Safety Evaluation of an Adaptive Signal Control Technology Using an Empirical Bayes Approach

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Developing Florida-specific Mobility Enhancement Factors (MEFs) and Crash Modification Factors (CMFs) for TSM&O Strategies

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WHEN PRE-TIMED SIGNALS FAIL: A STORY WE ALL KNOW

Source: Shutterstock.

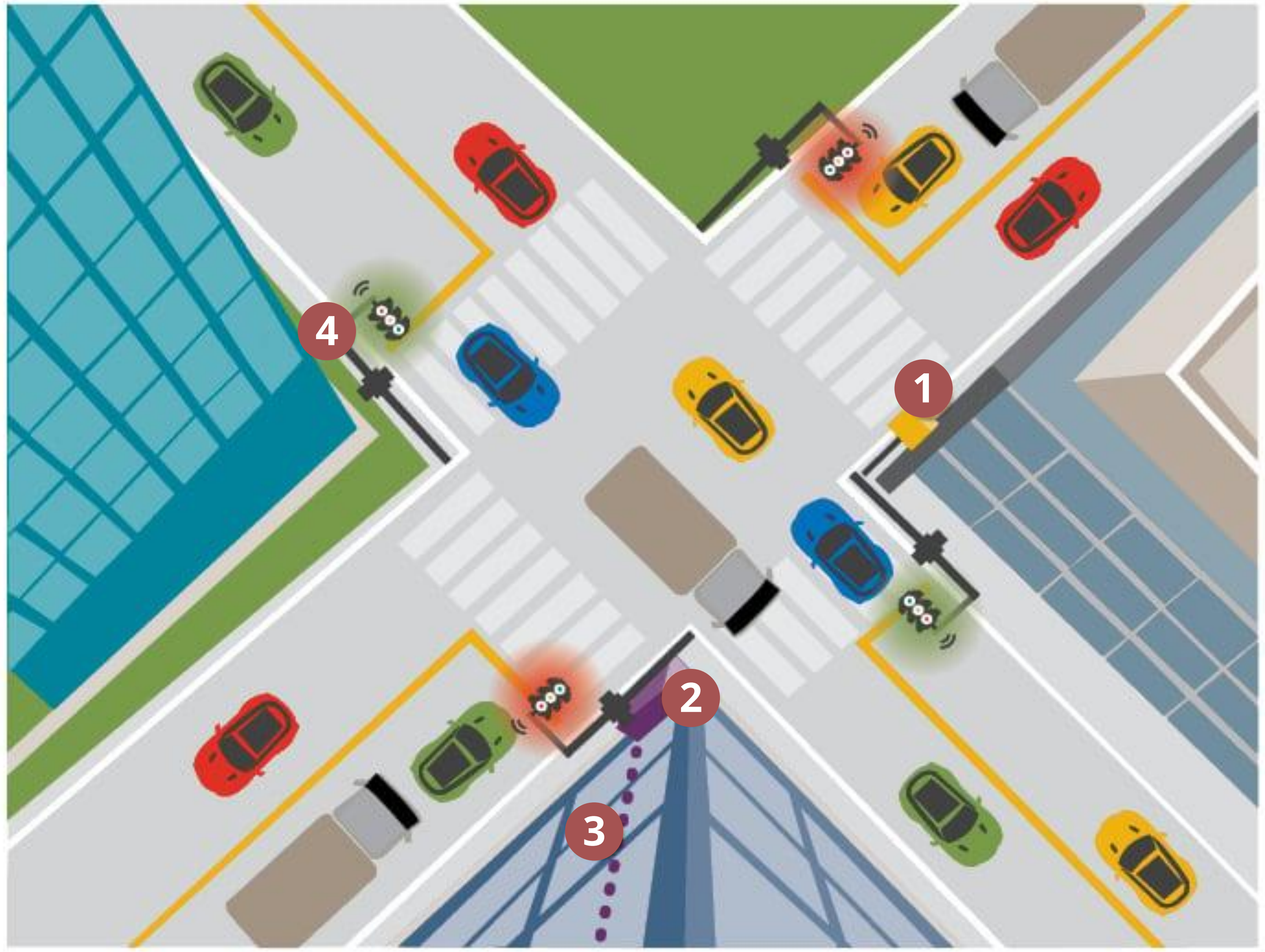
- Agencies use pre-timed, non-adaptive signal plans.
- This may cause excessive delays, stop-and-go flow, and congestion.
- Congestion raises driver stress and errors — ~30% of crashes linked to stress[1]

[1]Khattak, Z. H., M. D. Fontaine, and R. A. Boateng. 2018. "Evaluating the impact of adaptive signal control technology on driver stress and behavior using real-world experimental data." Transp. Res. Part F: Traffic Psychol. Behav. 58 (Oct): 133–144. https://doi.org/10.1016/j.trf.2018.06.006.

