [Yet the] systems engineering approach adds some challenges as a vendor. A proposal response can be more complex than a direct sell."*[3]

> *"From a systems bid—[it] comes up in all RFPs. [It] May not come up initially, but [they] will ask to include something about adaptive."*[4]

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

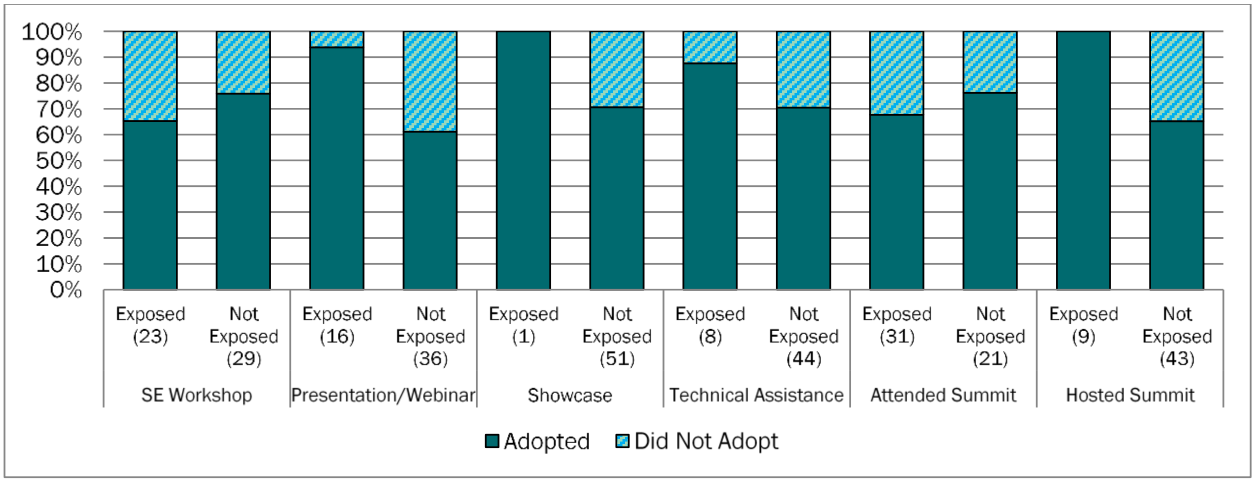
Part 1: Findings Based on Document Reviews and ASCT Interviews

Finding: EDC outreach efforts encouraged State and local transportation departments to adopt ASCT by increasing their awareness of the systems and their benefits and uses.

One way in which FHWA activities increased adoption of ASCTs was by increasing awareness and knowledge of the systems in State and local transportation departments. As described throughout this section, EDC had a notable impact on increasing agencies' knowledge of the technology and its capabilities. Figure 8 summarizes the available data on adoptions and potential exposure to EDC events. Potential exposure at the State level to presentations/webinars, showcases, technical assistance, and hosted summits are all associated with a higher likelihood of having at least one adoption in the State. Potential exposure to SE workshops and attendance at a summit are associated with a somewhat lower likelihood of adoption. These probabilities do not control for other possible influences, such as agency budget, updates to regional architectures, or congestion. A further caveat is that it is not clear whether a State received assistance because agencies in that State were already considering or planning on using ASC or whether FHWA outreach occurred regardless of prior consideration of ASC.

[3]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

[4]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.



Source: FHWA.

Note: The number of States is provided in parentheses.

Figure 8. Graph. Conditional percentage of adoptions in a State given phase 3 intervention type.

However, information from interviews supports the idea that EDC contributed to decisions to adopt. ASC vendors and traffic industry consultants noted the following

> *"EDC has raised awareness among public agencies about what is possible out there."*[5]

> *"There was no demand in the market prior to 2008–2009 (EDC). There was a perception that ASCT doesn't work prior to 2008. Some were so expensive, and many had been abandoned. EDC, without a shadow of a doubt, increased awareness in the practitioners. They would not have adopted without listening to EDC."*[6]

> *"There are a lot of bids [among vendors] for traffic control systems. Many bids mention adaptive. They're interested in getting involved someday even if it is not a requirement on this one product. They want their products now to be adaptable in the future. There is still a lot of interest in ASC but not necessarily bids for it."*[7]

> *"[Consultants'] official involvement started with EDC. We went to events as a participant. As a company, we have to make sure we are abreast of where the developments are going and advice and guidance FHWA is providing and the research."*[8]

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[5]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

[6]Industry Professional; phone interview conducted by evaluation team members Sari Radin and Jonathan Badgley in May 2015.

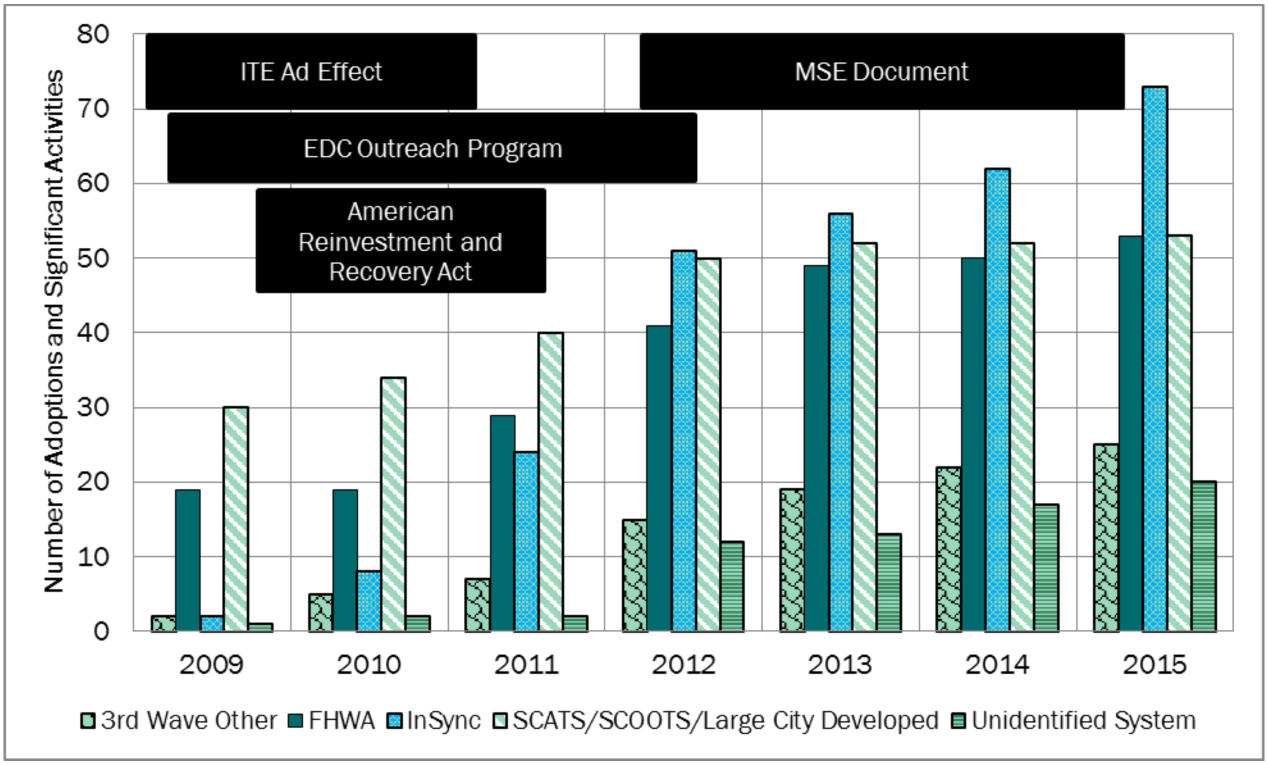
[7]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin and Jonathan Badgley in May 2015.

[8]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

> *"Consultants were a big part of drumming up interest in ASC. This helped it become an industry buzz, which led to more interest. FHWA provided information during this time."*[9]

> *"With the [EDC] workshops, [agencies] were exposed to technologies and I believe it sped up the adoption rates."*[10]

Figure 9 and table 10 show adoptions of ASCTs along with FHWA activities from 2009 to present. Adoption of both FHWA-developed and non-FHWA-developed ASCTs accelerated during this time period. The number of adoptions of FHWA-influenced technology increased quickly during the peak of EDC efforts (2009–2012) and then increased at a slower rate after the EDC Program ended its major push.



Source: FHWA.

Figure 9. Graph. Phase 3 timeline for ASCT adoptions and significant activities from 2009–2015.[11]

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[9]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[10]Industry Professional; phone interview conducted by evaluation team members Sari Radin and Jonathan Badgley in May 2015.

[11]It should be noted that EDC stopped collecting information about adoptions of ASC after 2012, so estimates of adoptions are likely to be underestimated. Florida Atlantic University's Laboratory for Adaptive Traffic Operations & Management's database, another significant source of adoptions, stopped maintaining or significantly reduced their effort in tracking which agencies had adopted which systems around this time as well.(22) These databases were supplemented with online news searches and information collected from vendor and State transportation department websites when possible.

Table 10. Phase 3 timeline of ASCT adoptions and significant activities from 2009–2015.

Description of Activities	2009	2010	2011	2012	2013	2014	2015
Number of FHWA systems deployed	19	19	29	41	49	50	53
Number of SCATS/ SCOOT/large city developed systems deployed	30	34	40	50	52	52	53
Number of third-wave other systems deployed	2	5	7	15	19	22	25
Number of InSync™ systems deployed	2	8	24	51	56	62	73
Number of unidentified systems deployed	1	2	2	12	13	17	20
Activities occurring	*ITE Journal* ad's effect and EDC Program(21)	*ITE Journal* ad's effect, EDC Program, and *American* Recovery and Reinvestment Act(21,31)	EDC Program and American Recovery and Reinvestment Act(31)	EDC Program and *Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems*(30)			

Another way in which FHWA's activities led to increased adoption was through development of the MSE document, which provided an easier and more reliable way for States to assess their traffic objectives and equipment needs and choose the most appropriate ASC system to deploy.(30) This is explained by the following interviewees:

> *"[Prior to SE] almost all local traffic engineers had no idea what the real capabilities of ASC were. They couldn't tell difference between [a] good and bad one… The objective was to provide detailed guidance to allow local traffic engineers to define what it is they want to achieve."*[1]

> *"Establishing a framework for questions and documenting problems. This forces people to figure out issues on their own or with the help of a consultant."*[2]

> *"I would say the process of SE ASCT has been great; they went through the process for the agencies to select the correct system. People are happier with their systems because they are going through the process and expectations have been corrected."*[3]

Table 11 shows the number of ASCT deployments in the United States. It is apparent that agencies have adopted a wide variety of systems, although some are more popular than others. For instance, while InSync™ is the most popular system, SCATS, ACS Lite, and Centracs™ also have a significant amount of deployments.

[1]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[2]Industry Professional; phone interview conducted by evaluation team member Emily Futcher in May 2015.

[3]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

Table 11. ASCT deployments in the United States from 1992–2015.

System	Number of Deployments	Affected by FHWA Technology Development
InSync™	73	No
SCATS	29	No
Unidentified	22	No
ACS Lite	18	Yes
Centracs™	17	Yes
SCOOT	15	No
QuicTrac™	10	No
OPAC	9	Yes
SynchroGreen™	8	No
NWSVoyage	6	No
LA-ATCS	6	No
RHODES	4	Yes
Kadence	3	Yes
ACDSS	2	No
Meadowlands Adaptive Signal System for Traffic Reduction	1	No
Surtrac	1	No
Grand Total	**224**	**N/A**

N/A = not applicable.

Despite increased interest in ASC products, agencies faced many unforeseen barriers (e.g., cost, lack of staff capacity to operate systems, lack of culture that embraces trying new things) that prevented them from adopting ASCT, many of which still remain. FHWA's research and products to date have not addressed all these barriers, many of which stem from the operation and maintenance of the systems. Evidence from the interviews includes the following:

> *"Many agencies are still reluctant to adopt ASC. Reasons for this are misinformation about cost of ASC (some estimates include cost of detection, communications infrastructure in addition to the ASC system itself), slow industry adoption of new technologies, understaffed agencies, and agencies not going after Federal funding."*[4]

> *"Engineers don't have a way to understand whether it's working or not. Bureaucrats are not risk takers (they want their pension and job stability). They have probably heard horror stories of implementing ASC. May not be a reflection on the technology as much as on the customer. It is rare to find an agency willing to experiment."*[5]

[4]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015

[5]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

> *"Agencies still really want ASC, but they still can't use technology that they have. In Tucson they aren't currently running two-thirds of their system—they are not ready to implement a more complicated system."[6]*

> *"We've had the vendor out here for a week at a time. We learn a lot but as soon as they leave we feel like there is still a ton we don't know. They have [Microsoft®] PowerPoint tutorials but they're not comprehensive. If I had 4 months to dedicate just to this, I'd probably be able to learn it, but I don't have that time."[7]*

> *"Infrastructure and detection are the biggest barriers to agencies adopting ASC. There are a lot of great ideas for implementing adaptive control but they need infrastructure to make decisions for them. Cameras, radars, many loops, etc.—the cost of detection and maintenance is a big hurdle."[8]*

> *"One of the misunderstandings is they could set it and forget it. Adaptive needs to be maintained or it is going to fall apart."[9]*

> *"Agencies want a solution that just goes off and runs autonomously."[10]*

> *"Clients immediately want adaptive rather than using SE to figure out what they need—some of the problems with adaptive in the past is when people are told it is something great but didn't go through the SE process and want adaptive but may not understand it or have staff to support it."[11]*

Part 2: Findings Based on The Evaluation Team's ASCT Traffic Signal Control Survey

Finding: FHWA and EDC resources support ASCT adoption at all stages of the adoption process. ASCT outreach promotes ASCT awareness and consideration, while the SE approach and direct FHWA support helps agencies navigate the complicated ASCT deployment process.

The findings here represent the results from 212 completed surveys of traffic signal control decisionmakers from agencies across the United States. The survey was conducted to better understand the adoption process for ASCT and the impact FHWA and EDC had on the stages of this

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[6]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

[7]State Transportation Engineer; phone interview conducted by evaluation team member Emily Futcher in May 2015.

[8]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[9]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[10]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[11]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

process. The survey was conducted in September and October of 2015. See appendix C for additional methodology and results.

Table 12 shows how State and local transportation departments are currently distributed across the four adoption stages (unaware, aware, consider, and purchase). Overall, the vast majority of agencies are aware of ASCT (89 percent aware and 11 percent unaware), and over half of the total number of agencies have considered or purchased the technology. Clearly, there is acceptance of ASCT among the sample, but to understand FHWA's impact on adoption, it is necessary to look at the sources informing each stage of the adoption process.

Table 12. Online survey respondent results by level of awareness and their representative usage of particular resources.

Awareness	Unaware	Aware	Considering	Adopted
Percentage of respondents	11	27	29	23
Average number of information sources used	N/A	3	4	5
Percentage of those who used FHWA or EDC resources	N/A	18	30	48

N/A = not applicable.

