Documented Safety Improvements of Adaptive Traffic Signals

Jim Clark, P.E.

Abstract. Each year, tens of thousands of lives are cut short by vehicular collisions and the financial toll of those crashes is on the rise. To put an end to these costly tragedies, governments and the traffic industry are investing in the safety of signalized roadways through emerging technologies in intelligent transportation systems (ITS) such as vehicle-to-vehicle and vehicle-to-infrastructure initiatives. While there are many worthwhile research initiatives currently underway to improve roadway safety, traffic adaptive signal control is proven to significantly reduce crashes and is immediately available for deployment. Traffic adaptive signal control builds on and leverages established concepts known to improve roadway safety, delivering measurable crash reduction in real-world deployments. There are many adaptive systems providing varying levels of performance; this study is based upon analysis of independently collected before-and-after crash data from four recent deployments of the InSync adaptive control system. In these case studies, InSync has demonstrated crash reductions from 15% to 30% in field implementations. The implications of the crash reductions in terms of injuries, fatalities and economic savings for communities are substantial. The crash data included in this white paper is from a limited scope of time and a larger scope is required to be truly conclusive; however, the data available at this time is significant, consistent and deterministic.

INTRODUCTION

The World Health Organization (WHO) calls traffic injuries a “global public health problem,” citing a human cost of 1.27 million lives lost per year in automotive collisions and other traffic crashes (1). In 2006, one of the worst years for traffic crashes in recent history, there were a reported 42,642 road traffic fatalities and a further 3,305,237 reported non-fatal road traffic injuries in the United States (2). While the frequency and number of fatalities show a steady decline in recent decades, deaths remain in the tens of thousands, and the monetary cost of those crashes is on the rise.

Beyond the lives cut short is the financial toll of fatal collisions, which costs the nation an estimated $6 million per fatality crash (3). The cost of non-fatal injury crashes, although comparatively less, is a substantial $126,000 per crash. This recent research by the insurance provider AAA reflects a trend in bringing the magnitude of road safety to the attention of the public and its elected officials. A synthesis of U.S. Census data of motor vehicle crash quantity (all types) and the AAA summation of the total cost of crashes, both from 2009, bears an average cost per collision of $27,731 (4,5).

As a result, transportation professionals are embracing the improved safety offered by emerging technologies in intelligent transportation systems (ITS). The automobile industry, United States Department of Transportation (USDOT) and the traffic control industry are making significant advancements in intersection safety through collision avoidance systems. These systems emphasize vehicle-to-vehicle and vehicle-to- roadside device communications; research is proving these are viable solutions. However, it will take many years before the needed roadway and vehicle fleet infrastructure are in place to realize the full magnitude of safety improvement. In the meantime, steps are being taken to help address this safety problem, and in the same efforts, prepare for these emerging technologies. One such step is the rapid development and increasing adoption of adaptive traffic control systems (ATCSs).

OBJECTIVE

The objective of this paper is to connect the operational benefits of ATCSs with their safety benefits. This objective is accomplished by reviewing the InSync adaptive traffic control signal system, which demonstrates substantial signal operation improvements and for which field safety data is readily available. This information is critical to traffic professionals, policymakers and researchers as it establishes a direct link to an immediately available solution to the high cost of traffic crashes.

BACKGROUND

While the WHO and the National Transportation Safety Board (NTSB) make ample recommendations for improving safety centered on developing in-vehicle technologies, law enforcement practices and human-factors engineering, the American Association of State Highway and Transportation Officials (AASHTO), in conjunction with other highway safety agencies, proposed a comprehensive Strategic Highway Safety Plan (SHSP) addressing 22 specific challenges (6). Of those, accidents at or near intersections present a particularly important challenge. In 2009, of the 33,808 reported fatalities on U.S. roadways, 7,043, or approximately 21%, were intersection-related (7). The SHSP cites the grim statistics that “on average, there are five crashes at intersections every minute and one person dies every hour of every day at an intersection somewhere in the United States” (8). It follows that the improvement of intersection infrastructure should be a priority in reducing the human and economic costs of traffic collisions.

