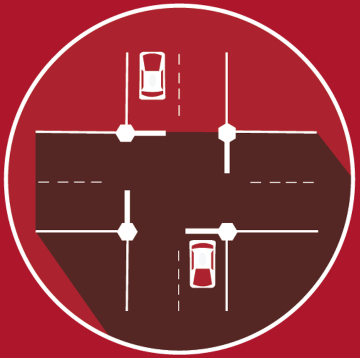
TECH**BRIEF**



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and
Technology
Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

https://highways.dot.gov/research

Developing Crash Modification Factors for Adaptive Signal Control Technologies

FHWA Publication No.: FHWA-HRT-20-073

FHWA Contact: Roya Amjadi, HRDS-20, ORCID: 0000-0001-7672-8485, (202) 493-3383, roya.amjadi@dot.gov

This document is a technical summary of the Federal Highway Administration report *Developing Crash Modification Factors for Adaptive Signal Control Technologies* (FHWA-HRT-20-072) (Avelar et al. 2021).

INTRODUCTION

The Federal Highway Administration (FHWA) established the Development of Crash Modification Factors (DCMF) Program in 2012 to address highway safety researchers' need to evaluate new and innovative safety strategies (improvements) using reliable, quantitative estimates of the effectiveness of these strategies in reducing crashes. Forty-one State departments of transportation provided technical feedback on safety improvements for the DCMF Program and implemented new safety improvements to facilitate evaluations. These States are members of the Evaluations of Low-Cost Safety Improvements Pooled Fund Study (ELCSI–PFS), which functions under the DCMF Program.

This project evaluated the safety effectiveness of adaptive signal control technologies (ASCTs) at urban intersections. The ELCSI–PFS Technical Advisory Committee determined that such an evaluation was among its high-priority activities.

STUDY OBJECTIVE

This evaluation assessed the potential of the ASCT safety-improvement strategy to reduce crashes in terms of total, fatal and injury, and PDO crashes and two intersection-specific crash types (i.e., angle and rear end). The research team developed crash-modification factors (CMFs) and benefit–cost (B/C) ratios for the safety improvement. Practitioners can use these CMFs and B/C ratios for decisionmaking in the project-development and safety-planning processes.

BACKGROUND

ASCTs continuously monitor arterial traffic conditions and queuing at intersections and dynamically adjust signal-timing-plan parameters to optimize one or more operational objectives. These objectives may include minimizing overall delays, balancing queue growth, or preventing queue spillback, among others. ASCTs perform signal-timing adjustments based on measured travel conditions in a corridor (FHWA 2017). Adaptive signal control is effective where daily variability in traffic demand results in unpredictable travel patterns. Adaptive signal controls rely on traffic sensor systems to measure changes in normal travel patterns and algorithms to dynamically alter traffic signal timing parameters (i.e., cycle, splits, and/or offsets) in response to measured or predicted conditions.

The principal benefits of ASCTs compared to conventional fixed-time signal systems are derived from a better distribution of signal green time, which improves corridor progression by reducing delay and congestion. Improving traffic flow and reducing stops can also improve traffic safety. This evaluation presents the findings from a crash-based evaluation that estimated safety improvements resulting from deploying ASCTs.

Many traffic industry vendors have developed and deployed an array of ASCT products during the last 30 yr. Examples of these systems include the Split Cycle Offset Optimization Technique (SCOOTTM), Sydney Coordinated Adaptive Traffic System (SCATS™), Real-time Hierarchical Optimized Distributed Effective System (RHODES), optimized policies for adaptive control (OPAC) (or virtual fixed cycle), Adaptive Control Software Lite (ACS Lite), and InSync.

Stevanovic (2010) indicated that ASCT deployments can reduce delay, number of stops, and other negative measures of traffic performance. The degree of operational benefit from installing ASCTs depends on several factors, such as the previous type of traffic control, the quality of previous signal timing, and the predictability or stability of traffic demand (Lodes and Benekohal 2013). ASCT deployments are most effective at locations where demand conditions are variable and unpredictable (FHWA 2012).