Table 13 highlights the information sources used by survey respondents at each level of engagement with ASCT. Those who are only aware of ASCT identified an average of three information sources, while those considering and purchasing ASCT accessed additional resources (on average four and five, respectively). Three sources—industry colleagues, traffic industry meetings/events, and journal articles/papers—were consulted most often as agencies initially investigated ASCT. These sources show that agencies seek formal information on ASCT but also look to their peers for information, examples, and guidance. As agencies move from awareness to consideration, traffic industry consultants become an important resource. Finally, vendors and distributors become more involved as agencies move to the purchase stage. See table 14 for the full list of sources by adoption stage.

Table 13. Top three resources used by level of awareness of evaluation team survey participants.

Awareness	Unaware	Aware	Considering	Adopted
Colleagues at other agencies	—	X	—	X
Traffic industry meetings and events	—	X	X	X (tie)
Journal articles and papers	—	X	X	X
Consultants	—	—	X	X (tie)
State transportation departments and/or metropolitan planning organizations (MPOs)	—	—	—	—
Vendors and/or distributors	—	—	—	—
Other sources used	—	—	—	—

—The resource was not a top three resource used.
X = particular resource was a top three resource used.

Table 14. Information sources by adoption stage based on the evaluation team's online survey (percent).

Survey Respondent Category	Total Engaged With ASCT (*n* = 162) (Percent)	Aware (*n* = 67) (Percent)	Consider (*n* = 53) (Percent)	Purchase (Adopt) (*n* = 42) (Percent)
Industry colleagues (outside agency)	59	57	53	71
Traffic industry meetings/events	56	42	64	67
Journal articles/papers	52	43	58	57
Consultants	51	39	55	67
Vendors/distributors	41	24	45	62
State transportation department/MPO	37	37	34	40
FHWA/EDC programs and resources	30	18	30	48
Own agency	19	7	19	36
Performance evaluations	17	4	17	36
Undergrad/graduate studies	6	6	11	0
Other	6	3	8	10

n = number of survey respondents represented.

Although FHWA/EDC programs and resources do not make the top of the list at any stage of adoption, FHWA/EDC content is often presented along with that of academics and vendors at traffic industry meetings/events. With 42 percent of those aware, 64 percent of those considering, and 67 percent of adopters attending these events and meetings, FHWA and EDC content is reaching its target audience. Direct FHWA/EDC programs and resources become more relevant as agencies get closer to purchase. While only 18 percent of respondents aware of ASCT have used FHWA/EDC resources, this percentage increases to 30 percent of those considering and 48 percent of adopters. From the evaluation team's interviews, it was determined that the MSE process and related materials serve as a guide to many agencies during the consideration and purchase stages, as indicated in the following interview excerpts:

> *"Systems engineering has been tremendous guidance. It's a really big help. If it's a federally funded project, there is nice structured guidance for that."*[12]

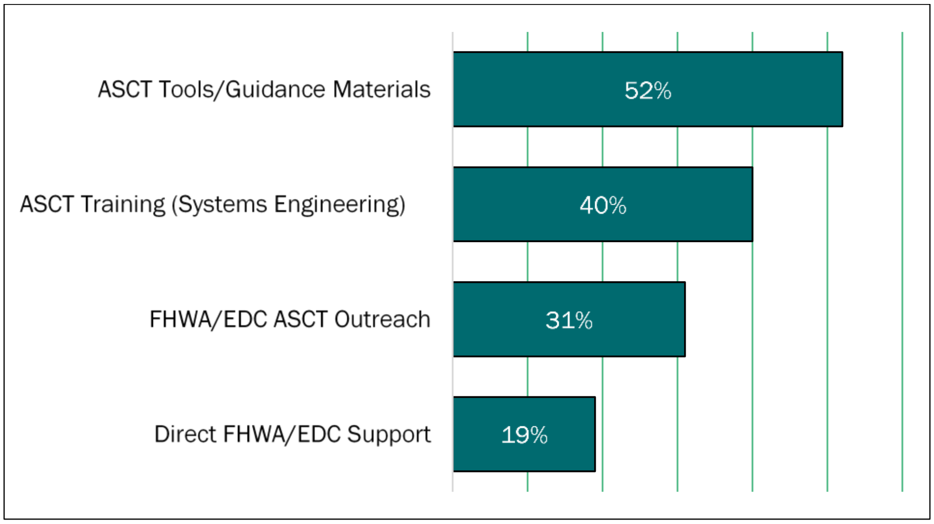
> *[SE approach] "Established a framework for questions and documenting problems. This forces people to figure out issues on their own or with the help of a consultant."*[13]

Figure 10 shows which FHWA/EDC programs and resources are used by those accessing the MSE document.(30) Due to small sub-sample sizes, the adoption stages were collapsed for reporting. Based on an unpublished internal survey distributed by the evaluation team (see appendix C), the ASCT tools and guidance materials and the ASCT SE training are the most used FHWA/EDC resources. These tools are accessed at all adoption stages and provide information about how to assess the need for an ASCT and also plan for and select one. Use of FHWA/EDC ASCT outreach was

[12]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[13]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

lower for those at the aware or consideration stages. This is likely due to the fact that formal outreach slowed after 2012. Few of those who are only aware of ASCT accessed direct FHWA/EDC support.



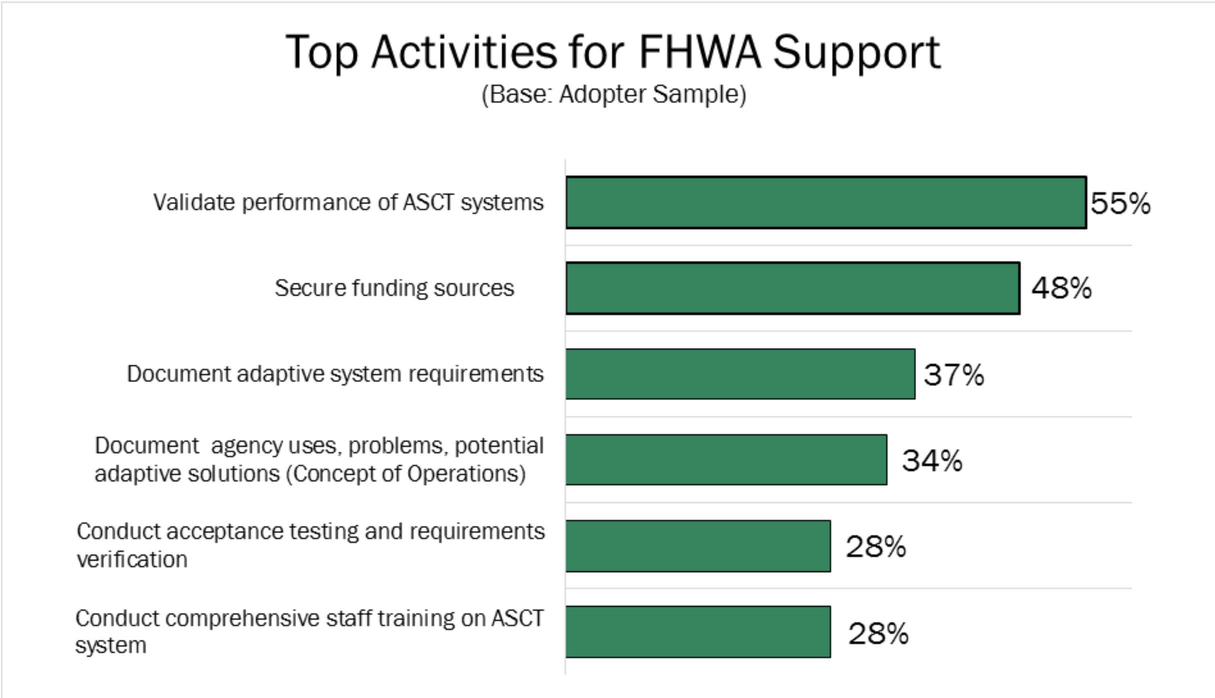
Source: FHWA.

Note: Only FHWA users were reported from the internal survey.

Figure 10. Graph. FHWA resources used.

The evaluation team's survey also collected information from adopters about the ASCT deployment activities for which they would like support.[14] The top activities, shown in figure 11, include help validating performance of ASCT systems (55 percent) after deployment and securing funding sources (48 percent). Other areas mentioned by more than one-third of adopters include providing assistance documenting adaptive system requirements (37 percent) and documenting uses, problems, and potential adaptive solutions (concept of operations) (34 percent).

[14]The adopters sample (n = 71) included adopters self-identified in the cross-section sample (n = 42) and the adopter oversample (n = 29).

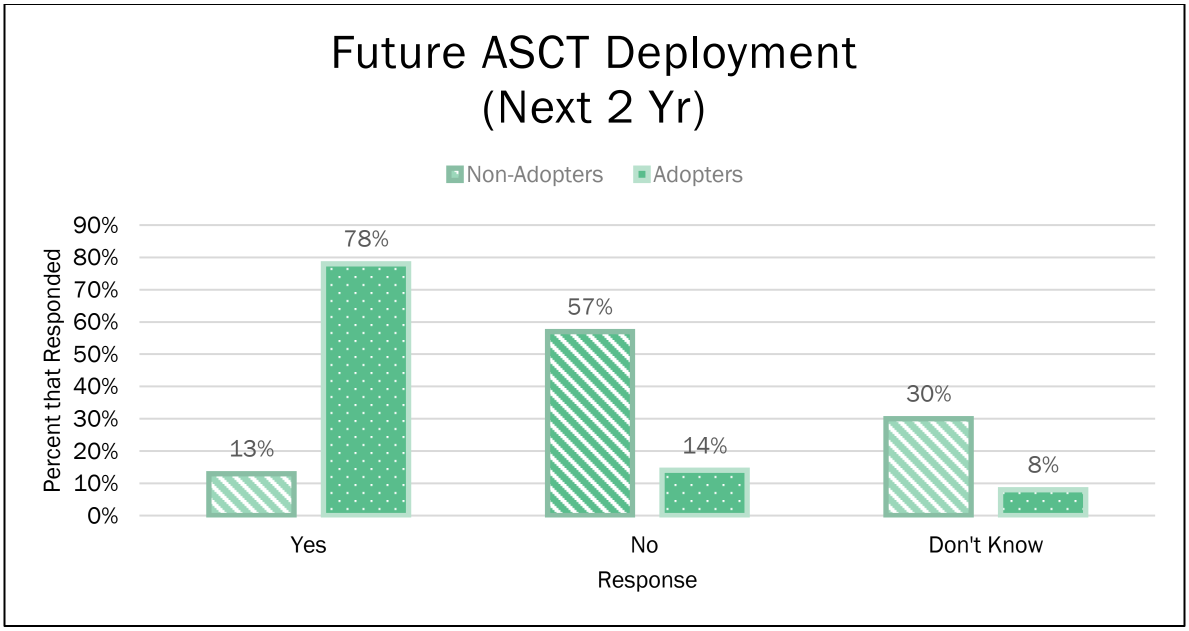


Source: FHWA.

Figure 11. Graph. Top deployment activities for FHWA support (base adopter support) based on online survey results.

Offering FHWA/EDC support in these areas can help both those considering ASCT and those who have already deployed the technology. Support for validating performance of ASCT systems will enable adopters to assess the current benefits of their systems, leading to informed decisions on whether to abandon, adjust, or expand the use of ASCT. Additional examples of system performance can also help inform those considering ASCT. Assistance in documenting elements of the concept of operations and adaptive system requirements could help agencies considering ASCT make faster, more informed decisions about the technology. Guidance while securing funding sources could also help agencies identify funds that could be used to initially purchase or expand ASCT systems.

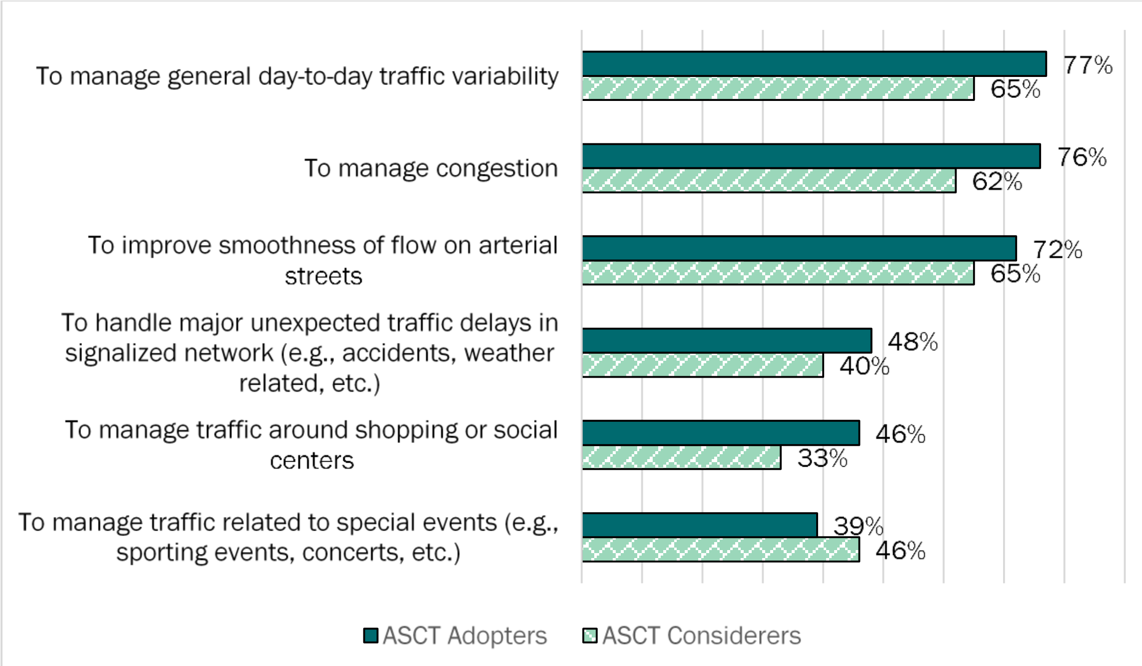
The survey findings presented in this section show how FHWA/EDC has affected the ASCT market at all levels of the adoption process. From general information on how the technology works to specific guidance for planning and deploying an ASCT system, the work FHWA/EDC has done has contributed to the acceptance and use of this technology. There is still the need for FHWA to support ASCT in the future as more agencies consider and research this technology. Figure 12 shows that 13 percent of non-adopters have plans to adopt ASCT in the near future. Additionally, 78 percent of the adopter sample plan to deploy ASCT on additional intersections and would benefit from continued FHWA support.



Source: FHWA.

Figure 12. Graph. Percentage of respondents anticipating future ASCT deployment in the next 2 yr based on online survey results.

However, despite support from FHWA and EDC, many agencies are still not convinced of the benefits of ASCT systems. State transportation departments cite barriers/challenges in deploying and operating ASCT that prevent them from adopting or expanding their use of the technology. To understand the barriers preventing agencies from adopting ASCT, it is important to understand whether adopters and non-adopters have the same traffic control objectives. Based on responses to the evaluation team's ASCT Traffic Signal Control Survey, this seems to be the case. Those currently considering ASCT and those who have adopted the technology have similar top traffic control objectives, as shown in figure 13 and table 15. These agencies want to keep traffic moving on arterial streets by managing congestion and day-to-day variability and improving smoothness of flow. Secondary objectives tend to have more specific purposes such as managing traffic around special events, shopping, or handling unexpected traffic delays due to accidents, weather, or construction. The success adopters have in achieving these common objectives and the communication of that success to those considering ASCT can help move these agencies to adoption. See appendix C for results of all objectives measured.



Source: FHWA.