To help practitioners address this costly issue, the Federal Highway Administration (FHWA) Office of Safety lists nine specific countermeasures to reduce crashes within the focus areas of intersections, pedestrians and roadway departures. The measures targeting intersections range from significant infrastructure changes – including converting signalized intersections to roundabouts – to minor changes such as adding retroreflective backplates to traffic signal heads (9). These measures may effectively eliminate or reduce red-light running and other causes of dangerous intersection conflicts. However, significant changes in infrastructure can be costly, time-consuming and impractical to implement. At the same time, minor changes have a limited scope of impact. Among the strategies proposed in the SHSP for decreasing danger at intersections are optimizing clearance intervals (Strategy 17.2 A2) and employing signal coordination (Strategy 17.2 A4) (10). Both strategies, categorized under the objective of reducing the “frequency and severity of intersection conflicts through traffic control and operational improvements,” prove effective while involving low to moderate cost and a short to medium time-frame of implementation using traditional signal timing optimization tools.

Traditional signal timing optimization tools are referred to as ‘off-line’ optimization. These tools, considered the lifeblood of the traffic engineering profession, have been used to coordinate signals to reduce stops and delays to travelers. However, to develop optimum off-line timing plans requires an on-going commitment of resources, including significant data collection every few years to keep pace with changing traffic demands. Often, agencies do not have the resources or budgets to make this commitment on a consistent basis. This lack of commitment was recently noted by the letter grade of "F" for Traffic Monitoring and Data Collection in the U.S., as judged by the National Transportation Operations Coalition (NTOC) (11). Traditionally, when transportation professionals speak of improvements from signal timing optimization, they tend to focus on 'operational' benefits (such as reduced stops, delay and travel times) with little quantification of safety benefits.

Off-line signal timing optimization tools are helpful, but there is a profound difference between what is commonly optimized versus what should be optimized. The topic was previously discussed in an ITE Journal article on the sensibility of split optimization (12). In brief, the Highway Capacity Manual (HCM) procedures have been the adopted analytical standard for performing traffic operational analyses in the U.S. since 1950 (13). The profession debated, made a conscious decision and agreed that delay of individual movements is to be used as the primary measure of effectiveness. Other than HCM2010 (previously known as SIGNAL2000) developed by Strong Concepts, the more popularly applied signal timing optimization tools optimize timings based on volume to capacity (v/c), or derivatives thereof, instead of optimizing based upon the agreed HCM delay of individual movements. Likely, most professionals are unaware of this issue. The combination of this lack of awareness, high cost of proper signal timing and ever-shrinking public resources causes the sub-optimal state of signal timing in the U.S., as recently indicated by the letter grade of "C" for Signal Timing Practices and Traffic Signal Operations for the U.S., as judged by the NTOC (14).

Adaptive traffic control is 'real-time' or continuous optimization where timings adapt to changing traffic demands. Some adaptive systems adjust each second while others adapt only as frequently as every ten minutes; some systems adjust splits and cycle lengths while others use more dynamic functionality. With longer than second-by-second adaptation, sudden surges in demand will likely be problematic – the demand is underserved when it happens and traffic may be over-served if conditions are closer to normal when the timing adjustment is made. And there is a critical aspect of adaptive control that is grossly misunderstood: the notion that a fixed cycle length is involved. Cycle length restricts a system's ability to think truly adaptively; it is a carryover constraint associated with off-line optimization.

Adaptive control functionality is quite different from off-line optimization methods. For instance, the InSync adaptive traffic control system constantly gathers traffic condition data then analyzes, optimizes and adapts the signal timings in real-time, every second, to serve changing traffic demands. This method contrasts with traditional, off-line optimization techniques in which data collection and signal re-timings are performed, ideally, every few years. Traditional optimization techniques develop predetermined system timing plans that are stored and downloaded based upon time of day or responsive control thresholds. Unless there is a stored plan that matches actual traffic conditions, they do not precisely accommodate variable or unpredictable traffic demand. InSync is an innovative ATCS that continuously optimizes traffic flow using artificial intelligence. InSync combines its local optimization algorithm with a global coordination plan to efficiently serve traffic demand on signalized roadways. InSync's global functions synchronize coordinated movements, creating varying green tunnels that move platoons of traffic through a designated route with minimal delay. The system's local optimization algorithm is based upon the agreed HCM primary measure of effectiveness – delay of individual movements – and serves all movements in relation to the green tunnel movements.