In addition to operational benefits, other potential nonsafety benefits of ASCTs noted in the literature previously cited include the following:

- Reductions in fuel consumption.
- Decreases in emissions and air pollution.
- Improvements in signal timing:
    - Decreased effort to develop signal timings; in some cases, it can reduce retiming intervals from years to minutes (FHWA 2012).
    - Lowered cost of periodic operational data collection and retiming.
    - Reduced cycle lengths, which produce better pedestrian response.
- Establishment of public transport priority and emergency vehicle priority.
- Better accommodation of roadwork and special events (compared to traditional systems).

METHODOLOGY

The research team identified available sources of before–after data suitable for evaluating the safety of ASCTs. Control groups or control series were added to the data-collection plan to strengthen the design whenever possible. Matching methods (e.g., Stuart 2010), such as propensity score matching, were used to assign control locations for Florida data to allow the research team to compare the treatment sites with control sites that have the most similar covariate distributions. To evaluate the safety effectiveness of ASCTs, the research team implemented an interrupted time series design for Virginia and Texas data, where comparison locations could not be included in the evaluation, and an interrupted time series design with comparison group (ITS-CG) for Florida data, where a robust set of comparison sites could be included.

Analysis methods used in this evaluation included variants of the empirical Bayes (EB) method, the full Bayesian (FB) estimation method, and generalized linear models with generalized estimating equations to implement segmented regression analyses. For the past decade, EB methods have been widely used for safety evaluations in before–after analyses. What the transportation safety community refers to as "the EB method" is in fact the combination of a specific study design (i.e., a before–after design with a reference group) and the EB method. To control for regression-to-the-mean bias, the EB method produces a weighted average between the observed and safety performance function (SPF)-estimated crashes according to the reliability of the SPF. The research team applied FB estimation methods for the before–after analysis with the ITS-CG design to cope with known limitations of the EB method (i.e., the need for reliable SPFs based on a fairly large reference group of at least a few hundred sites). Additionally, uncertainty in the estimated SPFs was not reflected in the final safety effectiveness estimate of the EB method, an issue corrected by applying the FB method. The research team also implemented a generalized linear segmented regression (GLSR) analysis using the Poisson–gamma mixture model, which describes a negative binomial error on the response variable, to account for time and intervention (i.e., installation of ASCTs) as key variables. This approach enabled the research team to account for trends and assess the expected change in safety resulting from installing ASCTs.

DATA

Although ASCT systems have been in use for 30 yr (roughly 20 yr in the United States), many were implemented for demonstration or experimental purposes. Additionally, the number of ASCT sites maintained in continuous operation for several years that can be aligned with a time series of crash data was limited in most cases the research team reviewed.

Further, the United States uses various detection layouts and strategies to adjust traffic control at sites with ASCT deployments. Initially, the research team focused on the five ASCT-type alternatives most commonly used in the United States (i.e., SCOOT, SCATS, RHODES, OPAC, and InSync).

After requesting data and locations for evaluation from several agencies, the research team received positive responses from multiple States. Limitations in the format and completeness of the data, however, led to the decision to pursue additional data collection and assembly for only three States. Ultimately, the research team prepared datasets for evaluation from these three States due to the restricted number of sites with sufficient implementation history and complete data for before and after periods. The limited number of sites and reduced availability of key variables (e.g., dates of installation or annual average daily traffic (AADT) for minor roads at intersections) were the main reasons to narrow the scope of additional data collection. The three States selected for evaluation were Florida, Texas, and Virginia.