Figure 13. Graph. Objectives for using ASCT systems based on Q31 and Q37 in the online survey.

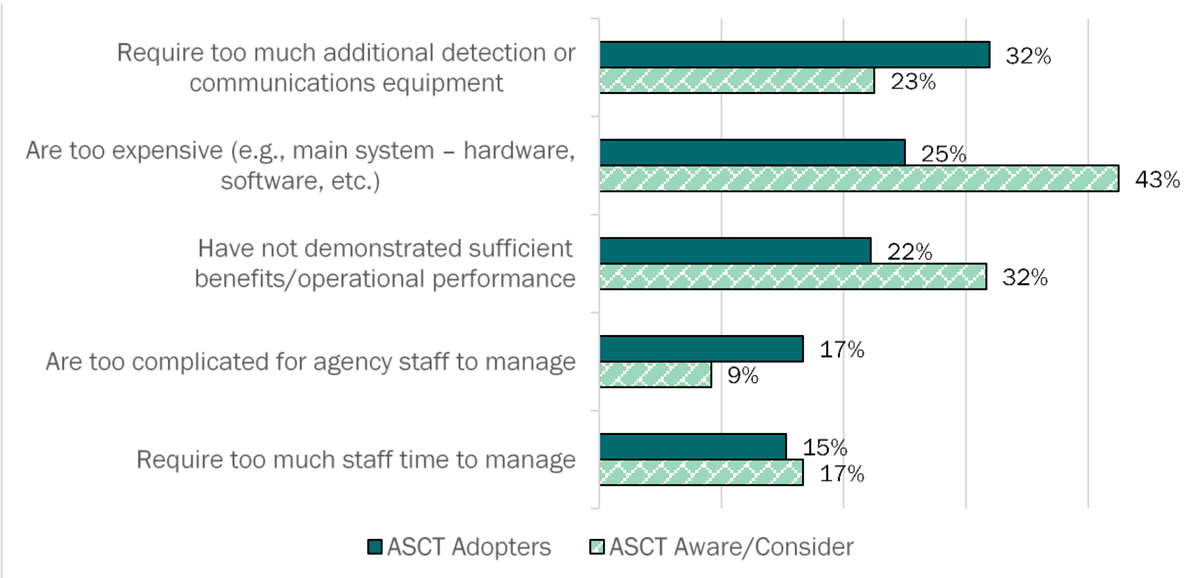
Table 15. Objectives for using ASCT systems based on Q31 and Q37 in the online survey.

Top Objectives	ASCT Considerers (Percent)	ASCT Adopters (Percent)
Manage general day-to-day traffic variability	65	77
Manage congestion	62	76
Improve smoothness of flow on arterial streets	65	72
Handle major unexpected traffic delays in signalized network (e.g., accidents, weather-related)	40	48
Manage traffic around shopping or social centers	33	46
Manage traffic related to special events (e.g., sporting events, concerts)	46	39

Based on the results from the survey, a majority of adopters reported that they were happy with their ASCT systems. A total of 66 percent said that they were somewhat or very satisfied with the system. Of the rest, 24 percent were neutral, and only 10 percent were somewhat or very dissatisfied. The results indicate that many users were having success with their ASCT systems, although at least one-third of users were having some issues with the technology, keeping their satisfaction scores lower.

The evaluation team wanted to understand the respondents who were not satisfied with their ASCT systems and asked adopters if they had experienced specified issues with their ASCT systems. The same issues were asked of agencies who were aware of or considering ASCT to see if they perceived these as barriers to purchase. The results show that there are consistencies in the perceived barriers and the actual issues experienced, as shown in figure 14 and in table 16. The top three barriers/ issues are the same for the two groups. For example, 43 percent of those aware of or considering

ASCT see the systems as too expensive, while 25 percent of those who adopted the technology say this was an issue for them. This barrier was the largest difference between adopters and aware/considerers where the other barriers presented roughly a 10 percent or less difference in opinion. Lack of demonstrated benefit/performance is also acknowledged by both groups, and those aware/considering rightly worry about needing too much additional detection equipment; more than 32 percent of adopters cite this as an issue they experienced. Appendix C provides the results of all issues/barriers measured.



Source: FHWA.

Figure 14. Graph. Top issues or barriers to adoption based on Q31 and Q37 in the online survey.

Table 16. Top issues or barriers to adoption based on Q31 and Q37 in the online survey.

Top Issue/Barrier	ASCT Aware/Considering (Percent)	ASCT Adopters (Percent)
It requires too much additional detection or communications equipment	23	32
It is too expensive (e.g., main system, hardware, software)	43	25
It requires too much staff time to manage	17	15
It has not demonstrated sufficient benefits/operational performance	32	22
It is too complicated for agency staff to manage	9	17
It requires too much staff time to manage	17	15
The agency does not currently have funding	41	N/A
The agency does not currently have expertise	33	N/A

N/A = not applicable.
Note: Those aware/considering were asked about a few additional barriers not asked of adopters: whether the agency currently has funding and whether the agency does not currently have expertise.

The following excerpts from interviews with ASCT adopters and consultants who work with them highlight these issues in the market:

> *"Infrastructure and detection are the biggest barriers to agencies adopting ASCT. There are a lot of great ideas for implementing adaptive control but they need infrastructure to make decisions for them. Cameras, radars, many loops, etc.—the cost of detection and maintenance is a big hurdle."*[15]

> *"There is a cultural problem in much of the traffic industry. Some agencies don't want to deal with new devices and new controllers. General costs are a barrier to ASC implementation."*[16]

These common barriers/issues indicate that to persuade additional agencies to purchase and fully satisfy existing ASCT users, the market needs to provide better value for the money by demonstrating performance (benefit), lowering the overall expense of systems (system costs and detection), or both. FHWA could help agencies considering ASCT as they investigate these barriers by working with them to identify detection needs upfront and providing up-to-date examples of ASCT system performance. As shown in figure 11, existing adopters also seek FHWA help in measuring performance (validating performance) to help them justify the deployment of the ASCT system.

Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Finding: ASCT implementation influenced by the ASC Program yielded measurable improvements in time savings for travelers.

FHWA did not fund any ASCT development or improvements during this phase, so they were not directly responsible for the improvement of any ASCTs. However, FHWA's EDC efforts as well as those in previous phases encouraged more ASC vendors and developers to pursue research on ASCTs. This likely led to improved systems. The results are seen in the improved performance of the current systems in reducing travel time and delay. Overall, as an industry, ASC performance seemed to have improved in terms of yielding improvements in travel time and delays.

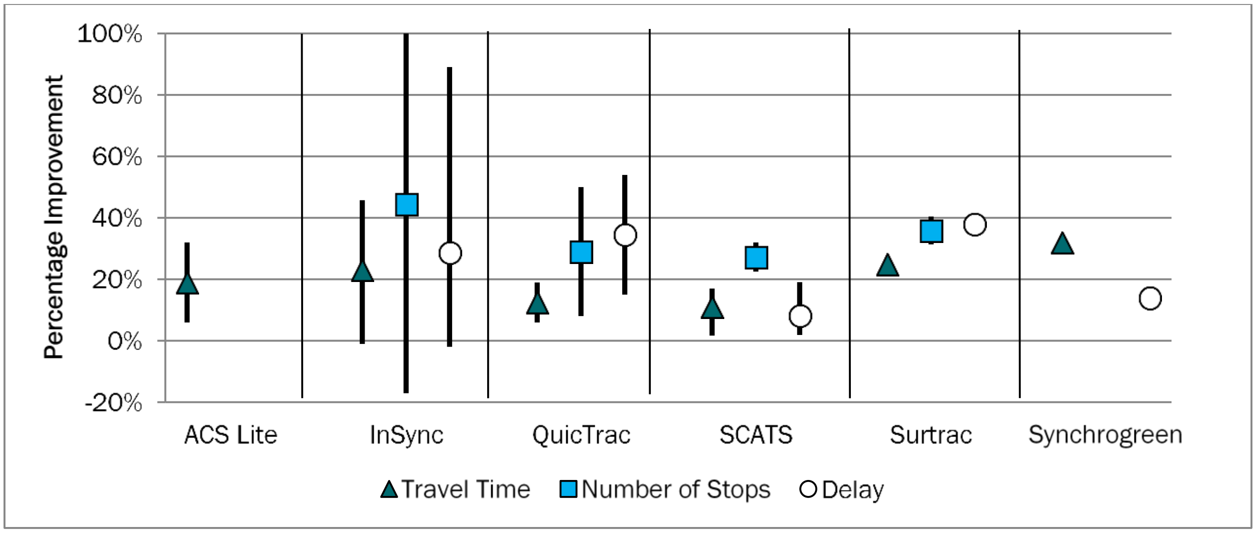
It is not possible to draw conclusions about which technologies were directly affected by FHWA's research and outreach. However, based on interview findings that suggest that some vendors pursued research because of FHWA's ASC efforts, it can be assumed that at least a few of the new technologies were affected by the FHWA R&T Program. Therefore, the R&T Program likely had some additional influence on time savings impacts during this phase.

Figure 15 and table 17 show the effectiveness of all ASCTs offered in the market during phase 3. The following nine products were available during phase 3: ACDSS, ACS Lite, InSync™, Kadence, QuicTrac™, SCATS, SCOOT, Surtrac, and SynchroGreen™. Every product on the market during this time, including those available in previous phases, was effective in reducing travel time, number of stops, and delays over TOD signal timing. Data were very limited for some of these products, so it was difficult to make comparisons between systems. All data in figure 15 are from independently

[15]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[16]Industry Professional; phone interview conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

developed before and after studies. Information and citations for these studies are found in appendix B.



Source: FHWA.

Figure 15. Graph. Effectiveness of ASCTs in phase 3.

Table 17. Percentage improvement of ASCTs in phase 3.

System	Travel Time Minimum (Percent)	Travel Time Median (Percent)	Travel Time Maximum (Percent)	Number of Stops Minimum (Percent)	Number of Stops Median (Percent)	Number of Stops Maximum (Percent)	Delay Minimum (Percent)	Delay Median (Percent)	Delay Maximum (Percent)
ACS Lite	6	19	32	—	—	—	—	—	—
InSync™	−1	23	46	−17	45	100	−2	29	89
QuicTrac™	6	13	19	8	29	50	15	35	54
SCATS	2	11	17	23	27	32	2	8	19
Surtrac	24	25	26	31	36	40	35	38	41
SynchroGreen™	30	32	34	—	—	—	14	14	14

—Data were unavailable.

4. Recommendations

The ASC Program activities took place over two decades and incorporated technology development, testing, and outreach. At the same time, the state of the practice was furthered by developments made by the private sector, Government funding availability, and the introduction of the SE planning requirement. This situation is typical of long-term efforts that are designed to develop and encourage adoption of emerging technologies. Future efforts could benefit from the following recommendations.

Recommendation: While focusing on technical issues, there should be consideration of and planning for the longer-term issues of market and deployment community issues.

In the first phase of the ASC Program, FHWA initially focused on addressing a technical issue to develop an ASC system that could be deployed in the United States without a full understanding of the needs and constraints of potential purchasers. Much of the market research conducted during this time focused on international examples because most ASC deployments at the time were in Europe and Australia, but the markets and needs in those regions were very different from those in the United States. The technologies and their successors developed during that first period have achieved limited adoption. At the beginning of the second phase, the program changed its technical focus to address issues identified in market surveys conducted by FHWA. The resulting technology, ACS Lite, was notably more successful, having addressed issues of concern.

For future research, FHWA should consider doing more extensive domestic market research at the outset. It is important to understand both the needs (i.e., problems to address) and the market's limitations that could present barriers to purchase (e.g., limited funding for equipment and limited agency expertise) upfront and, if a program unfolds over a number of years, to learn how those needs and barriers change over time. By the time that FHWA was planning EDC for ASCT, there were more vendors and products to choose from, and FHWA introduced the MSE process. While this report addressed a need that FHWA observed, it also created difficulties in some instances, such as expansions of existing ASCT deployments. At each step in the process, it is important to systematically gather information on needs to make the most effective decisions.

Recommendation: FHWA should consider how technology will be transferred to the market when conducting initial research. Strategies and processes should be updated periodically.

For technologies that are developed by FHWA that are ultimately proprietary and intended for wide use, it is necessary for vendors to offer those technologies in the market. There are a variety of ways to accomplish this goal (e.g., CRADAs, open-source technology), and different approaches may be appropriate at different times or in different markets. Before identifying a technology transfer strategy, it is important to understand how choices made in technology development and testing may facilitate or create barriers once the market is developed (i.e., Is the agency creating potential barriers for adoption through its research approach?). In phases 1 and 2 of ASC research, FHWA established a CRADA with the four major NEMA vendors to encourage them to make their equipment compatible with ACS Lite. In exchange for making their equipment compatible with ACS Lite, FHWA offered the vendors licenses to the ACS Lite algorithm. However, after FHWA arranged this licensing partnership, a new vendor, whose ASC technology did not rely on integration with NEMA systems, claimed FHWA was creating a competitive disadvantage for them by focusing on and promoting ACS Lite and the other ASCTs that rely on integration with NEMA systems. In phase 3, EDC broadened the pool of technologies that could be considered ASCT. This broader focus brought in additional vendors, which facilitated the growth of the market.

While it is not possible to anticipate all factors that may affect adoption at the beginning of research, it is necessary to periodically reassess how the development and promotion of technologies may affect the market. FHWA adapted to the changing ASCT market by expanding the scope of technologies that were included in promotional activities so that all vendors in the market could participate. However, the unanticipated disruption in the phase 2 research program created problems for some of the NEMA participants.

Vendor partners noted the following:

> *"We never did anything with ACS Lite after the field trial. [FHWA] had been talking about a second phase over the course of a year or two, but this never happened. We lost interest and moved on. We felt like we wasted our time on the whole field project. We had source code and could have continued developing on our own, but this wasn't what we expected to happen. FHWA had a road map and we expected them to follow it."*[1]

> *"Our company wasn't engaged because I would have needed to understand the benefits of being involved. ACS Lite seemed to die."*[2]

> *"[We] had a contract with FHWA to add features to ACS Lite, but this was cancelled due to [Vendor's] lobbying."*[3]

The EDC Program Manager noted that for a period, only the company that developed the algorithm for ACS Lite could provide it, and FHWA had not given it to any of the other vendors yet.[4]

Recommendation: Information about the technology itself and its related outreach program should be shared throughout FHWA.

There were instances during EDC outreach when FHWA field staff did not fully understand ASC and its applications, and this affected agencies' abilities to pursue ASC. For instance, an industry consultant who was interviewed noted that there was a lack of communication with division offices that hindered the use of *Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems*.[5](30) At the same time that the MSE document was being released, the division staff at FHWA did not have an understanding of what ASC was and how to fit it into the ITS world. FHWA should make sure that all staff who are responsible for a certain topic or product are

[1]FHWA Employee; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[2]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[3]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[4]FHWA Employee; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[5]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

aware of its applications and are able to communicate its uses and requirements to potential adopters.

Recommendation: Research programs should anticipate evaluation and coordinate with their strategic plans from the outset.