TRAFFIC SAFETY

Rear-end collisions and crashes involving left-hand turns are the most prominent traffic accidents occurring at intersections nationwide, with right angle collisions being the foremost cause of fatal injury (15). While sudden stops are likely to result in rear-end crashes, red-light running increases the likelihood of right-angle collisions. In their study of several corridors in Indiana, Wei and Tarko found red-light running to be the most frequent scenario for right-angle crashes: “Traffic violations by arterial vehicles lead to about 70% of all right-angle crashes” (16). Furthermore, red-light running is the most common type of crash to occur in urban areas (17). Upwards of 700 people are killed in red-light running collisions and an estimated 165,000 are injured annually (18).

ATCSs produce safety benefits by reducing the conditions that lead to crashes. Adaptive systems minimize the opportunities for conflicts by decreasing the number of stops, queues and delay through optimizing service at individual intersections and creating progression where possible and desired. According to the National Cooperative Highway Research Program (NCHRP), adaptive traffic control solutions reduce the likelihood of collisions at intersections “through reductions of some efficiency-related performance measures, which highly correlate with some safety metrics (e.g., a reduction in the number of stops reduces the chance of rear-end collisions)” (19). Often, ATCSs also seek to coordinate signals at least theoretically better than traditional off-line solutions by adapting in real-time to changing traffic demands. The FHWA recognizes the proven reduction of traffic collisions associated with reducing stops not only eliminates opportunities to run red lights, but also lessens the desire to “squeeze the lemon” or “beat” a red light (20).

To the extent adaptive traffic systems can accomplish reductions in stops, delay and queues through optimizing local signal operation and signal coordination, they should also improve safety, assuming all other factors remain consistent. Likewise, the greater degree of reduction of stops, delay and queues creates greater safety improvements.

Independent studies show InSync’s effectiveness at reducing stops, delay, queues and travel time in deployments nationwide. InSync is proven in multiple independent studies to reduce stops by up to 60-90%, delay by up to 50% and travel time by up to 50% (as well as fuel consumption and emissions by up to 30%) during peak periods on corridors previously operating coordinated timing plans (21). In part due to this substantial reduction in stops and improvement in traffic flow optimization, intersections operating with InSync show up to a 30% reduction in traffic collisions over previously off-line optimized timing plans. This performance is reflected in the recent recognition of an InSync deployment with Pennsylvania’s 2012 Road and Bridge Safety Improvement Award.

Evaluations in microsimulation offer further insight into the safety performance of traffic signal timing systems. Simulation studies provide the benefit of tightly controlled variables to test for factors otherwise difficult to measure in the field. In a recently completed third-party study, Dr. Aleksandar Stevanovic, P.E., one of the foremost traffic engineering researchers in the world, evaluated InSync in comparison with optimized time of day timing plans during peak periods through VISSIM modeling. The study reviewed safety performance using Surrogate Safety Assessment Model (SSAM) criteria, which determine the frequency, severity and type of potential roadway conflicts. The results show “[u]nder the existing conditions, InSync outperformed TOD signal timings in terms of total number of vehicular conflicts…rear-end and lane-changing conflicts” (22).

InSync's control change is in line with the strategies proposed by AASHTO in the SHSP and is proving to improve safety at roadway intersections. The unique characteristics of InSync correlating with its ability to significantly decrease stops, queues and delay as well as crashes include the following:

1. InSync optimizes traffic control based upon delay of individual movements as prescribed in the HCM.
2. InSync does not use a traditional cycle, thereby giving it greater flexibility to accommodate fluctuations in demand and better coordinate signals to create progression in both directions.
3. InSync not only gathers data in real-time but also optimizes in real-time, making adjustments to green time, phasing and sequencing as often as each second (23).

Because these characteristics are highly effective at reducing stops, queues and delay, and research indicates those are critical factors leading to crashes, it follows that their reduction is the reason InSync reduces crashes. The case studies in this paper show field results from four separate deployments of InSync validating its ability to decrease the frequency of crashes.