Florida

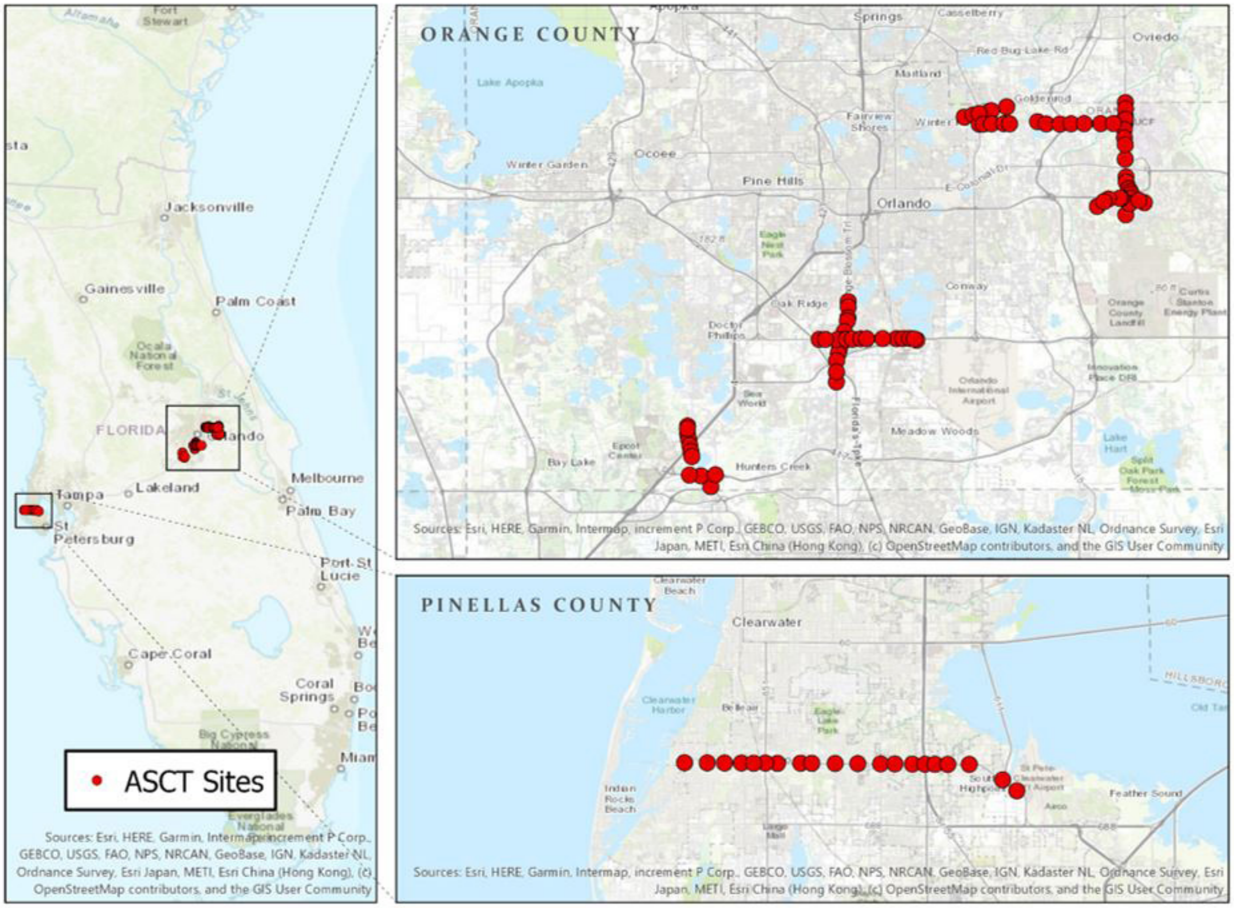
The research team collected data from 98 intersections from two counties in Florida, including 78 from Orange County and 20 from Pinellas County (figure 1). These ASCTs were distributed in six areas (or corridors).

The 20 ASCTs in Pinellas County were installed in 2014 and use InSync equipment. The ASCTs in Orange County, which also use InSync equipment, were installed at 78 intersections during 3 different years: 2015 (25 intersections), 2016 (11 intersections), and 2017 (42 intersections). The roadway design characteristics for major and minor legs were manually measured and collected from Google Earth™ satellite imagery (Google, Inc. 2019).

The research team collected 7 yr of crash data (2010 through 2016) for each intersection. The crash data were obtained from the Florida Department of Transportation (FDOT) State Safety Office. The research team created a 250-ft buffer around each intersection to identify intersection-related crashes, resulting in data from a total of 1,385 crashes collected across all study sites.

The research team also collected 7 yr of AADT data (2010 through 2016) for major and minor legs. The AADT data originated from three sources:

Figure 1. Map. ACST sites in Florida.



Screen capture by Texas A&M Transportation Institute using ArcGIS software. © 2019 Esri and its licensors. All rights reserved. Service Layer Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors, and the GIS User Community.