WHAT IS ADAPTIVE SIGNAL CONTROL TECHNOLOGY?

- ASCT is a real-time signal control system that automatically adjusts timings to match actual traffic demand.
- Primary goals:
  - improved efficiency,
  - better safety, and
  - reduced congestion-related emissions.
- The technology is future-ready and can integrate AI detection, V2I data, and connected/automated vehicle systems.

WHAT HAPPENS INSIDE AN ADAPTIVE SIGNAL SYSTEM?



Source: Hastings & Jerr (2019). Adaptive Signals, Enhanced Communities.

1. **Detectors:** collect real-time congestion and vehicle data
2. **Traffic cabinet:** processes local sensor data and forwards it to the cloud
3. **Cloud-based controller:** analyzes incoming data and computes timing updates.
4. **Signals receive:** updates green intervals, which vary to match current demand

Detect → Analyze → Optimize → Implement

LITERATURE REVIEW

Study	State	Number of study sites	Data collection period	SPF	Safety effectiveness method	Findings
Dutta et al. (2010)	MI	9 SCATS segments	1998-2008	NA	Before-After SCATS deployment	Reduction in crashes per year per mile[a]: • Incapacitating Injury by 31.03% • Non-incapacitating Injury by 42.5% • Possible Injury by 10.19% • PDO by 16.48%
		14 pre-timed segments	1998-2008	NA	Comparison study between SCATS and TOD	Reduction in crashes per year per mile[a]: • Total crash by 28.84% • Incapacitating Injury by 48.8% • Non-incapacitating Injury by 51.13% • Possible Injury by 36.36% • PDO by 24.58%
Lodes & Benekohal (2013)	NA	3 intersections	NA	NA	Survey Before-After	Reduction in total crashes[a]
Fink et al. (2016)	MI	498 intersections	2010-2012	NA	Cross-sectional analysis	• Reduction in angle crashes by 19.3% • Increase in non-serious injury crashes • Decrease in incapacitating injury crashes[a]
Ma et al. (2016)	VA	47 intersections	2006-2013	Calibrated	Before-After EB	Reduction in: • Total crashes by 17.0% • FI crashes by 8.0%[a]
Khattak et al. (2018)	PA	41 intersections	NA	Calibrated	Before-After EB	Reduction in: • Total crashes by 13.0% • FI crashes by 36.0% • Rear-end crashes[a]
Khattak et al. (2019)	• PA • VA	49 intersections in PA 42 intersections in VA	2007-2014 (PA) 2006-2016 (VA)	NA	Before-After	Reduction in: • Moderate and severe injury by 5.24% • Minor injury by 9.91%
Stevanovic et al. (2011)	NA	NA	NA	NA	Simulations and SSAM	ASCT generated fewer rear-end and total conflicts[a]

Note: [a] Means the results are not statistically significant; NA is not applicable.