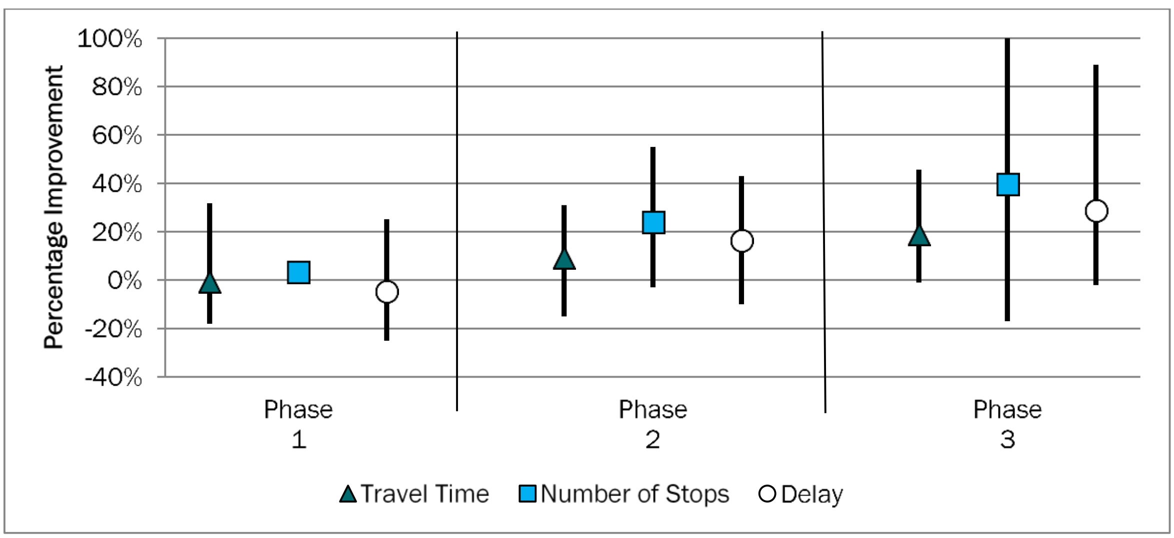
When designing a research effort, program managers should consider future evaluation needs (e.g., data and performance measures) and incorporate them into the research design. Evaluation during the research design would improve the quality and usefulness of future evaluations. There were certain ASC performance measures that were difficult to evaluate (e.g., congestion and attendance at FHWA ASC workshops) due to limited data. To ensure that sufficient data are available for evaluation, project managers should establish performance measures and collect data for those measures from the outset and develop regular progress reports to ensure that quality data are being collected throughout the program.

5. Conclusions

FHWA's activities had varying effects on the market and intended technology impacts over the three phases of ASC research and outreach. Their impacts primarily occurred through encouraging ASCT development, promoting adoption by agencies, and supporting improvement of ASCT effectiveness. On a holistic level, the ASC Program has had a positive effect on ASCT development and deployment and, ultimately, its impact on travel time and delays.

In the first phase, FHWA invested in exploratory research on ASCs, which resulted in few time savings and emissions benefits compared to ASCs that had been deployed internationally. Lessons learned from this phase and additional funding and research resulted in improved products in the second phase that showed significant improvements in travel time savings and emissions reductions. The fact that FHWA was investing in and promoting this technology also encouraged private firms and universities to conduct their own R&D on ASC. Many of these products proved effective in reducing travel time, number of stops, and delays as well. In all cases, these technologies improved travel time, number of stops, and delays.

By phase 3, most improvements in technology effectiveness resulted from private investment and development. However, it can be assumed that FHWA's EDC marketing and outreach had an indirect effect on the benefits from privately developed technologies based on evidence from the interviews. A summary of the change in effectiveness of all ASCTs over the course of FHWA's ASC Program is shown in figure 16 and table 18.



Source: FHWA.

Figure 16. Graph. Change in effectiveness of ASCTs over the course of the ASC Program.

Table 18. Change in effectiveness of ASCTs over the course of the ASC Program.

Phase	Travel Time Minimum (Percent)	Travel Time Median (Percent)	Travel Time Maximum (Percent)	Number of Stops Minimum (Percent)	Number of Stops Median (Percent)	Number of Stops Maximum (Percent)	Delay Minimum (Percent)	Delay Median (Percent)	Delay Maximum (Percent)
1	−18	−1	32	−1	3	7	−25	−5	25
2	−15	9	31	−3	24	55	−10	17	43
3	−1	19	46	−17	40	100	−2	29	89

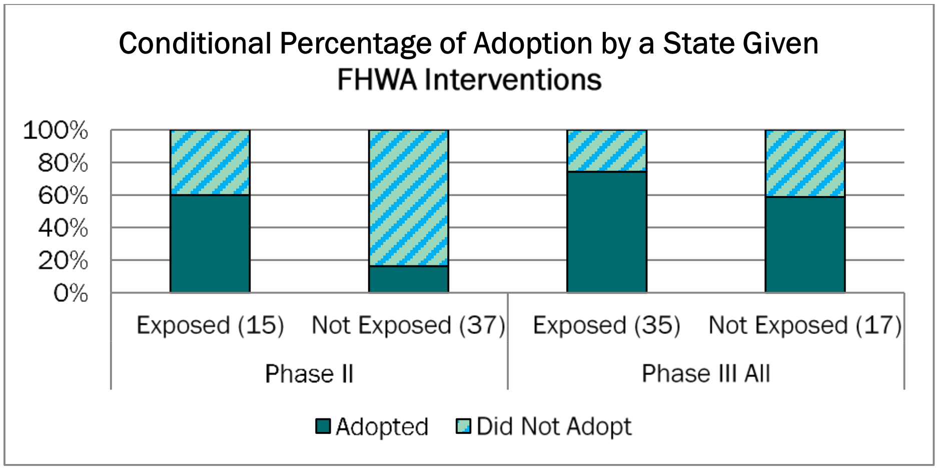
Figure 16 and table 18 show that the ability of ASCTs to steadily reduce travel time, delays, and number of stops improved over the course of the ASC Program. The number of ASCTs deployed in the United States today, however, is still very small compared to the number of traffic signals to which they could potentially be applied. As such, the cumulative effects of ASCTs in the United States are likely extremely small. Furthermore, the exact travel time and congestion savings as well as monetary benefits are difficult to measure because of data limitations. A few adopters discussed the estimated monetary benefits (in terms of travel time and delay savings) of their ASCT deployments in their evaluation reports. (Refer to appendix B for more information on FHWA activity related to evaluating ASCT deployments.)

Table 19 shows the estimated annual benefits for various deployments of ASCTs on the market from 1998–2012. Although these data are very limited, a rough estimate can be made about the total monetary savings of technologies affected by FHWA. The estimated annual benefits of ASCTs funded by FHWA are $474,333 for ACS Lite, $834,815 for OPAC, and $1,443,052 for RHODES. There are currently about 53 deployments of FHWA-affected technologies consisting of some mix of ACS Lite, OPAC, and RHODES. Therefore, it can be estimated that the effects attributed to FHWA's efforts fall somewhere in the range of $25,139,649 (assuming all deployments are ACS Lite and have benefits of $474,333) and $76,481,756 (assuming all deployments are RHODES and have savings of $1,443,052) per year. The number representing FHWA-affected efforts would increase as the number of deployments increases.

Table 19. Estimates of annual benefits from ASC systems.

System	Reference Number	Annual Benefits	Location	Year of Installation
SCOOT	28	$984,186	Toronto, Canada	1998
SCOOT	32	$806,500	Sao Paolo, Brazil	1998
SCATS	33	$583,996	Chula Vista, CA	2003
ACS Lite	34	$474,333 (aggregated average benefits)	Gahanna, OH; Houston, TX; and Bradenton, FL	2007
OPAC	35	$834,815	Pinellas County, FL	2007
RHODES	7	$1,443,052	Pinellas County, FL	2007
InSync™	36	$2,452,493	Lee's Summit, MO	2010
InSync™	37	$795,405	Upper Merion, PA	2010
SynchroGreen™	38	$370,025	Gloucester and Chesterfield Counties, VA	2010
InSync™	39	$1,722,152	Salinas, CA	2011
InSync™	40	$975,260	Wichita, KS	2011
InSync™	41	$1,326,000	Greeley, CO	2012
QuicTrac™	42	$898,000	Woodland Park, CO	2012

The marketing and outreach conducted through EDC likely had an effect on the number of deployments of all ASCTs (i.e., not just those directly affected by FHWA). This means that the total annual benefits may be even higher than those calculated above. Figure 17 shows the conditional probabilities of adoption given whether or not agencies within the State had exposure to FHWA activities. Phase 2 activities included ACS Lite outreach, which included ACS Lite exhibits at ITE, TRB, or similar events and ACS Lite pilot testing. Phase 3 outreach activities included attendance at an EDC summit, the hosting of an EDC summit, presentations/webinars, technical assistance, and showcases. Figure 17 shows that the probability of adoption for those who attended an EDC event was approximately 75 percent compared to 60 percent for those who did not attend an EDC event. It is possible that FHWA's activities were responsible for this estimated increase in adoption; however, this evaluation did not cover all potential activities that could have affected adoption rate.

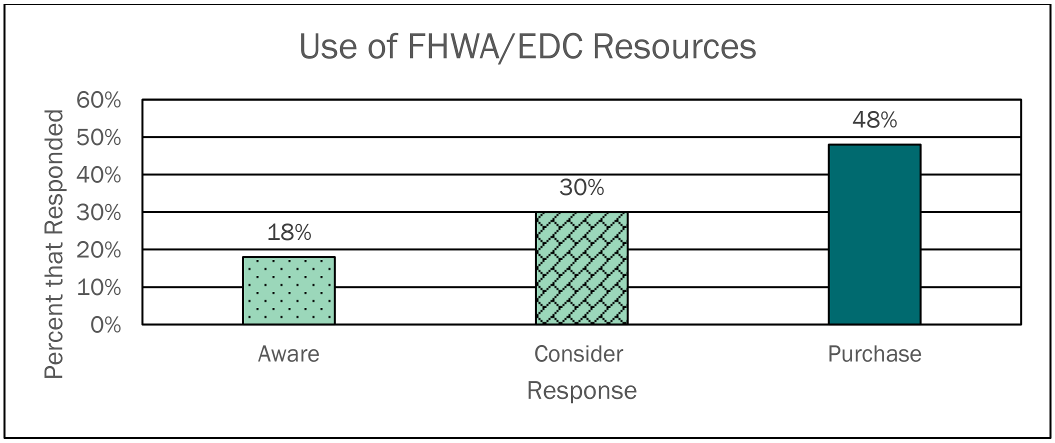


Source: FHWA.

Figure 17. Graph. Conditional probability of adoption given FHWA interventions.

Findings from the survey of traffic signal control decisionmakers also support the hypothesis that FHWA/EDC programs influenced the number of ASCT deployments. This influence can be seen at all stages of the ASCT adoption process, as shown in figure 18. Although relatively few traffic signal control decisionmakers at the awareness stage (18 percent) had directly accessed FHWA/EDC resources, many likely had exposure to EDC ASCT materials at industry meetings or events (56 percent attended). Direct FHWA/EDC exposure increased as agencies became more engaged with ASCT; a total of 30 percent of those considering ASCT and 48 percent of those purchasing (across all ASCT systems) reported accessing FHWA/EDC materials or attending outreach and training events. The SE process (trainings and materials) and direct FHWA support were key resources identified by these agencies. ASCT adopters interviewed by the evaluation team also indicated that they would like FHWA support in the future as they validate the performance of their ASCT systems and seek funding for additional purchases.[1]

[1]ASCT Adopters; phone interviews conducted by evaluation team members Jonathan Badgley and Emily Futcher in April and May 2015.



Source: FHWA.

Figure 18. Graph. Survey respondents using FHWA/EDC resources.

Based on the available data and interview findings, it is clear that the ASC Program and EDC outreach had a significant positive impact on ASCT development and adoption in the United States. It is also likely that the program produced positive impacts in terms of time and congestion savings; however, data were too limited to make any definitive conclusions. Because the program had such a long duration, it is not surprising that FHWA faced obstacles along the way. Nonetheless, the program was successful because of the way FHWA adapted to those challenges and made intermittent improvements to its program. Findings from this evaluation suggested several opportunities that FHWA had to anticipate and certain issues that had to be mitigated before they arose. For example, conducting more market research before initiating RT-TRACS and ACS Lite development could have revealed that there were barriers in the market that prevented agencies from being able to adopt regardless of how effective the technology was. In future research, FHWA should consider the findings and recommendations from this evaluation to eliminate hurdles before they arise.

Appendix A. Interview Methodology

The evaluation team conducted interviews with six types of stakeholders: (1) FHWA program managers, (2) technology developers (i.e., academics), (3) ASCT vendors (i.e., industry professionals), (4) traffic industry consultants (i.e., industry professionals), (5) ASCT adopters, and (6) ASCT prospective adopters. The evaluation team developed a detailed interview guide for each stakeholder group. The FHWA program manager interviews focused primarily on the ASC Program and activities. The interview guides for non-FHWA interviews contained a standard set of core questions designed to help the evaluation team understand the respondents' roles in the traffic signal industry and their experiences with ASCTs. From there, the guides were tailored to each stakeholder group. Interviews with technology developers and vendors focused on getting information about their experiences with FHWA's research program and the market at this time. Interviews with ASC adopters and prospects as well as consultants included questions about the process for considering and purchasing ASCTs as well as their experiences with the FHWA outreach efforts. Table 20 shows interview topics by non-FHWA stakeholder group.

Table 20. Interview topics by non-FHWA stakeholder group.

Interview Question Scope	Indepth Interview Topics	ASCT Vendors (Partner and Other)	Technology Developers	Traffic Consultants	ASC Prospects	ASC Adopters
Background	Role in traffic signal industry	X	X	X	X	X
Background	Experience with ASCT	X	X	X	X	X
Background	Knowledge of/experience with RT-TRACS	X	X	—	—	—
Background	Technology/program impact	X	X		—	—
R&T ASC research phase 2 (ACS Lite)	Experience with ACS Lite development program	Partner only	X	—	—	—
R&T ASC research phase 2 (ACS Lite)	Experience with ACS Lite pilot test/demo (goals/ performance/impact)	Partner only	X	If applies	—	Pilot site only
R&T ASC research phase 2 (ACS Lite)	Participation in ACS Lite outreach	Partner only	X	—	—	—
R&T ASC research phase 2 (ACS Lite)	Attend ACS Lite outreach	X	X	X	—	—
R&T ASC research phase 2 (ACS Lite)	ACS Lite technology/ program impact	X	X	X	—	—
R&T ASC research phase 3 (EDC)	Participation in EDC outreach	X	X	X	–	--
R&T ASC research phase 3 (EDC)	Attend EDC ASCT outreach or training	X	X	X	X	X
R&T ASC research phase 3 (EDC)	EDC outreach and training impact	X	X	X	X	X

Interview Question Scope	Indepth Interview Topics	ASCT Vendors (Partner and Other)	Technology Developers	Traffic Consultants	ASC Prospects	ASC Adopters
ASCT adoption (self or client)	Needs/objectives for traffic controls system	—	—	X	X	X
ASCT adoption (self or client)	Details of systems adopted (considered)	—	—	X	X	X
ASCT adoption (self or client)	Sources of information	—	—	X	X	X
ASCT adoption (self or client)	Satisfaction with system	—	—	X	—	X
ASCT market	Changes seen in market	X	X	X	—	—
ASCT market	Factors impacting adoption/barriers to adoption	X	X	X	X	X

—Topic was not discussed.
X = the topic was discussed.