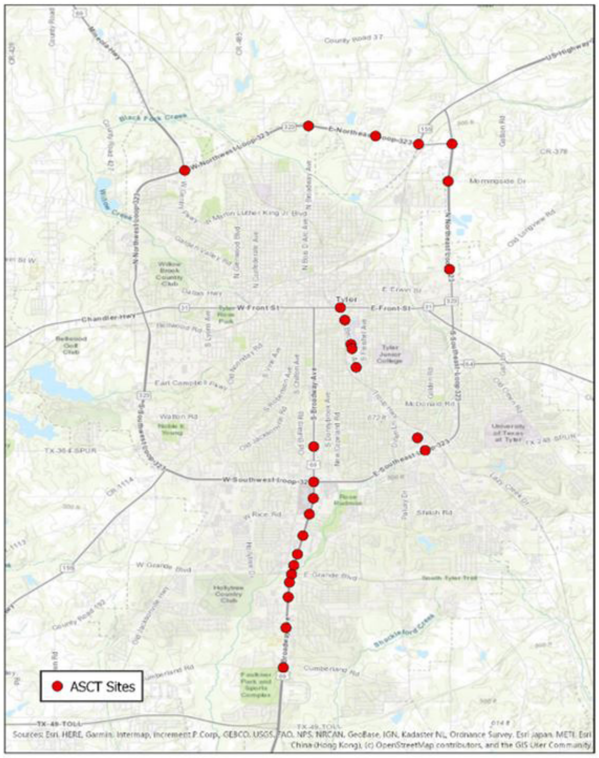
- Historical Annual Average Daily Traffic Shapefile obtained from the FDOT Transportation Data and Analytics Office website (FDOT 2019). This shapefile contains 5 yr of AADT data (2014 through 2018) for road segments in Florida.
- Orange County traffic counts accessed through the Orange County Government website. This web-based platform provides up to 20 yr (1999 through 2018) of traffic volume data for each traffic count location (Orange County Government Florida 2019).
- Pinellas County traffic count maps obtained from the county's website. These maps represent 8 yr of traffic averages (2011 through 2018) (Pinellas County Florida 2019).

Texas

The research team collected data from 25 intersections in Tyler, TX (figure 2). These locations were on three corridors:

- Loop 323 from US 69N south, east, and north to Commerce St.
- US 69 (Broadway) from Amherst Dr. to Cumberland Rd.
- Beckham Ave. from Frontage Rd. (SH 31) south to Loop 323.

Figure 2. Map. ASCT sites in Tyler, TX.



Screen capture by Texas A&M Transportation Institute using ArcGIS software. © 2019 Esri and its licensors. All rights reserved. Service Layer Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors, and the GIS User Community.

These ASCTs were installed in 2012 using ASC Lite equipment. The roadway design elements for major and minor legs were manually measured and collected from Google Earth satellite imagery (Google, Inc. 2019).

The research team collected 8 yr of crash data (2010 to 2017) for each study site. The Texas Department of Transportation (TxDOT) Crash Records Information System supplied the crash data (TxDOT 2019a). As with the Florida sites, the research team created a 250-ft buffer around each intersection to select intersection-related crashes. The period of analysis was expanded to 8 yr to obtain a stable baseline of comparison for the after period. The team identified a total of 4,067 intersection-related crashes during the 2010 to 2017 period.

TxDOT supplied the AADT data for major and minor legs of each intersection from its Roadway Inventory Data system (TxDOT 2019b). The research team collected 8 yr of AADT data corresponding to the years of crash data (2010 to 2017) for both the major and minor legs.

Virginia

The research team collected data from 68 intersections equipped with InSync ASCT systems in 7 counties in Virginia (figure 3).

In 2011, ASCTs were installed at 18 study sites, while another 50 ASCTs were installed in 2012. The research team manually measured the roadway design characteristics of major and minor legs using Google Earth satellite imagery. The Virginia Department of Transportation (VDOT) provided crash data for 8 yr (2006 through 2013).[1] The research team identified a total of 3,547 intersection-related crashes at these study sites from 2006 through 2013.