Furthermore, this level and type of dynamic signal control will be necessary to achieve full benefits from the emerging technologies of vehicle-to-vehicle and vehicle-to-infrastructure communications. Knowledge of vehicles' locations, speed, originations and destinations is only as valuable as the traffic network's ability to adapt to demand in real-time. Leveraging these advanced and proper methods of signalization can best accommodate and serve the demand once it is known.

CASE STUDIES – INITIAL SAFETY BENEFITS

Evidence from the following four before-and-after studies provides early feedback on the safety benefits of InSync adaptive traffic control deployments in Columbia County, Georgia; Topeka, Kansas; Lee's Summit, Missouri; and Springdale, Arkansas. Initial data on InSync deployments at these four sites reflect the key benefit of confirmed stop frequency, delay and travel time reductions: a subsequent decline in intersection-related crashes.

Columbia County, Georgia

Coordinating and optimizing signal performance on high-volume, intersecting arterials is one of the more challenging tasks for a traffic engineer. In 2009, Columbia County, Georgia, selected adaptive traffic control to solve this challenge on its Washington Road and North Belair Road intersecting corridors. The County deployed InSync at five intersections along one mile of Washington Road as well as five signals on Belair Road at and surrounding the intersection of these two corridors (see Figure 1).

Figure 1: Washington Road—Evans, Georgia

A before-and-after study revealed significant reductions in stops, travel time and delay on Washington Road, a corridor with an average daily traffic (ADT) of 40,000. The County's traffic engineer, Glen Bollinger, provided the crash data for the year before and after deployment of adaptive traffic technology. In 2009, before deployment, the Washington Road study corridor experienced 162 total crashes with 114 of those occurring at intersections (as opposed to mid-block). In 2010, after deployment of InSync, the study corridor experienced 120 crashes of which 79 occurred at intersections. These figures represent a 26% reduction in total crashes and a 31% reduction in crashes at intersections.


WASHINGTON ROAD IN COLUMBIA COUNTY, GEORGIA

			CHANGE	
COLLISION LOCATION	2009	2010	QUANTITY	PERCENTAGE
Mid Block / Driveway Collisions	48	41	-7	-14.6%
Intersection Collisions	114	79	-35	-30.7%
Total	162	120	-42	-25.9%

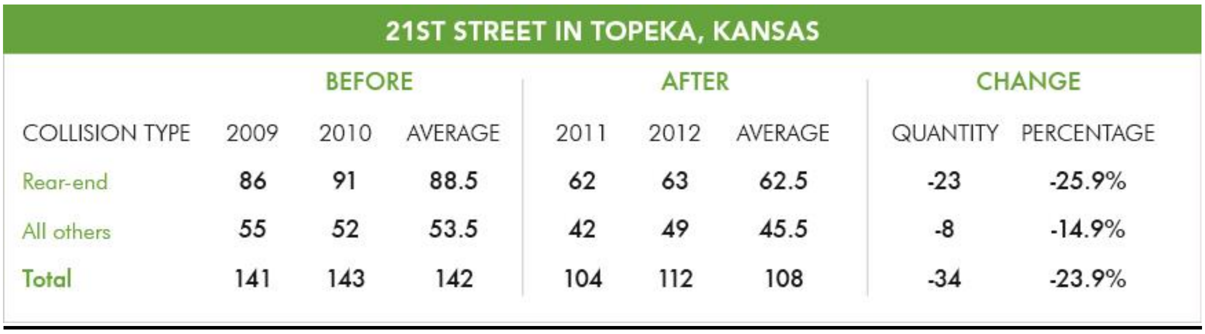
Table 1: Washington Road in Columbia County, Georgia

Topeka, Kansas

In January 2011, the City of Topeka, Kansas installed InSync at seven intersections along 21st Street, a corridor with an ADT of 25,311, replacing its previous coordinated fixed-timing plan to improve signal operations and conserve energy (see Figure 2). This deployment was a portion of a 22-intersection project funded by a U.S. Department of Energy grant; however, the benefits reach beyond the scope of fuel conservation alone. The optimizations of traffic flow that lowered emissions in Topeka also reduced the total number of crashes and especially reduced rear-end collisions as compared to the previously operating coordinated timing plans.