The interviewees were sent a copy of the core questions the evaluation team intended to ask in advance. A detailed list of the interviewees is included in table 21.

Table 21. ASCT Evaluation interviewee list.

Role, Organization, or Jurisdiction	Position	Interviewee Category	Interview Date
FHWA's RC	Traffic Management Specialist	FHWA Employee	6/1/2015
FHWA ASC Program Manager	Team Leader	FHWA Employee	5/7/2015
Kimley-Horn and Associates (former University of Arizona, Siemens)	Director of Smart Mobility	Industry Professional	5/8/2015
University of Arizona	Transportation Engineer	Industry Professional	5/7/2015
Anne Arundel County, MD	Traffic Signal Engineer	Industry Professional	5/12/2015
Salt Lake City, UT	Traffic Signal Operations Engineer	Industry Professional	5/19/2015
Econolite	Chief Technology Officer	Industry Professional	5/14/2015
Siemens	Product Manager	Industry Professional	5/11/2015
Peek Traffic	Chief Technology Officer	Industry Professional	5/18/2015
McCain	Product Manager	Industry Professional	6/3/2015
Rhythm Engineering	President	Industry Professional	5/22/2015
DKS Associates	Civil Engineer	Industry Professional	5/22/2015
TransCore	Associate Vice President	Industry Professional	5/8/2015
Pennsylvania Department of Transportation	Traffic Engineer	State Transportation Engineer	5/19/2015
Cobb County Department of Transportation	Traffic Engineer	State Transportation Engineer	5/18/2015
Seminole Florida Department of Transportation	Traffic Engineer	State Transportation Engineer	5/21/2015

Role, Organization, or Jurisdiction	Position	Interviewee Category	Interview Date
Virginia Department of Transportation	Engineering Manager	State Transportation Engineer	5/21/2015
Massachusetts Department Transportation	State Traffic Engineer	State Transportation Engineer	5/26/2015
Transportation Engineering Firm	Professional Engineer	State Transportation Engineer	5/21/2015

The interviews yielded detailed notes with key quotes on the topic areas covered in each interview. The evaluation team analyzed the notes individually and divided the data into three chronological phases: (1) R&T RT-TRACS research, (2) ACS Lite R&D, and (3) EDC outreach. The team then looked-for evidence to support or refute the primary and secondary hypotheses within these phases and further categorized the evidence by hypothesis. After synthesizing the notes into phase and hypothesis categories, the team made preliminary observations about the findings and their impacts on the predicted outcomes from the logic model and hypotheses. The evaluation team also used information from the interviews to inform the timeline analysis, provide input for the quantitative survey, and provide findings and quotes to inform the outcomes of each phase of the evaluation. Findings from the analysis of interview notes are located in the Overview section in chapter 3.

The evaluation team also conducted a narrative analysis that looked at the "story" of each interviewee. Rather than describing each interviewee's story separately, the evaluation team combined their stories into a single description of the program activities and outcomes in each phase, referencing applicable evidence from various interviewees. Findings from the interviewees' stories are described in the Overview section in chapter 3.

While reviewing the data, the evaluation team also searched for evidence that would support the primary and secondary evaluation hypotheses related to the overall program (i.e., not just each phase). Because the core hypotheses transcended the chronological phases, it was important to identify overarching themes that could be discussed generally. These data were categorized separately, and the findings are described in chapter 5.

Appendix B. ASC Program Description

This appendix describes detailed findings about the ASC Program that were uncovered through the literature review and interviews. The Baseline subsections describe the state of the ASCT industry at the beginning of the phase as well as non-FHWA activities that were occurring, and the FHWA Activities and Outputs subsections describe the FHWA intervention that potentially led to the outcomes discussed in the Evaulation Findings section. The evaluation team used the information presented in this appendix to draw conclusions about the outcomes and impacts of FHWA's activities.

B.1 Phase 1

The first phase of the ASC Program included all FHWA and industry activities that occurred from 1992 (initiation of FHWA's ASC research) until 2002 (end of RT-TRACS). The following discussion of hypotheses describes the baseline conditions in the market before FHWA intervention and then the FHWA activities and outputs and their effect on the market.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Baseline

In the early 1990s, there was a limited amount of ASC activity in the United States. Two systems, SCOOT and SCATS, had been widely available in Europe and Australia since the 1970s; however, at that time, no companies in the United States were selling a viable system.(43) There were several companies and universities, however, that were beginning to research the feasibility of ASC use in the United States. Since the 1980s, researchers at the University of Arizona had been developing an algorithm that could be deployed in the United States.(44) The foreign distributors of SCOOT and SCATS coordinated with domestic traffic signal companies to conduct research and plan field deployments in the early 1990s.[1] The general goal of this research was to understand how ASCs could enter the U.S. market and what factors it would take for the technology to succeed. Although it took several more years before market-ready ASC products were launched in the United States, it demonstrates that there was interest in the systems before RT-TRACS was launched.

Independent industry activity related to ASCs continued to grow throughout the 1990s. In 1994 to 1995, a major U.S. traffic signal vendor met with the SCATS team in Australia with the intent of getting a deal to market SCATS in the United States. Another U.S.-based company that was focused on transportation management services ultimately became the U.S. distributor of SCATS and began doing R&D to make the system compatible with U.S. traffic signal infrastructure. Private companies funded a few field deployments to test their systems on U.S. corridors, and SCATS became available in 1998.[2]

[1]ASC Stakeholders; phone interviews conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

[2]ASC Stakeholders, phone interviews conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in May 2015.

FHWA Activities and Outputs

Recognizing the potential for ASCs in the United States but with little knowledge of applicability, FHWA initiated a research program on ASCs in 1992. The goal of the program, known as RT-TRACS, was to take advantage of advances in computer technology to create an ASC algorithm that could be widely deployed in the U.S. market. Through this program, FHWA provided funding to four organizations to develop and test innovative ASC algorithms.(45,46) Three of the organizations developed the following field-deployable algorithms:

- OPAC (University of Massachusetts Lowell).*
- RHODES (University of Arizona).
- RTACL (University of Pittsburgh).

Development of the algorithms wrapped up in 1995, and FHWA began organizing field tests for each of the algorithms in 1996.(3) FHWA coordinated with several major traffic signal vendors during this phase because they had to integrate the algorithms with the test site agencies' existing traffic controllers. The locations where the field tests occurred, the systems tested, and the dates the final evaluation reports were published for the four field tests are shown in table 22.

Table 22. Summary of RT-TRACS pilot tests.

System	Pilot Test Location	Final Evaluation Report Publication Date
OPAC	Reston, VA(10)	1999(10)
RTACL	Chicago, IL(11)	2001(11)
RHODES	Seattle, WA(12)	2002(12)
RHODES	Tucson, AZ(13)	2003(13)

The pilot programs showed mixed results; none of the systems significantly improved travel time and delays. Note that results from the pilot programs were established from numerous tests and surveys conducted and distributed by FHWA; these tests and surveys are discussed in greater detail in section 3.1 of this report. Test results from some pilot sites showed that RTACL and OPAC made traffic conditions worse. In other sites, however, test results showed that OPAC and RHODES were able to maintain traffic conditions on very congested corridors, and this was considered an achievement by those running the tests. Although the algorithms were not perfect, they showed promise and areas for improvement. RTACL was not considered successful, and the recommendation was to continue developing the algorithm before deploying it again.

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

Baseline

There was a market for ASC in Europe and Australia; however, few agencies had deployed the technology in the United States. There were a few deployments of SCATS prior to RT-TRACS, but these were rare because of the expense of deploying the foreign systems on North American traffic control equipment. Furthermore, there was little knowledge of ASC among agencies in the United

*Revised 1/8/2019

States during this period. One interviewee noted that "RT-TRACS was where industry started to be aware of adaptive technology, but there was little knowledge at agency level at this time."[3]

FHWA Activities and Outputs

Through RT-TRACS, FHWA funded four pilot deployments in the late 1990s and early 2000s in Reston, VA; Chicago, IL; Seattle, WA; and Tucson, AZ.(10–13) The pilot sites were chosen based on the relationships FHWA and the technology developers had with those locations and on their relative convenience. For example, Tucson, AZ, was chosen because it is close to the University of Arizona, where RHODES was developed, and Reston, VA, is close to FHWA's TFHRC. It was easier for researchers to monitor the deployments in corridors that they could access regularly. The developers of two of the systems, OPAC and RHODES, introduced their algorithms at the TRB Traffic Signal Systems Committee meeting in 1998.(47) Additional information on the principals and equipment requirements of these systems were given during ASC workshops over the next several years. Information on the performance of the technology, in the form of pilot site evaluations, was published between 1999 and 2003.(3) Results from the pilot tests showed that none of the tested algorithms (i.e., OPAC, RHODES, and RTACL) showed strong evidence of reducing travel time and delays; however, OPAC and RHODES were able to maintain existing traffic conditions on complex corridors, which developers and FHWA found promising.

As the pilot testing was wrapping up, FHWA did some market research to better understand the perceptions of ASC among a wide range of potential adopters. The pilot tests revealed that the technology was seen as very complicated to maintain; all of the pilot sites eventually deactivated their systems after the tests ended due to the technology's complexity and the need to upgrade detection systems. In 2002, FHWA conducted a survey of agencies and held an ITE roundtable discussion to gauge agency staff's attitudes toward the technology.(48) The findings showed that the market viewed the ASC systems available on the market as too expensive, too complex to implement and maintain, and not compatible with existing traffic signal infrastructure. They used findings from this survey to inform the scope and goals of their next research phase, which was developing ACS Lite.

Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Baseline

At the beginning of phase 1, there were no ASCTs that could be used effectively with U.S. traffic signal infrastructure. Foreign systems, such as SCOOT and SCATS, could be deployed in the United States only if the specific corridor had an Australian or European traffic signal controller. Abroad, however, SCOOT and SCATS were found to be very effective in reducing travel time, delays, and number of stops in the corridors where they had been deployed.(49) It was because these systems were so effective abroad that FHWA and others in the traffic signal industry became so interested in their application in the U.S. market.

FHWA Activities and Outputs

FHWA's goal during RT-TRACS was to develop an ASC algorithm that would function in the U.S. market. In 1996, FHWA conducted pilot tests in four cities, Reston, VA; Chicago, IL; Seattle, WA; and Tucson, AZ, to test the effectiveness on the OPAC and RHODES algorithms.(10–13) The measures

[3]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

FHWA used to test effectiveness included travel time and delays. FHWA also unofficially monitored factors such as cost and State transportation departments' opinions of the technologies.

B.2 Phase 2

Phase 2 includes all activities that occurred from 2002–2008 as well as some early activities from 2009.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Baseline

In the 1990s, interest for ASC among vendors, FHWA, and potential adopters was growing. The results of FHWA's survey (see appendix B) and pilot tests revealed that a feasible U.S. ASC system needed to be easier for traffic engineers to install and maintain its costs within the reach of typical small- and medium-sized agency budgets.(14) FHWA used this information to begin developing a new algorithm, ACS Lite, which would be less complex and expensive than the algorithms developed in RT-TRACS.

In the previous phase, several U.S. traffic control vendors had been coordinating with foreign technology companies to research the applicability of existing products in the U.S. market.[4] In this phase, two companies began updating the foreign systems to make them compatible with U.S. traffic signal infrastructure. For example, in 2007, a transportation management services company released a new version of SCATS that was compatible with 1070 controllers. An international company focused on engineering, energy, and technology also began selling and implementing SCOOT systems in the United States.

U.S. signal vendors continued their independent research on ASC, while engineering and/or technology companies developed new systems during this phase (see section 3.2 of this report for more information). For instance, a start-up company released a product called InSync™ in 2007. Additionally, a major U.S. signal vendor developed a new adaptive system and deployed it in San Marcos in 2005. This system was the foundation for its current system, QuicTrac™.

Industry meetings during this phase increasingly included discussions and presentations on ASC. Many of these meetings were run by FHWA or included presentations of FHWA-developed technologies. Additionally, vendors that were interviewed mentioned attending national and local meetings or presentations sponsored by vendors, distributors, or other industry groups to share and receive information on ASC. One vendor mentioned that these meetings helped them get a pulse on the market and demand for adaptive products. After years of research and testing, ASC vendors slowly began reaching out to local agencies to market their products. This type of activity increased greatly once there was more competition in the market.

FHWA Activities and Outputs

FHWA activities during this phase were primarily focused on developing and marketing ACS Lite. The goal of ACS Lite was to develop a lower-cost algorithm that would be easier for traffic engineers to install and use than its predecessors. FHWA planned to split the development of ACS Lite into two stages. The first stage would be developing and testing the algorithm, and the second stage would be adding features to the algorithm. FHWA awarded the first stage of algorithm development

[4]ASC Adopters; phone interviews conducted by evaluation team members Lora Chajka-Cadin, Jonathan Badgley, and Emily Futcher in April and May 2015.

to a domestic branch of an international company focused on engineering, energy, and technology in 2002 after releasing an RFP to the industry.

FHWA recognized that in order to make ASC both functional and affordable for agencies, the algorithm should be made compatible with traffic controllers already in use in the United States. Around the time that ACS Lite development started, FHWA coordinated with the four major NEMA vendors to encourage them to make their equipment compatible with ACS Lite. In exchange for making their equipment compatible with ACS Lite, FHWA offered the vendors licenses to the ACS Lite algorithm. Although the algorithm was complete in 2004, it took the vendors several years to receive the final algorithm code because of issues related to intellectual property and challenges developing the contract language. From 2004–2008, each vendor ran a pilot test to demonstrate the effectiveness of ACS Lite on their controller. The results of these demonstration tests are discussed in chapter 3.(15–18)

FHWA intended to organize a second phase of ACS Lite development where they would develop new features for ACS Lite and share the updated algorithm with the four NEMA vendors. In 2009, however, this additional development was canceled due to external factors. A vendor who developed a competing product but who was not part of the ACS Lite Program petitioned the U.S. Department of Transportation (USDOT) to stop the program due to the unfair advantage the funding provided to the partner vendors. The four partner vendors who were prepared to participate in this second phase of development waited over a year for FHWA to move forward with it before cancellation. These events were perceived as slowing the launch of the NEMA vendors' ACS Lite-based products.

While ACS Lite was being finalized, FHWA also engaged in outreach activities to promote its program and the growing number of ASC products. This involved organizing workshops around the country to promote the existing algorithms from RT-TRACS and ACS Lite. They also gave presentations at industry events such as TRB (Traffic Signal Committee) to promote its products.(50) The ACS Lite Program Manager at FHWA informally reached out to traffic engineers from 2005–2007 when ACS Lite was in beta testing to show agencies the concept and ACS Lite architecture as well.

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

Baseline

As of 1999, 13 agencies had deployed an ASC system in the United States. There were many challenges and barriers to adoption of existing technologies, such as lack of compatibility with standard U.S. controllers and cost, which hindered its widespread adoption. Additionally, many had the perception that ASC systems were not successful in their current deployments, too complicated, and too expensive. One interviewee noted the following:

> *"10 years ago, one vendor's response to why they had not developed an adaptive system was the clients are not requesting the adaptive capability."*[5]

Another interviewee stated the following:

> *"Prior to 2008 there was a perception that ASCT doesn't work."*[6]

[5]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[6]Industry Professional; phone interview conducted by evaluation team members Sari Radin, Jonathan Badgley, and Emily Futcher in May 2015.