ANALYSIS

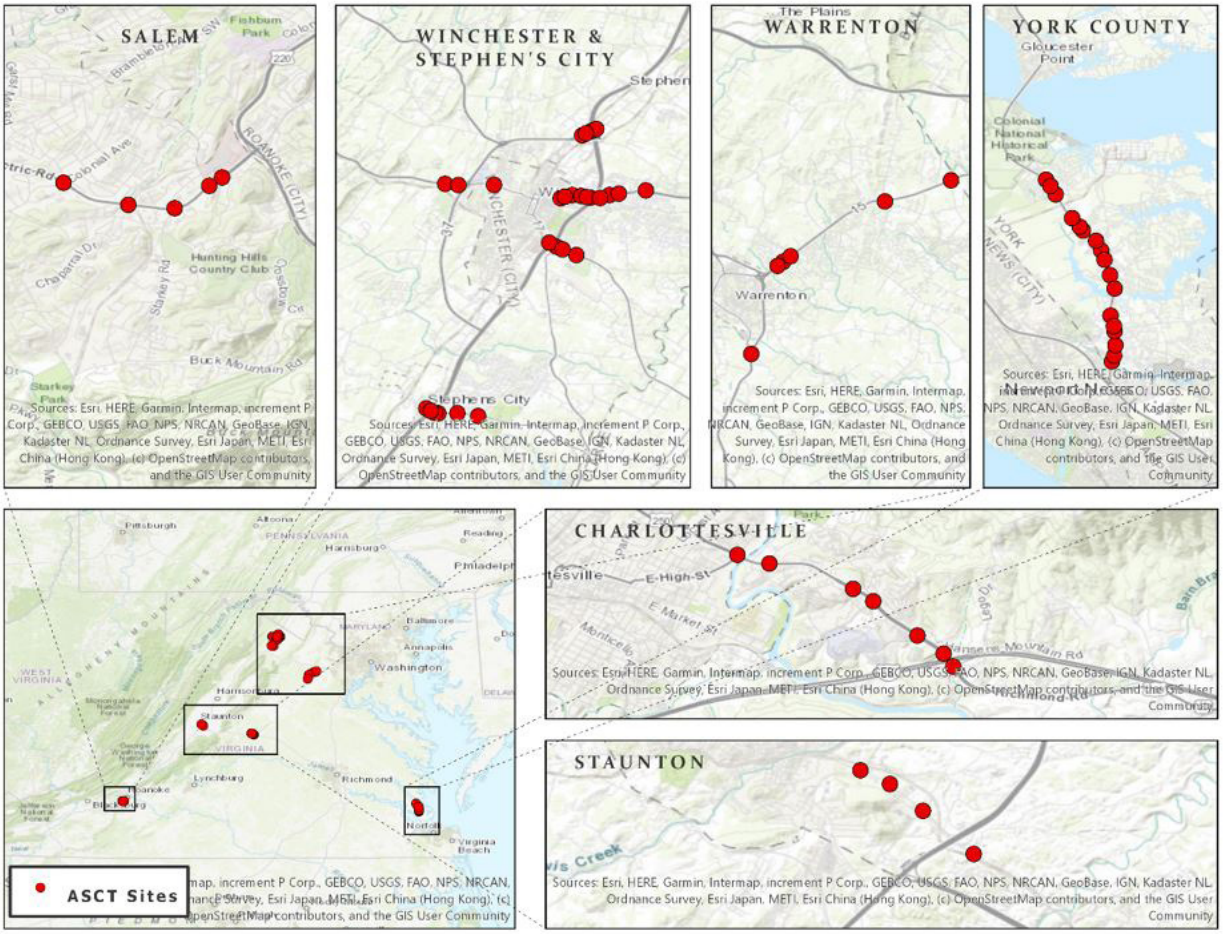
Florida

The research team conducted the safety evaluation of ASCTs in Florida by employing two evaluation approaches: a before–after analysis using the EB method and before–after analysis with comparison groups using the FB estimation method. The Florida data included 98 intersections with ASCTs, which were installed between 2014 and 2017. Because the period for the Florida crash data was from 2010 through 2016, the 42 intersections with ASCT implementations in 2017 were used as reference sites for the EB analysis and comparison sites for the FB analysis. The 11 intersections treated during 2016 were excluded

---

[1] The study team obtained this crash data via email from the Safety, Operations, and Traffic Engineering Team at VDOT in February 2018.

Figure 3. Map. ASCT sites in Virginia.