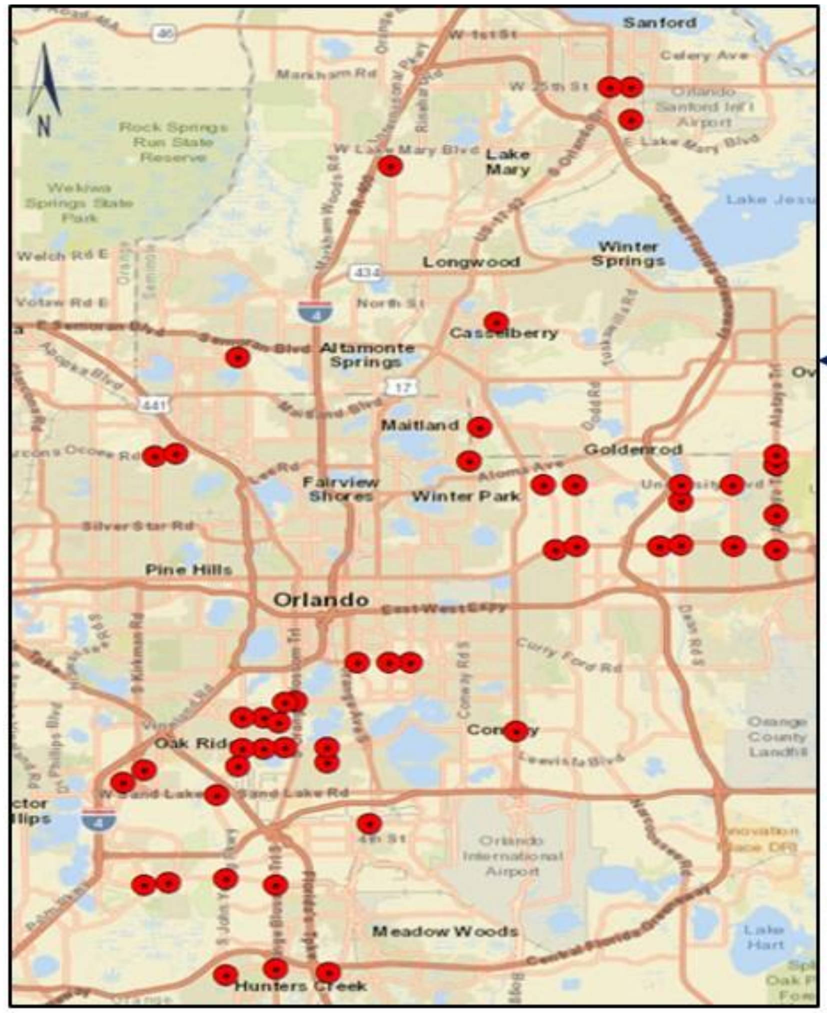
RESEARCH GAP

- Few studies have evaluated ASCT safety effects, and many report inconclusive results.
- Most past studies used calibrated HSM SPFs and simple before–and–after EB methods.
- These methods miss key variables and confounding factors, so more robust approaches are needed.

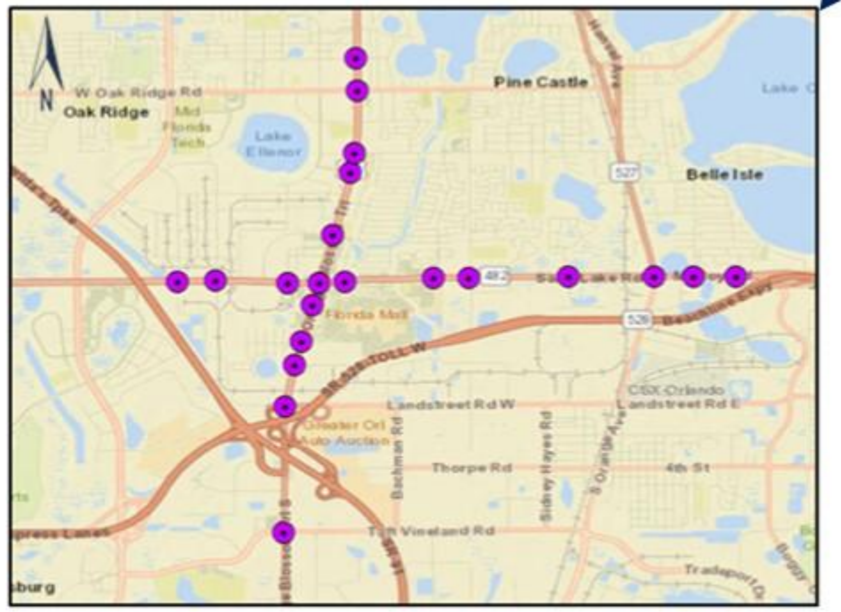
OBJECTIVE

Quantify the safety effectiveness of adaptive signal control technology (ASCT).