Figure 2: 21st Street—Topeka, Kansas

According to Linda Voss, City Engineer for Topeka, in the two years prior to installation of InSync, the 21st Street corridor experienced a total of 141 and 143 crashes. In the two years after InSync deployment, the corridor experienced an average of 108 collisions. The addition of InSync to the seven signals for which this crash data was gathered reveals a reduction of over 30 collisions per year, or 24% fewer crashes.



21ST STREET IN TOPEKA, KANSAS

	BEFORE			AFTER			CHANGE	
COLLISION TYPE	2009	2010	AVERAGE	2011	2012	AVERAGE	QUANTITY	PERCENTAGE
Rear-end	86	91	88.5	62	63	62.5	-23	-25.9%
All others	55	52	53.5	42	49	45.5	-8	-14.9%
Total	141	143	142	104	112	108	-34	-23.9%

Table 2: 21st Street in Topeka, Kansas

Lee’s Summit, Missouri

In 2009, the Missouri DOT (MoDOT) installed InSync at 12 signals along 2.5 miles of Highway 291, a corridor with an ADT of 25,779, in Lee’s Summit (Kansas City area) as part of Operation Safe Highway 2009 (see Figure 3). Before InSync, the corridor operated with coordinated timing plans, and, due to the frequency of red-light running, warranted extra enforcement measures, including the use of “tattle-tale” lights and the assignment of specifically tasked police patrols (24).

Figure 3: Highway 291—Lee’s Summit, Missouri

The installation of InSync resulted in up to a 95% reduction in stops and an 87% reduction in delay during peak periods, according to independent research by MRIGlobal (25). By substantially reducing these factors, InSync reduced crashes on the corridor by 17% over the previous coordinated timing plan, according to the report issued by the Lee’s Summit Police Department. The red-light running enforcement measures ceased soon after implementation of InSync as they were deemed no longer necessary (26). Instead, MoDOT and the Lee’s Summit Police Department allowed InSync to manage traffic in the corridor such that red-light running was no longer an issue requiring additional enforcement.

During a press conference following the deployment, Tom Evans, P.E., the MoDOT traffic engineer who directly oversaw the implementation of InSync on the Highway 291 corridor, said “we were doing red light enforcement…when we stuck the system in.” According to Evans, the Lee’s Summit police captain “said he was suspending his red-light running enforcement because there were just no cars there to run the red light when it goes red” (27).

Two miles west of Highway 291, the Chipman Road portion of InSync’s Lee’s Summit deployment, which won the Kansas City Chapter of ITE’s 2011 Excellence in Transportation Award, reflects similar safety results. According to City Traffic Engineer Michael Park, from January 2009 to January 2011, when the corridor was operating a coordinated timing plan, the Chipman Road corridor, from Pryor Road to Ward Road (approximately one mile with 8 signals contained within a sub-network signal system and an ADT of 27,000), averaged 44.5 crashes every 6 months. During the 6 month period from January 2011 to July 2011, after installation of InSync, the same corridor experienced 38 crashes. Comparison of these numbers indicates a 15% crash reduction over the previous coordinated timing plan.

CHIPMAN ROAD IN LEE'S SUMMIT, MISSOURI

	BEFORE			AFTER	CHANGE	
COLLISION TYPE	2009	2010	AVERAGE	2011*	QUANTITY	PERCENTAGE
Rear-end	52	46	49	44	-5	-10.2%
Left-turn	13	10	11.5	6	-5.5	-47.8%
All others	22	35	28.5	26	-2.5	-8.8%
Total	87	91	89	76	-13	-14.6%

*Data was supplied for the first six months of 2011. Data was doubled to estimate an annual quantity.

Table 3: Chipman Road in Lee's Summit, Missouri

Springdale Arkansas

In April 2010, the City of Springdale, Arkansas installed InSync at eight intersections along Thompson/Highway 71B, a three mile corridor with an ADT of 32,987 (see Figure 4). The Springdale Police Department reported InSync reduced crashes on the corridor by 30% based on crash data for the 12 months before and 12 months after the InSync installation. The police department data indicate there were 61 accidents in the 12 months prior to the installation date and 44 accidents during the 12 months afterward.