Screen capture by Texas A&M Transportation Institute using ArcGIS software. © 2019 Esri and its licensors. All rights reserved. Service Layer Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors, and the GIS User Community.

from both EB and FB before–after analyses because no after data were available.

For the EB before–after analysis, the research team developed SPFs based on the data from the reference sites. The research team then used these SPFs to estimate the expected crash frequencies at the treated sites had treatments not been applied and calibrated SPFs for each year of the before–after periods rather than just for each period (Hauer 1997; Park et al. 2010, 2019).

The research team also examined crashes by employing an FB before–after analysis method. The team fitted the Poisson–gamma mixture model (equivalent to the negative binomial distribution) with a change point to total, fatal and injury, property-damage-only (PDO), rear-end, and angle crashes. The research team followed the steps for implementing FB before–after evaluations with two comparison groups (corresponding to implementation years 2014 and 2015) as proposed by Park et al. (2010).

By its nature, an EB before–after analysis cannot account for the uncertainty in the SPF estimates in the safety effectiveness estimate. In contrast, the FB analysis can incorporate uncertainty in model parameters into the final safety effectiveness estimate.

Texas

Because neither reference nor comparison sites were available in the Texas study, the team conducted the safety evaluation of ASCTs using a GLSR analysis. A negative binomial regression model that introduced time as a variable to control for overall trend and intervention (i.e., installation of ASCTs) as a variable was employed to estimate the effect of the ASCT. The Texas crash data contained 25 intersections with ASCTs installed in 2012. The research team obtained yearly crash data at each intersection for years 2010 through 2017. As an estimation method, the team used generalized estimating equations to account for correlations in crash counts obtained for multiple years at the same intersection.

Virginia

As previously discussed, VDOT provided data for 68 intersections with ASCTs. As was the case with the Texas data, neither reference nor comparison sites were available, so the research team again conducted its safety evaluation using a GLSR analysis and applied a negative binomial regression model to control for trend and intervention.

RESULTS

For Florida, CMFs were estimated using two alternative methods: the EB method and FB method. The latter is considered more robust as it better accounts for sources of uncertainty. The research team estimated the CMFs for Texas and Virginia from a negative binomial GLSR analysis using generalized estimating equations. Table 1 presents the results of these analyses.

For Florida, the results indicated no statistically significant changes in total, fatal and injury, PDO, or rear-end crashes. The increase in angle crashes for the Florida sites was statistically significant based on the EB before–after analysis; however, it was not statistically significant for the FB analysis. Because the FB analysis method better accounts for uncertainty in the data than the EB method, FB uncertainty estimates tend to be larger than those resulting from the EB approach. As a result, EB analysis results often underestimate true uncertainty and may incorrectly indicate statistical significance.

The analysis of Texas corridors estimated a CMF of 1.000 (0-percent reduction) in total crashes (statistically insignificant). It also showed a 10.5-percent increase in fatal and injury crashes (statistically insignificant), a 4.7-percent decrease in PDO crashes (statistically insignificant), a 44-percent reduction in rear-end crashes (statistically significant at the 95-percent confidence level), and a 2.8-percent increase in angle crashes (statistically insignificant).

For Virginia, the analysis indicated a 13.3-percent reduction in total crashes (statistically significant at the 90-percent confidence level), a 35.8-percent reduction in fatal and injury crashes (statistically significant at the 95-percent confidence level), a 1.9-percent increase in PDO crashes (statistically insignificant), a 39.6-percent reduction in angle crashes (statistically significant at the 95-percent confidence level), and a 2.0-percent increase in rear-end crashes (statistically insignificant).

ECONOMIC EFFECTIVENESS

Because of the mixed results (no statistically significant change in safety in Florida and significant crash reductions in Texas and Virginia), the research team conducted an economic evaluation for two scenarios:

1. The safety benefit estimated from the Virginia dataset is realized.
2. No measurable safety effect is realized (the worst-case outcome observed in this study).

When assuming a 13.3-percent reduction in total crashes (as indicated by the analysis results in Virginia), the research team estimated a B/C ratio of 65.56. When assuming no safety benefit derived from ASCT installations (as the results from Florida suggested), the B/C ratio estimate dropped to 25.46. In both cases, a B/C ratio larger than 1.0 indicated that the benefits obtained from implementing ASCT outweigh the costs. These results considered an adjusted value of a statistical life, average crash costs in the three States, cost savings due to reduced congestion, costs of operating new software, costs of maintenance, and other metrics recommended in *NCHRP Synthesis 403: Adaptive Traffic Control Systems: Domestic and Foreign State of Practice* (Stevanovic 2010).