A combination of these factors resulted in there being very little demand for ASCs in the United States. Industry groups began increasing their marketing and information-sharing efforts on ASCs during this phase. One vendor mentioned the following:

> *"By 2000, there was an interest in ASC which was demonstrated by calls for papers, presentations on experiences, etc., at ITS America, ITE, and IMSA [International Municipal Signal Association] By the mid-to-late-2000s, most shows had adaptive."*[7]

Staff from local and State agencies were in attendance at these events. Vendors also began to reach out to their potential customers, especially as competition in the market increased. One vendor noted the following:

> *"Anyone that was interested in ASC, we met with."*[8]

Consultants increased their efforts in the ASC market during this phase. Their support to agencies interested in ASCT during this phase consisted of providing information on ASCT (e.g., which systems are available, popular, and easy to use) and making suggestions about which systems to purchase.

Agencies learned about ASCs through FHWA outreach and other sources, including ITE, other industry groups, local vendors, and informal communication with other agencies. ITE has local chapters where agencies can give presentations on their adaptive systems. Local vendors would share information on their products with any interested potential customers.

FHWA Activities and Outputs

As mentioned in chapter 3 on phase 2 evaluation findings, each of the four NEMA vendors participated in an FHWA-sponsored pilot test of ACS Lite using their controller. The four pilot sites were located at Gahanna, OH; Houston, TX; Bradenton, FL; and El Cajon, CA.(15–18) The purpose of the sites was to reveal the effectiveness of ACS Lite on typical U.S. controllers. Two additional demonstration sites were also funded in 2006–2008 in Pickerington, OH, and Tyler, TX.(51,52)

FHWA developed a marketing plan for ACS Lite in 2008 with the goal of deploying ACS Lite as a market-ready technology for local and State arterial systems. The objectives of this effort were to increase awareness of the capabilities of ACS Lite, provide guidance on the effective use and application of ACS Lite, and ensure that the needs of target users were being met. The activities proposed in the marketing effort were hosting Web conferences, exhibits at industry events, and training workshops as well as building partnerships and champions for the technology. FHWA also developed a number of marketing materials, including an advertisement in the *ITE Journal* that was published in August 2006.(21) Table 23 and table 24 describe some of the FHWA outreach activities during this period supporting RT-TRACS and ACS Lite systems.

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[7]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[8]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

Table 23. FHWA phase 2 outreach activities.

Location	Event	Activity	Date
Washington, DC	TRB Annual Meeting(53)	ACS Lite exhibits	January 2008
Miami, FL	ITE Technical Conference(54)	ACS Lite exhibits	March–April 2008
Phoenix, AZ	International Municipal Signal Association International Meeting	ACS Lite exhibits	July 2008
New Orleans, LA	American Public Works Association 2008 Congress(55)	ACS Lite exhibits	August 2008
New York, NY	ITS America World Congress(56)	ACS Lite exhibits	November 2008
State College, PA	Pennsylvania State University Traffic Engineering Conference	Presentations and workshops	December 2007
Overland Park, KS	ACS Lite workshop	Presentations and workshops	December 2007
Lincoln, NE	ACS Lite workshop(57)	Presentations and workshops	March 2008
N/A	National Transportation Operations Coalition webcast(58)	Presentations and workshops	August 2008

N/A = not applicable.
Note: Reference information is not included for all events, as they were unreleased internal FHWA documents.

Table 24. TRB traffic signal systems committee meetings with ASCT presentations.

TRB Meeting	Date	Location	Subject
January 2007 Workshop on Operating Traffic Signal Systems in Oversaturated Conditions(59)	1/21/2007	Washington, DC	General ASCT algorithms
2006 Mid-year Committee Meeting(60)	7/10/2006	Woods Hole, MA	ACS Lite early results
January 2006 Workshop on Performance Measures(60)	1/22/2006	Washington, DC	ASC-Lite data technical presentation
2005 Mid-year Committee Meeting(60)	7/10/2005	Las Vegas, NV	ASC-Lite data technical presentation
January 2005 Workshop on Best Practices for Signal Timing and Operations(60)	1/9/2005	Washington, DC	Presentations on detection
January 2004 Workshop on Signal Control Priority for Transit and ASC(60)	1/11/2004	Washington, DC	ACS Lite, SCATS, and SCOOT,
2003 Mid-year Committee Meeting(60)	7/27/2004	Portland, OR	Discussion of general ASCT algorithm technical papers(61)
January 2001 Workshop on ASC Systems(60)	1/7/2001	Washington, DC	LA-ATCS, SCOOT, SCATS, RHODES, and OPAC
2000 Mid-Year Committee Meeting(60)	7/9/2000	Seattle, WA	ACS Lite
January 2000 Workshop on ASC Systems(60)	1/9/2000	Washington, DC	SCOOT, SCATS, LA-ATCS, OPAC, and RHODES
1998 Mid-Year Committee Meeting(60)	7/12/1999	Pacific Grove, CA	MOTION, RHODES, SCOOT, OPAC, RT-TRACS, and SCATS

Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Baseline

At the beginning of phase 2, there were only four ASC products available in the U.S. market: SCOOT, SCATS, RHODES, and OPAC. Two of the algorithms developed through RT-TRACS showed promise in managing travel time and delays; however, they were considered too costly and complicated to be widely adopted. Foreign systems such as SCOOT and SCATS were seen as effective systems; however, at the time, they were not compatible with U.S. traffic signal controllers and were used mainly for larger, centralized traffic systems, which hindered their adoption in the United States. ACS Lite was developed and piloted in this phase.

FHWA Activities and Outputs

FHWA sponsored four pilot tests and funded three additional demonstration sites in 2004–2008. The four pilot sites were located in Gahanna, OH; Houston, TX; Bradenton, FL; and El Cajon, CA.(15–18) The purpose of the tests was to reveal the effectiveness of ACS Lite on typical U.S. controllers. FHWA presented the results of these tests at industry events such as TRB.(62)

B.3 Phase 3

Phase 3 included all activities that occurred during the ASC Program from 2009–2012, such as the development and deployment ASC programs and what inputs accelerated this process.

Development

Hypothesis 1: FHWA R&T ASC activities accelerated the development of ASCTs.

Baseline

By the time FHWA kicked off its EDC promotion of ASC in 2009, eight products were already being offered in the U.S. market (i.e., SCOOT, SCATS, RHODES, OPAC, NWSVoyage, QuicTrac™, LA-ATCS, and InSync™). During the EDC period, companies that had been involved with FHWA's development programs as well as independent vendors entered the market.

Companies continued doing R&D during this phase in addition to marketing current products, which suggested the potential for more competitors in the future. In particular, various agencies, vendors, and research institutions developed methods and tools for monitoring and evaluating ASC installations in real time. Many systems algorithms and real-time choices were opaque to the agencies because there was no real-time interface, and no systems were designed with the ability to monitor the performance of the system in real time. This secondary market is evidence that the first technical problem, adaptive traffic management, had been solved relatively well enough by the industry that the next technical issue of evaluation and monitoring will yield a greater return than spending more resources on new ASC technologies.

FHWA Activities and Outputs

In late 2010, phase 2 of ACS Lite development ended due to political issues related to the funding of ACS Lite development for the exclusive use of private companies. Due to this development, USDOT decided that its promotion of ASC had to cover all adaptive technologies and not just ACS Lite.

USDOT then focused its efforts on marketing all ASCTs as a pool of technologies rather than making recommendations about specific products. FHWA shared information about all ASCTs on the market through its website, presentations, workshops, and other resources.(5) EDC also developed MSE documents to guide interested agencies through a structured process to select and deploy ASCT.(30) FHWA invited vendors to support their products through EDC outreach. Vendors and technology developers were also used as subject matter experts in creating content for EDC presentations and in developing guidance documents.

Deployment

Hypothesis 2: FHWA R&T ASC activities accelerated the deployment of ASCTs.

Baseline

By 2009, there were 51 deployments of ASCs in the United States. There was growing interest and awareness of ASCs; however, many agencies still viewed the technology as a research product that was not market ready. Several of the other competing systems that were tested prior to 2010 (including RT-TRACS and ACS Lite) had been deactivated. Interviewees described such occasions but were reluctant to name specific agencies or systems that had failed. There were several industry activities occurring during this phase that were not related to FHWA but also affected interest and adoption of ASC systems.

Table 25 shows the number of FHWA activities in each State through phases 2 and 3 and the adoptions that may have been influenced by these activities. These adoption periods do not line up with the phases because the effect of the activities could not logically affect the adoption in those periods. For instance, the pilot results were completed from 2005–2007, so they could not have had an effect on adoptions in 2005 and earlier. Instead, a 3-yr effect horizon from when the activities started was included.

Table 25. Number of FHWA outreach activities and adoptions by State.

State	Phase 2 Activities*	Number of ASC Adoptions from 2007–2010	Phase 3 Activities**	Number of ASC Adoptions from 2011–2015
Alaska	—	—	2	—
Alabama	—	—	1	4
Arkansas	—	1	2	3
Arizona	Yes	1	2	4
California	Yes, pilot	6	2	16
Colorado	—	—	2	5
Connecticut	—	—		2
District of Columbia	Yes	—	2	—
Delaware	—	—	1	—
Florida	Yes, pilot	1	3	7
Georgia	—	4	3	4
Hawaii	—	—	—	—
Iowa	—	—	1	2
Indiana	—	—	1	2
Illinois	—	—	2	3
Indiana	—	—	4	4
Kansas	Yes	2	—	3
Kentucky	—	—	–	2

State	Phase 2 Activities*	Number of ASC Adoptions from 2007–2010	Phase 3 Activities**	Number of ASC Adoptions from 2011–2015
Louisiana	Yes	—	1	—
Massachusetts	Yes	—	2	2
Maryland	—	1	3	2
Maine	—	—	—	—
Michigan	—	1	–	4
Minnesota	—	—	2	1
Missouri	—	—	1	9
Mississippi	—	—	1	2
Montana	—	—	2	—
North Carolina	—	—	1	—
Nebraska	Yes	—	3	—
North Dakota	—	—	1	—
New Hampshire	—	—	2	—
New Jersey	—	1	3	1
New Mexico	Yes	—	3	1
Nevada	Yes	—	2	—
New York	–	—	1	6
Ohio	Pilot	2	4	7
Oklahoma	–	—	1	1
Oregon	Yes	3	3	5
Pennsylvania	Yes	1	3	18
Puerto Rico	—	—	1	—
Rhode Island	—	—	—	
South Carolina	—	1	—	3
South Dakota	—	—	3	—
Tennessee	—	—	2	1
Texas	Pilot	3	2	11
Utah	—	—	2	2
Virginia	—	—	—	6
Vermont	—	—	—	1
Washington	Yes	1	2	2
Wisconsin	—	—	2	4
West Virginia	—	—	1	5
Wyoming	—	—	1	2
Total	**15**	**29**	**83**	**157**

—No activity occurred (e.g., no lite exhibits and pilot sites, adoptions, and/or EDC activities).
*Phase 2 activities included ACS Lite exhibits and/or pilot sites.
**Phase 3 activities included attendance and/or hosting of the ASC EDC Summit Session, presentations, webinars, technical assistance from FHWA staff, SE workshops, and ACS Lite showcases.

Funding

One vendor who entered the market in 2009 began researching, promoting, and assisting agencies in obtaining Federal funding sources (e.g., Congestion Mitigation and Air Quality Improvement (CMAQ) Program, Department of Energy funds, grants) that States and local agencies could apply for to fund adaptive systems. Although FHWA did not provide funding explicitly for ASC, there were certain funding sources that States were able to use for ASC. This was the first time that many State and local agencies considered Federal funding sources for adaptive projects.(61) This shift in use of CMAQ funds and other Federal funds occurred around 2010. Around this time, funding for six projects came from the American Recovery and Reinvestment Act, which increased the amount of funding available to States for "shovel ready" transportation projects.(31)

Funding has had a significant effect on ASC adoption. Because the systems are so expensive to purchase and maintain, many local agencies rely on Federal and State funding for their systems. One interviewee (vendor) noted that "with bills like the Clean Air Act, a lot of money such as CMAQ become available [for ASC]. When funding is depleted, we see fewer adaptive projects coming up."[9](63) Another stated that ASCT "wouldn't go anywhere without funding. Having available funding is why adaptive has gained popularity."[10] Although not an activity driven by FHWA, the awareness and use of Federal funding opportunities for ASC also had an effect on increased adoption.

Industry

Private sector vendors and consultants continued to play a role in sharing information on ASCs to agencies. Vendors provided information on their products directly to agencies and through industry organizations such as ITE. Consultants shifted their support from giving agencies advice on what systems to implement to help them go through the SE process.

Word of Mouth

Many local agencies began sharing information through networking. As more agencies adopted ASC, agencies in the surrounding areas would ask for their experience with the system and recommendations on whether to deploy similar systems. For instance, Anne Arundel County, MD, which had been one of the federally sponsored sites, served as a consultant for other projects in Maryland and one in Virginia, where they shared their experiences with ASCT. Following Anne Arundel's deployment of ACS Lite, Baltimore, MD, initiated a project to install InSync™. Additionally, Seminole County, FL, received many requests from agencies around Florida to see its system. Agencies also attended more formal networking opportunities such as local ITE chapter events.

FHWA Intervention

In late 2010, phase 2 of ACS Lite development ended due to political issues. At this point, FHWA decided that its promotion of ASC had to cover all adaptive technologies and not just ACS Lite. FHWA then focused its efforts on marketing all ASCTs as a pool of technologies rather than making recommendations about specific products.

The ASC EDC Program was focused on marketing ASC as a market-ready technology. The goals of EDC were to have 40 agencies use ASCT/EDC tools to guide their decisions about ASC and to develop performance measures and address data needs to support evaluation of ASCT. FHWA's activities during this phase focused on marketing and outreach and included hosting workshops, organizing webinars, developing case studies, and creating promotional and informational materials

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[9]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

[10]Industry Professional; phone interview conducted by evaluation team members Jonathan Badgley and Emily Futcher in May 2015.

(e.g., brochures, a website, frequently asked questions).[5] See table 26 for a list of EDC activities and States represented at these events.

Table 26. EDC activity and adoptions summary.

Activity	Total Number of Events	Total Number of States Represented	Total Number of States Adopting
EDC summit presentation (hosting or attending)	9	32	20
ASCT showcase	1	1	1
Presentations and webinars (ASCT)	17	17	15
SE workshops	23	23	15
Technical assistance	8	8	7
Total	**58**	**42**	**40**

Table 27 serves as an example of EDC outreach activities through 2015. It may not include all events, meetings, or direct support to State transportation departments.

Table 27. Number of ASC adoptions of FHWA and non-FHWA supported systems.

System	Phase 1 (1992–2002)	Phase 2 (2002–2009)	Phase 3 (2009–2015)
FHWA	14	4	34
Non-FHWA	24	25	123

FHWA did not provide any grant funding for ASC through EDC. The workshops had different focuses depending on their audiences and timing.[64] Some of the workshops showed how each ASCT system worked, and others provided an overview of or training on the SE process. Workshop attendees included potential adopters, traffic industry consultants, and vendors.