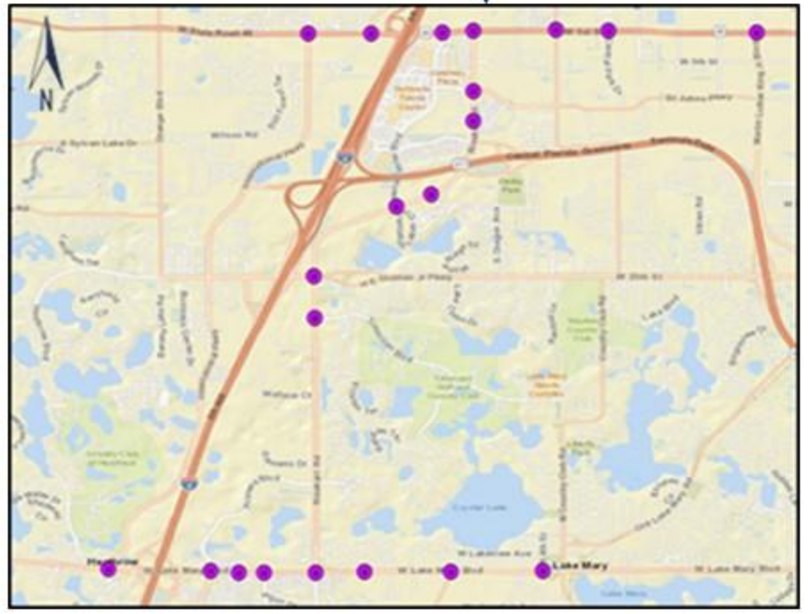
SITE DESCRIPTION



Comparison sites



Orange County treatment sites



Seminole County treatment sites

Treatment Sites

- 42 four-legged signalized intersections in Seminole and Orange counties, FL, with ASCT:
  - 27 InSync ASCT signals
  - 15 SynchroGreen ASCT signals
- Site selection criteria:
  - Geometric homogeneity
  - At least 2 years of before-and-after crash data
  - No construction activity during the study period

Comparison Sites

- 47 signalized intersections without ASCT selected
  - Located in the same jurisdictions as treatment sites
  - Used to develop agency-specific full safety performance functions (SPFs)
  - Matched to treatment sites based on traffic volumes, geometric characteristics, land use information, and signal phasing
  - Comparability verified using Hauer's test to ensure a valid match

ANALYSIS PERIOD

Number of intersections	Treatment year	Before period	Number of years in the before period	After period	Number of years in the after period
2	2013	2011-2012	2	2014-2018	5
6	2014	2011-2013	3	2015-2018	4
26	2015	2011-2014	4	2016-2018	3
8	2016	2011-2015	5	2017-2018	2

SPF MODEL VARIABLES

Explanatory Variables

- Traffic volume
- Number of lanes
- Number of exclusive right lanes
- Median presence
- Median width
- Speed limit
- Land use
- Left turn signal phases
- Presence of bus stop

→

Response Variables

- Total Crashes
- Angle Crashes
- Rear-end Crashes
- Fatal/injury Crashes
- Property damage only Crashes

DESCRIPTIVE STATISTICS

Variables	Period	Treatment intersections				Comparison intersections			
		Min	Max	Mean	Std	Min	Max	Mean	Std
Total crashes (crash/year/intersection)	Before	1	98	32.73	25.57	2	96	38.23	18.81
	After	0	103	20.07	24.85	2	96	39.92	18.12
Rear-end crashes (crash/year/intersection)	Before	0	54	18.75	15.15	0	58	23.29	13.20
	After	0	56	14.97	14.41	0	64	22.76	12.15
Angle crashes (crash/year/intersection)	Before	0	7	0.90	1.21	0	8	1.45	1.43
	After	0	4	0.67	0.79	0	9	1.85	1.46
PDO crashes (crash/year/intersection)	Before	0	70	25.29	20.71	1	69	28.4	14.46
	After	0	84	17.02	18.58	0	69	29.2	12.86
FI crashes (crash/year/intersection)	Before	0	28	8.08	5.73	0	30	9.83	5.39
	After	0	27	5.7	6.97	0	33	10.72	6.76

EMPIRICAL BAYES METHODOLOGY

Step 1: SPF

Treatment & comparison intersections data

Develop SPF using comparison intersections data

Use SPF to predict safety performance at treatment intersections had ASCT not been installed