CONCLUSIONS

The objective of this study was to perform a rigorous safety effectiveness evaluation of ASCT installations. To accomplish the goals of this study, the research team compiled safety data from Florida, Texas, and Virginia. The evaluation included total, fatal and injury, PDO, rear-end, and angle crashes.

When analyzing the Florida data, the research team implemented two estimation methods (EB and FB) that yielded similar and statistically insignificant estimates of effectiveness for four out of the five crash types

Table 1. Comparison of CMFs for ASCTs obtained by State and analysis approach.

State	Methodology	Total	Fatal and Injury	PDO	Angle	Rear End
FL	EB	1.045	1.039	1.022	1.207**	1.003
FL	FB	1.042	1.033	1.027	1.239	0.940
TX	GLSR	1.000	1.105	0.953	1.028	0.560**
VA	GLSR	0.867*	0.642**	1.019	0.604**	1.020

*Statistical significance at a 90-percent confidence level.
** Statistical significance at a 95-percent confidence level.

evaluated. However, for angle crashes, the EB analysis indicated a large and statistically significant increase (20.7 percent) after the installation of ASCTs. The more robust FB method found a similar estimate (a 23.9-percent increase) not to be statistically significant. The result from the FB method was considered the most plausible of the two (i.e., no evidence of a change in angle crash frequency) given that this method accounted for a source of uncertainty that the EB method ignores.

Results from the Texas analysis, based on interrupted time series, also showed mostly insignificant changes in safety associated with ASCT installations. The notable exception was a statistically significant reduction (44 percent) in rear-end crashes. This result was consistent with past literature. For example, Khattak (2016) reported reductions of 34 percent in total crashes and 45 percent in fatal and injury crashes.

The results from Virginia produced evidence of significant reductions in total crashes (a 13.3-percent reduction, or 0.867 CMF, significant at the 10-percent significance level), fatal and severe crashes (a 35.8-percent reduction, or 0.642 CMF, significant at the 5-percent significance level), and angle crashes (39.6-percent reduction, or 0.604 CMF, significant at the 5-percent significance level). These results are consistent with past literature. Past research has reported additional improvements in terms of delay, queue lengths, and travel time; for example, Stevanovic et al. (2011). Regarding crash-based evaluations, Ma et al. (2016) estimated a CMF of 0.92 for total crashes and 0.83 for fatal and injury crashes.

Regarding statistically insignificant results, it should be noted that such results could indicate either the absence of a change in safety performance, or the presence of very small safety effects that could not be detected in the datasets used in this study. Additionally, it was notable that the results that were statistically significant were not consistent across the three States, which points to differences between installations. The research team speculates that differences in the safety effectiveness of ASCTs probably depend on the specific technologies implemented and local operational characteristics of the sites under study.

REFERENCES

Avelar, R., Park, E.S., Dixon, K., Li, X., Li, M., and Dadashova, B. (2021). *Developing Crash Modification Factors for Adaptive Signal Control Technologies*, Report No. FHWA-HRT-20-072, Federal Highway Administration, Washington, DC.

Esri. (2019). ArcGIS Desktop, Release 10.5.1, Environmental Systems Research Institute, Redlands, CA.

FHWA. (2012). "Every Day Counts (EDC) Exchange: Adaptive Signal Control Technology—Managing Risks, Achieving Objectives." Webinar held August 16, 2012. Available online: https://www.fhwa.dot.gov/innovation/everydaycounts/edc_exchange/asct.cfm, last accessed July 27, 2020.

FHWA. (2017). "Adaptive Signal Control Technology," (website). Available online: https://www.fhwa.dot.gov/innovation/everydaycounts/edc-1/asct.cfm, last accessed August 27, 2020.

FDOT. (2019). "Transportation Data and Analytics Office, Geographic Information System (GIS)" (website). Available online: https://www.fdot.gov/statistics/gis/default.shtm, last accessed July 27, 2020.