SE Approach

The MSE process was developed as part of the EDC Program. FHWA believed that States had been abandoning their systems because they did not fully understand the costs and amount of labor it takes to maintain a system before purchasing one. To address this problem, FHWA developed an MSE process and document for ASC.[30] The purpose of the document was to allow those interested in purchasing an ASC system (e.g., agencies) to follow a structured process that would help them decide which product, if any, was the best fit, rather than the agency making the decision based on a sales pitch or word of mouth. By following this process, agencies could be more confident that the finished product they ended up with was what they actually needed. The process of SE was not a new idea, but its application to ASC was. After the completion of this document, all States planning to adopt ASC using Federal funds were required to complete the SE process. The development of the document was funded through EDC.

Mobility

Hypothesis 3: FHWA ASC activities improved mobility and reduced emissions.

Baseline

By 2009, there was still no ideal adaptive technology on the market. Many of the technologies on the market worked in some instances but not always to the extent that agencies expected. They also were still difficult for many agencies to maintain and were expensive. Consultants and other professionals in the industry presented on results from ASCT implementations at industry events such as ITE and TRB.[65]

The private sector and universities continued doing research on an efficient ASC system. For instance, the private industry is working with the University of Toronto on a new product that uses artificial intelligence. Research on this product began in 2007, and it is still in the R&D phase. Other private firms that already have products on the market continued updating their systems to make them more efficient.

FHWA Activities

There were no FHWA activities related to technology effectiveness during phase 3. Their efforts focused primarily on outreach and marketing an already established technology and not on improving the technology itself. The technology development activities occurred mostly in the private sector during this phase.

Appendix C. ASCT Online Survey Methodology and Results

This appendix describes the methodology of the online survey conducted with a representative cross section of traffic signal decisionmakers from local, regional, and State agencies. The tables show tabulated results from questions used to inform the evaluation. Discussion of the survey findings can be found in section 3.3, Phase 3: EDC Outreach.

C.1 Methodology

The methodology for the online survey was as follows:

- **Target population:** Traffic signal control decisionmakers in agencies who were prospects for ASCT (i.e., 10 or more signalized intersections in jurisdiction).
- **Sample frame:** City/municipal, county, or State governments with transportation budgets of $100,000 or more and population of 10,000 or more (approximately equates to 10 signalized intersections).
- **Data source**: U.S. Census Bureau.(66)
- **Results**: Over 6,200 qualifying cases.
- **Sample selection:** The sample was selected as follows:
    1. A random sample was selected from the sample frame to represent a cross section of different sized agencies across the United States.
    2. The evaluation team randomly selected 2,000 participants from sample frame (assuming 8–10 percent response rate) using random number generation in Microsoft® Excel. FHWA division offices conducted online and phone research to identify a name, phone number, and email address for a State transportation department contact at each location.
    3. The research yielded close to 1,200 valid contacts.
    4. A vetted list was provided by FHWA district offices based on a contacts list sent to said FHWA district offices to be approved. In total, 26 districts responded, and contact information was updated or replaced based on district office knowledge.

The evaluation team supplemented the representative cross section sample with a sample of known ASCT adopters gathered earlier during the evaluation and from district offices. These data were used to boost sample size for adopters, which allowed a separate analysis of this group. Note that the oversample was separated from the cross-section sample when reported in total.

C.2 Data Collection and Analysis

The data collection and analysis occurred as follows:

- **Method:** An online self-directed questionnaire was used.
- **Questions:** Questions were primarily structured closed-ended questions (with a few open-ended questions).
- **Screening criteria:** Screening criteria included whomever was the decisionmaker for traffic signal control equipment purchaser.
- **Survey duration:** The survey duration was 10–15 min.
- **Dates conducted:** Tests were conducted from September 16, 2015, to October 16, 2015.
- **Outgoing sample:** The outgoing sample included 1,137 representative cross sections and 105 adopter oversamples.
- **Number of surveys completed**: A total of 212 surveys (17 percent of 1,137) were completed.[1] This included 183 cross sections (16 percent of 1,137) and 29 adopter oversamples (28 percent of 1,137).
- **Data preparation:** Data were cleaned and checked; coded responses were loaded into Stata® for analysis, and open-ends were loaded into Microsoft® Excel.
- **Analysis methods used:** Analysis methods used included aggregate descriptive statistics, cross tabs, etc.

C.3 Topline Results

Topline results are included to point out some interesting findings in the data. They do not represent a complete analysis of the data. Note that some findings are based on small sample sizes ($n < 30$).

Respondent Profile

The respondent profile was as follows:

- The majority of the representative cross samples came from city/municipal agencies, although there was a good representation of counties (over 20 percent).
- States made up a bigger percentage of adopters (cross section and oversample), and more county agencies as opposed to States were represented in the cross-section adopter sub-sample.

[1]The sample of 212 represents an overall response rate of 17 percent. The evaluation team did not have the resources to follow up with non-responders to increase the response rate. While the survey represents a cross section of the United States by region and agency type, the sample may have some first responder bias (where more interested agencies (e.g., those considering or adopting ASCT) were more interested in completing the survey without an incentive or multiple reminders).

- Adopters, on average, had larger signalized intersection networks.

Table 28 describes the jurisdiction with whichs survey respondents associate.

Table 28. Question 1: Which of the following describes your jurisdiction?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
City/municipality	66	72	48	62	55
County	23	20	33	17	27
State	8	5	17	17	15
Other	3	4	2	3	3

Table 29 notes whether or not the respondents were involved in deciding the selection of traffic signal systems or control equipment for their particular city, state, or county.

Table 29. Question 2: Are you involved in the decision regarding the selection of traffic signal systems or control equipment for your city/State/county?

Answer	Cross section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
Yes	100	100	100	100	100
No/don't know	0	0	0	0	0

Table 30 shows how many signalized intersections the respondents' departments or agencies operated or maintained.

Table 30. Question 3: How many signalized intersections does your department/agency operate or maintain?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
Less than 10	17	21	5	0	3
10 to 29	24	26	19	0	11
30 to 99	23	25	12	38	22
100 to 299	21	18	31	38	34
300 or more	15	10	33	24	30
Mean	**251**	**203**	**414**	**319**	**373**

Table 31 shows that adopters tend to have more full-time employees dedicated to traffic control.

Table 31. Question 8: In total, how many full-time employees in your agency are dedicated to the following subject areas?

Answer	Cross Section Total (*n* = 179)	Cross Section Non-Adopters (*n* = 138)	Cross Section Adopters (*n* = 41)	Oversample of Adopters (*n* = 29)	Combined Adopters (*n* = 70)
Traffic signal design (mean)	1.66	1.64	1.76	2.17	70
Traffic signal operations (mean)	2.54	2.14	3.88	3.07	1.93
Traffic signal maintenance (mean)	4.29	3.38	7.39	6.03	3.55

Table 32 reports how well traditional traffic signal operations accommodate traffic conditions experienced in each respondent's jurisdiction.

Table 32. Question 9: How well do traditional traffic signal operations accommodate traffic conditions experienced in your jurisdiction?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
80 percent or more of the traffic conditions	46	49	36	41	38
60 to 79 percent	31	30	36	38	37
40 to 59 percent	8	4	21	7	15
20 to 39 percent	3	1	7	3	6
Less than 20 percent of the traffic conditions	1	1	0	7	3
Don't know	11	14	0	4	1

Table 33 shows respondent estimates of how many signalized intersections in their jurisdiction they operate in a coordinated mode.

Table 33. Question 10: How many of the signalized intersections in your jurisdiction would you estimate you operate in a coordinated mode?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
80 percent or more	19	15	31	38	34
60 to 79 percent	25	26	21	31	25
40 to 59 percent	15	13	24	17	21
20 to 39 percent	15	16	12	14	13
Less than 20 percent	21	24	12	0	7
Don't know	5	6	0	0	0

Table 34 shows how many signalized intersections in respondents' jurisdictions are currently equipped with ASCT.

Table 34. Question 11: Are any of the signalized intersections in your jurisdiction currently equipped with ASCT?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
Yes	18	0	76	93	83
No	67	80	24	7	17
Don't know	15	20	0	0	0

Table 35 shows if respondents' jurisdiction are planning to deploy ASCT on any of their signalized intersections within the next 2 yr.

Table 35. Question 12: Is your jurisdiction planning to deploy ASCT on any signalized intersections in the next 2 yr (24 mo)?

Answer	Cross Section Total (*n* = 151) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 10) (Percent)	Oversample of Adopters (*n* = 2) (Percent)	Combined Adopters (*n* = 12) (Percent)
Yes	18	13	100	100	100
No	54	57	0	0	0
Don't know	28	30	0	0	0

Note: Adopters were self-identified using the question, "Which of the following best describes your experience with ASCT?" Some of these adopters have projects in progress and did not report current ASCT-equipped intersections.

Within the total cross section sample, very few respondents (11 percent) were unaware of ASCT, and just over half considered or deployed ASCT, as is evidenced by the responses in in table 36.

Table 36. Question 24: Which of the following best describes your experience with ASCT?

Answer	Cross Section Total (*n* = 183) (Percent)	Cross Section Non-Adopters (*n* = 141) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
I had not heard of ASCT before taking this survey	11	15	0	0	0
I am aware of ASCT, but my department/agency has not considered it for my jurisdiction	37	48	0	0	0
My department/agency has considered ASCT but has not deployed it	29	38	0	0	0
My department/agency has deployed (or currently in the process of deploying) ASCT	23	0	100	100	100

The following list describes respondents' (among those aware of ASCT) knowledge of ASCT:

- Adopters rated their ASCT knowledge considerably higher than those who have not adopted the technology (see table 37). Only 26 percent of non-adopters rated their knowledge as good/very good compared with 65 percent of total adopters (59 percent cross section and 72 percent oversample).
- Adopters were also more likely to have first become aware of ASCT more than 5 yr ago (i.e., 65 percent of combined adopters; see table 38).

Table 37. Question 25: How would you rate your knowledge of ASCT (among those aware of ASCT)?

Answer	Cross Section Total (*n* = 162) (Percent)	Cross Section Non-Adopters (*n* = 120) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
Very poor	2	3	0	0	0
Poor	23	30	5	0	3
Fair	40	41	36	28	32
Good	27	20	45	58	51
Very good	8	6	14	14	14

Table 38. Question 26: When did you first become aware of ASCT (among those aware of ASCT)?

Answer	Cross Section Total (*n* = 162) (Percent)	Cross Section Non-Adopters (*n* = 120) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample of Adopters (*n* = 29) (Percent)	Combined Adopters (*n* = 71) (Percent)
Within the last 5 yr	54	60	38	31	35
6–10 yr ago	26	22	38	38	38
More than 10 yr ago	17	15	24	31	27
Don't know	3	3	0	0	0

Adoption Process

This section looks at the factors affecting adoption of ASCTs among those who are engaged with the technology (at least aware). Those unaware have been removed, leaving 162 from the representative cross section for analysis. (The oversample was not included for this analysis.) The following list details respondent awareness of ASCT and their level of deployment based on when they became aware:

- Knowledge of ASCT improves as agencies move closer to adoption and learn more about the technology (see table 39).
- Adopters of ASCT are less likely to have first learned about the technology recently (38 percent) versus those who are aware or considering (66 and 53 percent, respectively), as seen in table 40.

Table 39. Question 25: How would you rate your knowledge of ASCT (among those aware of ASCT)?

Answer	Cross Section Total (*n* = 162) (Percent)	Aware (*n* = 67) (Percent)	Consider (*n* = 53) (Percent)	Purchase (Adopt) (*n* = 42) (Percent)
Very poor	2	4	2	0
Poor	23	39	19	5
Fair	40	43	38	36
Good	27	12	30	45
Very good	8	1	11	14

Table 40. Question 26: When did you first become aware of ASCT?

Answer	Cross Section Total (*n* = 162) (Percent)	Aware (*n* = 67) (Percent)	Consider (*n* = 53) (Percent)	Purchase (Adopt) (*n* = 42) (Percent)
Within the last 5 yr	54	66	53	38
6–10 yr ago	26	21	23	38
More than 10 yr ago	17	9	23	24
Don't know	2	4	2	0

Table 41 displays what sources respondents used to learn about ASCT.

Table 41. Question 27: From what sources have you learned about ASCT?

Answer	Cross Section Total (*n* = 162) (Percent)	Aware (*n* = 67) (Percent)	Consider (*n* = 53) (Percent)	Purchase (Adopt) (*n* = 42) (Percent)
Colleagues at other State transportation departments	59	57	53	71
Traffic signal industry meetings or events	56	42	64	67
Journal articles, papers, reports, etc.	52	43	58	57
Traffic industry consultants	51	39	55	67
ASCT vendors or distributors	41	24	45	62
State transportation department or MPO	37	37	34	40
FHWA division offices, FHWA's RC, EDC Program, or National Highway Institute	30	18	30	48
Your own State transportation department	19	7	19	36
ASCT system performance evaluations or ASCT system comparisons	17	4	17	36

Answer	Cross Section Total (*n* = 162) (Percent)	Aware (*n* = 67) (Percent)	Consider (*n* = 53) (Percent)	Purchase (Adopt) (*n* = 42) (Percent)
Undergraduate or graduate studies	6	6	11	0
Don't know	1	1	2	0
Other	6	3	8	10

Adopters had the most use of all FHWA/EDC resources except for direct FHWA support, which was slightly higher for those considering ASCTs. The following facts should be noted:

- Fewer respondents who were just aware of ASCT or considering ASCT have attended ASCT outreach programs.
- Few respondents who were just aware of ASCT have used direct FHWA/EDC support.
- More detail on which FHWA resources were used is detailed in table 42.

Table 42. Question 29: Which of the following FHWA resources were used?

Answer	Cross Section Total (*n* = 48) (Percent)	Aware (*n* = 12) (Percent)	Consider (*n* = 16) (Percent)	Purchase (Adopt) (*n* = 20) (Percent)
ASCT tools and guidance materials	52	50	50	55
ASCT training about the ASCT SE process	40	33	38	45
ASCT outreach program	31	17	19	50
Direct FHWA support	19	8	25	20

ASCT Adopter Analysis

This section includes results from an analysis of adopters from both the cross-section sample and the oversample. There do seem to be some differences between the two adopter groups, which may be due to how long ago adoption took place. The following facts should be noted:

- The top goals among all adopters included managing traffic variability, managing congestion, and improving smoothness of flow.
- For cross section adopters managing special events traffic was higher, while for the oversample, managing traffic around social centers was higher.
- Cross section adopters selected congestion more frequently than did oversample adopters.
- ASCT that was compatible with existing signal system was more of a contributor to deployment (purchase) for the oversample adopters.

More detail on what prompted respondents to deploy ASCT is shown in table 43.

Table 43. Question 31: Which of the following describe reasons why your [Q1] deployed ASCT?

Answer	Combined Adopters Sample (*n* = 71) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample Adopters (*n* = 29) (Percent)
Manage general day-to-day traffic variability	77	79	76
Manage congestion	76	83	66
Improve smoothness of flow on arterial streets	72	74	69
Handle major unexpected traffic delays in signalized network (e.g., accidents, weather related)	48	45	52
Manage traffic around shopping and other social centers	46	45	48
Reduce labor and cost to retime traffic signals	41	38	45
Handle diversion traffic around freeway incidents (e.g., accidents, construction, weather)	41	40	41
Manage traffic related to special events	39	45	31
Manage conflicts between vehicular traffic and other modes	14	14	14
Don't know	0	0	0
Other	6	7	3

Factors contributing to why respondents decided to deploy ASCT is detailed in table 44.