Figure 4: Thompson/Highway 71B—Springdale, Arkansas

HIGHWAY 71 IN SPRINGDALE, ARKANSAS

	BEFORE	AFTER	CHANGE	
	MAY 2009 – APRIL 2010	MAY 2010 – APRIL 2011	QUANTITY	PERCENTAGE
Total	63	44	-19	-30.2%

Table 4: Highway 71B in Springdale, Arkansas

SUMMARY OF CASE STUDIES INCLUDING FINANCIAL COST SAVINGS

DEPLOYMENT		BEFORE	AFTER	CHANGE		
CORRIDOR AND AGENCY	SCOPE	AVERAGE ANNUAL CRASHES		QUANTITY	PERCENTAGE	ANNUAL CRASH-RELATED COST SAVINGS**
Columbia County, GA Washington Road	5 Intersections 1 Mile	162 Period: 2009	120 Period: 2010	-42	-26%	$1,164,702
City of Topeka, KS 21st Street	7 Intersections 1 Mile	142 Period: 2009-2010	108 Period: 2011-2012	-34	-24%	$942,854
Missouri DOT Missouri Highway 291	12 Intersections 2.5 miles	262 Period: 2006 - 2008	217 Period: 2009	-45	-17%	$1,247,895
City of Lee's Summit, MO Chipman Road	8 Intersections 1 Mile	89 Period: 2009 - 2010	79* Period: Jan 2011 - July 2011	-13	-15%	$360,503
City of Springdale, AR Thompson Road / Hwy 71	8 Intersections 3 Miles	63 Period: May 2009 - Apr 2010	44 Period: May 2010 - April 2011	-19	-30%	$526,889

* The six months of data was doubled to estimate an annual number of crashes.

** (Annual reduced accidents) x ($27,731 average cost per accident based on U.S. Census Bureau and AAA data for 2009). Does not include financial savings from other benefits such as saved time and fuel.

CONCLUSIONS AND RECOMMENDATIONS

The above qualitative and preliminary data support the effectiveness of adaptive traffic control, and InSync in particular, in improving road safety. The NCHRP, FHWA and other highway safety agencies recommend adaptive traffic control and signal coordination as proven, cost-effective methods of reducing vehicular collisions at or near intersections. InSync confirms with initial results that intersection safety is greatly improved. These preliminary findings reveal InSync’s real-time signal coordination and dynamic signal optimization based upon delay of individual movements provide significant improvement even on arterials previously operating coordinated timing plans. While these initial findings demonstrate InSync’s adaptive traffic control significantly reduces crashes and improves safety, a more thorough, quantitative analysis including multiple years of both before and after data is recommended once the system has been in place long enough to collect more thorough data. The quantified impact of InSync on accident reduction and improved safety may be shown to increase given a longer study period as roadway users become increasingly familiar with the system’s operation and more data from these and other locations accumulates.

The USDOT initiative emphasizing vehicle-to-vehicle and vehicle-to-roadside device communications is an exciting technological approach and should go a long way in improving roadway safety. Unfortunately, it will take many years before the necessary roadway and vehicle fleet infrastructure are in place to realize the full safety benefits envisioned. However, the deployment of adaptive traffic control systems such as InSync is an immediately available solution that helps address the safety problem presented at the beginning of this article. Finally, it is important to note that the hardware and software intelligence infrastructure offered by ATCSs fully embraces the USDOT initiative to develop vehicle-to-vehicle and vehicle-to-roadside device communication systems. This infrastructure is required to support Signal, Phase and Timing data, often referred to as SPaT, which is an integral component of the future vehicle-to-vehicle and vehicle-to-roadside device communications development. Thus, the deployment of adaptive control systems will help to achieve the USDOT initiative to improve roadway safety sooner.

ACKNOWLEDGEMENTS

A special thanks to Mr. Douglas E. Noble, P.E., P.T.O.E., ITE Senior Director of Management and Operations who provided excellent technical comments and suggestions regarding the development of the paper.