Google®. (2019). Google Earth™ Pro v7.3.2.5779, Mountain View, CA. Available online: https://www.google.com/earth/versions/#earth-pro, last accessed July 27, 2020.

Hauer, E. (1997). *Observational Before–After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety*, Pergamon Press, Oxford, UK.

Khattak, Z. (2016). "Evaluating the Operational and Safety Aspects of Adaptive Traffic Control Systems in Pennsylvania." Master's Thesis, University of Pittsburgh, Pittsburgh, PA. Available online: http://d-scholarship.pitt.edu/26899/1/ZulqarnainKhattak_etdPitt2016_%28final%29.pdf, last accessed July 29, 2020.

Lodes, M., and Benekohal, R., (2013). *Safety Benefits of Implementing Adaptive Signal Control Technology: Survey Results*, Report No. FHWA-ICT-12-020, Federal Highway Administration, Washington, DC.

Ma, J., Fontaine, M., Zhou, F., Hu, J., Hale, D., and Clements, M., (2016). "Estimation of Crash Modification Factors for an Adaptive Traffic Signal Control System." *Journal of Transportation Engineering, 142*(12), American Society of Civil Engineers, Reston, VA.

Orange County Government Florida. (2019). "Orange County Traffic Counts" (website). Available online: https://www.orangecountyfl.net/, last accessed July 27, 2020.

Park, E.S., Carlson, P., and Pike A. (2019). "Safety Effects of Wet-Weather Pavement Markings." *Accident Analysis and Prevention, 133,* Article 105271, Elsevier, Amsterdam, Netherlands. Available online: https://doi.org/10.1016/j.aap.2019.105271, last accessed July 27, 2020.

Park, E.S., Park, J., and Lomax, T. (2010). "A Fully Bayesian Multivariate Approach to Before-After Safety Evaluation." *Accident Analysis and Prevention, 42*, pp. 1118–1127, Elsevier, Amsterdam, Netherlands.

Pinellas County Florida. (2019). "Pinellas County Enterprise GIS" (website). Available online: http://new-pinellas-egis.opendata.arcgis.com/, last accessed July 27, 2020.

Stevanovic, A. (2010). NCHRP Synthesis 403: *Adaptive Traffic Control Systems: Domestic and Foreign State of Practice*, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC. Available online: http://www.trafficwareuniversity.com/sites/default/files/nchrp_syn_403_0.pdf, last accessed July 27, 2020.

Stevanovic, A., Kergaye, C., and Haigwood, J. (2011). "Assessment of Surrogate Safety Benefits of an Adaptive Traffic Control System." *Third International Conference on Road Safety and Simulation*, September 14–16, Indianapolis, IN.

Stuart, E. (2010). "Matching methods for causal inference: A review and a look forward." *Statistical Science: A Review Journal of the Institute of Mathematical Statistics, 25*(1), pp. 1–21, Institute of Mathematical Statistics, Beechwood, OH.

TxDOT. (2019a). "TxDOT Crash Report Online Purchase System" (website). Available online: https://cris.dot.state.tx.us/public/Purchase/app/home/welcome, last accessed July 27, 2020.

TxDOT. (2019b). "Roadway Inventory" (website). Available online: https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html, last accessed July 27, 2020.

Researchers—This study was performed by Principal Investigator Raul Avelar (ORCID: 0000-0002-3962-1758) along with Eun Sug Park (ORCID: 0000-0001-6224-7007), Xiao Li (ORCID: 0000-0002-6762-2475), Karen Dixon (ORCID: 0000-0002-8431-9304), Minh Li (ORCID: 0000-0003-0129-1615), and Bahar Dadashova (ORCID: 0000-0002-4592-9118). The Contracting Officer's Representative and Task Manager was Roya Amjadi (HRDS-20, ORCID: 0000-0001-7672-8485) of the FHWA Office of Safety Research and Development. This study was performed by Texas A&M Transportation Institute under contract DTFH6116D00039.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the divisions and Resource Center.

Availability—This TechBrief may be obtained online at https://highways.dot.gov/research.

Key Words—Crash modification factor, CMF, ASCT, adaptive signal control technology, safety.

MARCH 2021

FHWA-HRT-20-073
HRDS-20/03-21(300)E