Table 44. Question 32: Did any of the following factors contribute to your [Q1] deploying ASCT?

Answer	Combined Adopters Sample (*n* = 71) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample Adopters (*n* = 29) (Percent)
Budget or funding became available to use for traffic signal control	76	74	79
Local infrastructure was in place to accommodate ASCT requiring little additional detection or communication equipment	45	45	45
ASCT became available that was compatible with existing signals/signal system	45	38	55
Additional resources were available to learn about/get training on ASCT	15	17	14
More vendors were providing ASCT systems	14	17	10
Cost of ASCT systems declined	11	14	7
None of these	6	7	3

Activities

The following facts are highlighted in table 45 and should be noted:

- The most often completed activities were securing funding sources, identifying clear traffic objectives, and documenting system requirements.
- The activities for which adopters wanted the most help from FHWA were securing funding sources and validating performance of ASCT systems.

Table 45. Question 33: Which of the following activities did your department/agency complete?

Answer	Combined Adopters Sample (*n* = 71) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample Adopters (*n* = 29) (Percent)
Identify clear traffic objectives	59	55	66
Document agency uses, problems to be solved, and potential adaptive solutions (concept of operations)	46	40	55
Document adaptive system requirements	56	52	62
Conduct acceptance testing and requirements verification	37	29	48
Secure funding sources	66	62	72
Evaluate procurement approach	39	36	45
Dedicate staff to regularly manage, operate, and maintain ASCT	37	24	55
Conduct comprehensive staff training on ASCT system	32	38	24
Secure post-installation support from vendor/ distributor	52	48	59
Validate performance of ASCT systems	52	48	59
None of these	7	7	7
Don't know/not sure	7	10	3

Satisfaction

The following facts regarding satisfaction should be noted:

- Table 46 shows that, overall, 66 percent of adopters were either somewhat or very satisfied with their ASCT system, and the oversample was even more satisfied (73 percent). The cross-section sample had more who fall in the neutral or non-satisfied categories.
- Table 47 shows that those who have had issues identify additional detection equipment, expense, and lack of demonstrated performance as dissatisfiers.
- The oversample also identified that the systems were too complicated for staff to use.

Table 46. Question 35: In general, how satisfied are you with your ASCT system(s)?

Answer	Combined Adopters Sample (*n* = 71) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample Adopters (*n* = 29) (Percent)
Very dissatisfied	1	2	0
Somewhat satisfied	8	10	7
Neither satisfied nor dissatisfied	24	26	21
Somewhat satisfied	35	29	45
Very satisfied	31	33	28

Table 47. Question 36: Which of the following issues have you had with your ASCT system(s)?

Answer	Combined Adopters Sample (*n* = 71) (Percent)	Cross Section Adopters (*n* = 42) (Percent)	Oversample Adopters (*n* = 29) (Percent)
Require too much additional detection or communications equipment	32	29	38
Are too expensive (e.g., main system—hardware, software)	25	29	21
Have not demonstrated sufficient benefits/operational performance	23	17	31
Are too complicated for agency staff to manage	17	12	24
Require too much staff time to manage	15	14	17
Are too difficult to maintain	14	12	17
Require too much staff training/steep learning curve	13	14	10
Are not adequately supported by vendors/distributors	13	10	17
Malfunction too frequently	11	10	14
Take too long to deploy/are too complicated to deploy	8	7	10
None of these	21	29	10
Other	27	31	21

Adopter Network/Equipment Profile

Note that the adopters sampled in table 48 through table 53 include only 59 total adopters. A total of 12 adopters had projects that were currently in progress when the survey was administered, so they were not asked these questions. The following facts should also be noted:

- Oversample adopters had a larger number of ASCT intersections on their network.
- Cross section adopters were more likely to have less than 10 intersections equipped with ASCT.
- Close to 40 percent of adopters had undertaken more than one ASCT project to equip their intersections.

Table 48. Question 11: Are any of the signalized intersections in your jurisdiction currently equipped with ASCT?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
Yes	83	76	93
No	17	24	7
Don’t know	0	0	0

Table 49. Question 13: How many of these signalized intersections are equipped with ASCT?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
50 or more	19	9	30
20 to 49	27	34	18
10 to 19	22	12	33
Less than 10	32	44	19

Table 50. Question 14: How many of these [Q13] ASCT intersections are regularly running adaptively?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
All/most regularly run adaptively (80 percent or more)	73	78	67
Many regularly run adaptively (60–79 percent)	10	6	15
Some regularly run adaptively (40–59 percent)	3	0	7
Few regularly run adaptively (20–39 percent)	7	9	4
Very few/none regularly run adaptively (less than 20 percent)	5	3	7
Don't know/not sure	2	3	0

Table 51. Question 15: In total, how many ASCT projects has your organization [Q1] undertaken to equip the ASCT intersections?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
1	51	50	52
2–4	24	22	26
5–9	12	13	11
greater than or equal to 10	5	6	4
Don't know	8	9	7

The following facts should be noted as a supplement to table 52:

- InSync™ was the most commonly mentioned ASCT provider (41 percent), while ACS Lite was used by 8 percent of respondents, and SCATS was used by 15 percent of respondents.
- Approximately half of agencies surveyed considered other ASCT systems. ACS Lite was often considered as well as SCOOT and SynchroGreen™.

Table 52. Question 16: Which ASCT systems has your agency deployed?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
InSync™	41	31	52
SCATS	15	16	15
Centracs™	14	13	15
ACS Lite	8	9	7
QuicTrac™	5	6	4
SynchroGreen™	3	6	0
SCOOT	5	3	7
OPAC	2	3	0
LA-ATCS	0	0	0
RHODES	0	0	0
Other (please specify)	15	13	19
Don't know/not sure	14	22	4

Table 53 asks if respondents' departments or agencies considered any other ASCT systems when they selected ASCT.

Table 53. Question 18: Did your department/agency consider any other ASCT systems when selecting ASCT?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
Yes	51	44	59
No	36	41	30
Don't know/not sure	14	16	11

Table 54 shows what other ASC systems were considered by respondents.

Table 54. Question 19: What other systems were considered?

Answer	Combined Adopters Sample (*n* = 30) (Percent)	Cross Section Adopters (*n* = 14) (Percent)	Oversample Adopters (*n* = 16) (Percent
ACS Lite	47	57	38
SCOOT	40	43	38
SynchroGreen™	43	43	44
InSync™	30	36	25
SCATS	33	36	31
Centracs™	23	14	31
LA-ATCS	13	14	13
QuicTrac™	13	14	13
OPAC	0	0	0
RHODES	0	0	0
Other (please specify)	7	0	13
Don't know/not sure	7	7	6

The following facts for table 55 through table 57 should be noted:

- Over half of respondents deployed ASCT within the past 2 yr, although many have had multiple installations of the technology.
- Oversample adopters were more likely to have had systems installed in 2012 or earlier.
- The cross-section samples were more likely to have had their most recent installation in 2015.

- Close to half (46 percent) of all ASCT projects have used Federal funding, while slightly more use local funding. The oversample was more likely to have used Federal funding and local funding.
- A total of 78 percent of adopters said that they will deploy additional ASCT in the next 2 yr.

Table 55. Question 17: In what year was your most recent ASCT system deployed?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
2012 or earlier	15	6	26
2013	15	22	7
2014	31	28	33
2015	34	41	26
2016 or later (in progress)	3	3	4
Don't know/not sure	2	0	4

Table 56. Question 20: What funding sources were used to purchase the ASCT system(s)?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
Local	51	44	59
Federal (e.g., CMAQ, Surface Transportation Program, Safety)	46	38	56
State	37	38	37
Grant funding (e.g., Department of Energy, USDOT Advanced Technology Innovation)	7	9	4
Don’t know/not sure	7	9	4
Other (please specify)	12	19	4

Table 57. Question 21: Is your jurisdiction planning to deploy ASCT on any additional signalized intersections in the next 2 yr (24 mo)?

Answer	Combined Adopters Sample (*n* = 59) (Percent)	Cross Section Adopters (*n* = 32) (Percent)	Oversample Adopters (*n* = 27) (Percent)
Yes	78	72	85
No	14	16	11
Don't know/not sure	8	13	4

Considerations and Barriers Agencies Faced When Deciding for or Against ASCT Tables

The following facts should be noted:

- Table 58 shows that managing traffic variability, managing congestion, and improving smoothness of flow are the top goals among those considering ASCT.
- Table 59 shows that the expense of ASCT combined with lack of funding are the top barriers for those aware or considering. Specifically, lack of demonstrated performance is a bigger concern for those who were aware and also considering adopting ASCT. Additionally, those who are only aware of ASCTs feel that they do not have the proper expertise to plan for ASCT.

Table 58. Question 37: What was your department/agency trying to achieve when considering ASCT for your jurisdiction?

Answer	Combined Aware/Consider (*n* = 120) (Percent)	Aware of ASCT (*n* = 67) (Percent)	Considering ASCT (*n* = 53) (Percent)
Manage general day-to-day traffic variability	—	—	65
Improve smoothness of flow on arterial streets	—	—	65
Manage congestion	—	—	62
Manage traffic related to special events (e.g., sporting events, concerts)	—	—	46
Handle major unexpected traffic delays in signalized network (e.g., accidents, weather-related)	—	—	40
Manage traffic around shopping and other social centers (e.g., shopping centers, restaurants, churches)	—	—	33
Handle diversion traffic around freeway incidents (e.g., accidents, construction, weather)	—	—	27
Reduce labor and cost to retime traffic signals	—	—	21
Manage conflicts between vehicular traffic and other modes (transit, pedestrians)	—	—	12
Don't know/not sure	—	—	4
Other (specify)	—	—	0

—This question was not asked for this group.

Table 59. Question 38: Which of the following describe barriers that have kept your department/agency from deploying ASCT?

Answer	Combined Aware/Consider (*n* = 120) (Percent)	Aware of ASCT (*n* = 67) (Percent)	Considering ASCT (*n* = 53) (Percent)
It is too expensive (e.g., main system—hardware, software)	43	37	50
Agency does not currently have funding for ASCT system	41	42	40
Agency does not currently have expertise to plan for/deploy ASCT	33	43	19
It has not demonstrated sufficient benefits/operational performance	32	27	38
It requires too much additional detection or communications equipment	23	24	21
It requires too much staff time to manage	17	21	12
It is too difficult to maintain	9	9	10
It is too complicated for agency staff to manage	9	12	6
It requires too much staff training/steep learning curve	8	4	13
It malfunctions too frequently	5	6	4
It takes too long to deploy/is too complicated to deploy	3	4	0
It is not adequately supported by vendors/distributors	2	1	2
None of these	6	7	4
Other (specify)	18	18	17

Appendix D. EDC Outreach Attendee Agencies

Table 60 provides a list of agencies that participated in EDC Summit events as well as their adoption of ASCT prior to, during, and after EDC activities. Data were collected from two sources: EDC event, type of agency, and agency/company were collected by EDC through event attendance records of EDC Summit events, and adoptions were collected from the internal interview sources detailed in appendix A. The EDC Event Location column describes the location of the EDC outreach events that were intended by the agency/company.

Table 60. EDC outreach attendee agencies.

Type of Agency	EDC Event Location	Agency or Company Attendee	Adoptions Prior to Phase 3	Adoptions in 2009–2010	Adoptions in 2011–Present
Local	Colorado	Rapid City, SD, Area Metropolitan Planning Organization	0	0	0
Local	Georgia	Florida Department of Transportation D7—Tampa	0	1	1
Local	Georgia	Greenville County Planning Department	0	0	0
Local	Illinois	Chicago Department of Transportation	0	0	1
Local	New Jersey	New Jersey Meadowlands Commission	0	0	1
Local	Virginia	City of Alexandria, VA, Department of Transportation & Environmental Services	0	0	1
Local	Washington	City of Spokane, WA, Department of Public Works & Utilities	0	0	1
Local	Washington	Clark County Public Works, Traffic Engineering	0	0	0
Local	Washington	Idaho Transportation Department—District 2	0	0	2
Other	Illinois	Purdue University Joint Transportation Research Program	—	—	—
Other	Colorado	Mid-America Regional Council	—	—	—
Other	Colorado	Utah Local Technical Assistance Program	—	—	—
Other	Georgia	Sain Associates/American Council of Engineering Companies—Alabama	—	—	—
Other	Georgia	Puerto Rico Highway and Transportation Authority	0	0	0
Other	Massachusetts	University of Delaware	—	—	—
Other	New Hampshire	Oklahoma/Arkansas Chapter, American Concrete Pavement Association	—	—	—
Other	New Jersey	American Council of Engineering Companies of New York	—	—	—
Other	Virginia	Asphalt Pavement Association of West Virginia	—	—	—
Other	Virginia	West Virginia Local Technical Assistance Program	0	0	5
State	California	Arizona Department of Transportation	1	1	4
State	California	Nevada Department of Transportation	0	0	0
State	Colorado	Colorado Department of Transportation	0	0	5
State	Colorado	Montana Department of Transportation	0	0	0
State	Colorado	South Dakota Department of Transportation	0	0	0
State	Colorado	Utah Department of Transportation	1	0	2
State	Colorado	Wyoming Department of Transportation	0	0	2

Type of Agency	EDC Event Location	Agency or Company Attendee	Adoptions Prior to Phase 3	Adoptions in 2009–2010	Adoptions in 2011–Present
State	Georgia	Alabama Department of Transportation	0	0	4
State	Georgia	Georgia Department of Transportation	2	4	4
State	Georgia	Mississippi Department of Transportation	0	0	2
State	Georgia	Tennessee Department of Transportation	0	0	1
State	Illinois	Illinois Department of Transportation	0	0	2
State	Illinois	Indiana Department of Transportation	0	0	4
State	Illinois	Ohio Department of Transportation	1	1	7
State	Illinois	Wisconsin Department of Transportation	0	0	4
State	Massachusetts	Massachusetts Department of Transportation	0	0	2
State	Massachusetts	New Hampshire Department of Transportation	0	0	0
State	Minnesota	Iowa Department of Transportation	0	0	2
State	Minnesota	Missouri Department of Transportation	0	0	9
State	Minnesota	Nebraska Department of Roads	0	0	0
State	New Hampshire	Arkansas Highway and Transportation Department	0	0	3
State	New Hampshire	Louisiana Department of Transportation and Development	0	0	0
State	New Hampshire	New Mexico Department of Transportation	0	0	1
State	New Jersey	New Jersey Department of Transportation	4	0	1
State	New Jersey	Pennsylvania Department of Transportation	0	1	18
State	Virginia	District of Columbia Department of Transportation	0	0	0
State	Virginia	Delaware Department of Transportation	1	0	0
State	Virginia	Maryland State Highway Administration	0	1	2
State	Virginia	North Carolina Department of Transportation	2	0	0
State	Virginia	Virginia Department of Transportation	4	0	7
State	Washington	Alaska Department of Transportation & Public Facilities	0	0	0
State	Washington	Oregon Department of Transportation	2	1	5
State	Washington	Washington State Department of Transportation	0	1	3

—Either no adoptions were made or data were unavailable.

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