Step 2: CMF

Compare observed and expected safety performance at treatment intersections

Crash Type

- Total crashes
- Angle crashes
- Rear-end crashes
- Fatal/injury crashes
- PDO crashes

ASCT Type

- InSync
- SynchroGreen

AADT Levels

- < 44,000 vpd
- > 44,000 vpd

Years in After Period

- ≥ years in the after period

EMPIRICAL BAYES METHODOLOGY

Concern	How we addressed it	Why it matters
Regression-to-the-mean bias	EB before–after with comparison group	Removes apparent safety gains caused by selection of unusually high (or low) pre-treatment crash counts
Confounding factors	Developed full SPFs that include multiple explanatory variables using data from comparison sites	Isolates the ASCT effect from concurrent influences that would otherwise distort CMFs
Unsuitable comparison groups	Selected comparison sites using Hauer's comparability test	Ensures a valid counterfactual and reduces selection bias in the EB estimate
Wrong functional form/model misspecification	Bayesian negative binomial regression with overdispersion parameter	Produces better fit, realistic uncertainty, and more reliable CMF estimates

CMFS: CRASH TYPE

Crash category	Mean	95% CI		Standard error	% Reduction in target crashes
		Upper limit	Lower limit		
Total crashes	0.948	0.955	0.942	0.003	5.2%
Rear-end crashes	0.878	0.886	0.870	0.004	12.2%
Angle crashes	0.979[a]	1.011	0.947	0.016	2.1%
FI crashes	0.958	0.971	0.945	0.007	4.2%
PDO crashes	0.943	0.951	0.936	0.004	5.7%

[a]Not significant at a 95% confidence level.

CMFS: ASCT TYPE

ASCT type	Crash category	Mean	95% CI		Standard error	% Reduction in target crashes
			Upper limit	Lower limit		
InSync	Total crashes	0.950	0.958	0.943	0.004	5.0%
	Rear-end crashes	0.894	0.904	0.885	0.005	10.6%
	Angle crashes	0.933	0.969	0.898	0.018	6.7%
	FI crashes	0.976	0.991	0.961	0.007	2.4%
	PDO crashes	0.936	0.951	0.930	0.007	6.4%
SynchroGreen	Total crashes	0.966	0.980	0.951	0.007	3.4%
	Rear-end crashes	0.933	0.943	0.922	0.005	6.7%
	Angle crashes	1.015[a]	1.077	0.954	0.031	-1.5%
	FI crashes	0.916	0.934	0.896	0.010	8.4%
	PDO crashes	0.927	0.940	0.914	0.007	7.3%

[a]Not significant at a 95% confidence level.

CMFS: # YEARS IN THE AFTER PERIOD

Crash category	Mean	95% CI		Standard error	% Reduction in target crashes
		Upper limit	Lower limit		
Total crashes	0.981	0.988	0.973	0.004	1.9%
Rear-end crashes	0.909	0.919	0.900	0.005	9.1%
Angle crashes	1.001[a]	1.038	0.964	0.019	-0.12%
FI crashes	0.987	1.002	0.972	0.008	1.3%
PDO crashes	0.981	0.990	0.972	0.005	1.9%

[a]Not significant at a 95% confidence level.

CMFS: AADT LEVELS

AADT (veh/day)	Total crashes		Angle crashes		Rear-end crashes		FI crashes		PDO crashes	
	CMF	Std. error	CMF	Std. error	CMF	Std. error	CMF	Std. error	CMF	Std. error
AADT < 44,000	1.002[a]	0.006	0.888	0.024	0.923	0.007	0.890	0.010	1.045[a]	0.007
AADT > 44,000	0.836	0.004	0.860	0.022	0.760	0.005	0.938	0.009	0.805	0.004

[a]Not significant at a 95% confidence level.

CONCLUSIONS

- ASCT improves traffic operations and measurably reduces crashes at signalized intersections.
- This study supplies CMFs and a replicable method to quantify safety benefits and conduct economic appraisals.
- Findings support agency decisions to invest in, prioritize, and scale ASCT deployments across corridors.

STUDY LIMITATION

- The model's spatial transferability across and within the state was not tested.
  - Transferability matters because reusable model parameters save data-collection and re-estimation costs.
  - Future work should evaluate transferability and, if needed, develop adjustment factors or location-specific recalibration.

THANK YOU

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