REFERENCES

(1) World Health Organization. “The State of Road Safety around the World.” Global Status Report on Road Safety. 2009.

(2) World Health Organization. “Country Profiles: United States of America.” Global Status Report on Road Safety. 2009.

(3) Larry Copeland, “AAA: Fatal Motor Vehicle Crash Costs $6 Million.” USA Today, November 3, 2011. http://www.usatoday.com/news/nation/story/2011-11-02/fatal-vehicle-crashes-cost-millions/51051030/1.Accessed: March 2012.

(4) United States Census Bureau, 2009. http://www.census.gov/compendia/statab/2012/tables/12s1103.pdf. Accessed: July 2012.
(5) Cambridge Systematics. “Crashes vs. Congestion – What’s the Cost to Society.” November 2011. http://newsroom.aaa.com/wp-content/uploads/2011/11/2011_AAA_CrashvCongUpd.pdf Accessed: July 2012.
(6) American Association of State Highway and Transportation Officials (AASHTO). AASHTO Strategic Highway Safety Plan. Washington, DC, USA: AASHTO, 2005. http://safety.transportation.org/doc/safety-strategichighwaysafetyplan.pdf.
(7) Federal Highway Administration (FHWA). Intersection Safety. http://safety.fhwa.dot.gov/intersection/. Accessed: March 2012.
(8) AASHTO, 2005.
(9) Federal Highway Administration. Proven Safety Countermeasures. http://safety.fhwa.dot.gov/provencountermeasures/. Accessed: March 2012.
(10) Transportation Research Board. Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 12: A Guide for Reducing Collisions at Signalized Intersections. NCHRP Report 500. Washington, DC, USA:
Transportation Research Board, 2004.
(11) 2012 National Traffic Signal Report Card, Technical Report, National Transportation Operations Coalition (NTOC) http://www.ite.org/reportcard/. Accessed: July 2012.
(12) James E. Clark, “Assessing the Sensibility of Signal Timing Split Optimization in Addressing Congestion,” ITE Journal, August 2008.
(13) Highway Capacity Manual. Washington, DC; Transportation Research Board, 2010.
(14) NTOC, 2012.
(15) AASHTO, 2005.
(16) Wei Li and Andrew P. Tarko, “Safety Consideration in Signal Coordination and Road Design on Urban Streets.” Presentation at the 4th International Symposium on Highway Geometric Design, Valencia, Spain, June 5-9, 2010.
(17) Federal Highway Administration (FHWA). Red Light. http://safety.fhwa.dot.gov/intersection/redlight/brochure/. Accessed: March 2012.
(18) Federal Highway Administration (FHWA). Red-Light Running. http://safety.fhwa.dot.gov/intersection/redlight/. Accessed: March 2012.
(19) NCHRP Synthesis 403, Adaptive Traffic Control Systems: Domestic and Foreign State of Practice, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, USA, 2010.
(20) Federal Highway Administration (FHWA). “Engineering Countermeasures to Reduce Red-Light Running.” Intersection Safety Issue Briefs, Third Edition. Washington, DC, USA: Federal Highway Administration, 2009.
(21) Rhythm Engineering. Self-Optimizing Traffic Signals. http://rhythmtraffic.com/how-insync-works/. Accessed: March 2012.
(22), Aleksandar Stevanovic and Milan Zlatkovik, “Comparative Evaluation of InSync and Time-of-Day Signal Timing Plans under Normal and Varied Traffic Conditions.” Feb 2013.
(23) Reggie Chandra and Chris Gregory, “InSync Adaptive Traffic Signal Technology: Real-Time Artificial Intelligence Delivering Real-Work Results.” March 2012.
(24) M. Jessica Hutton, Courtney D. Bokenkroger, and Melanie M. Meyer, “Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee’s Summit, Missouri.” Kansas City, Missouri: Missouri Department of Transportation (MoDOT), 2010.
(25) Hutton et al., 2010.
(26) Ibid.
(27) Rhiannon Ally, “InSync Traffic System.” NBC Action News. Kansas City, Missouri. March 2010. http://www.youtube.com/watch?v=beLUgWeugNU Accessed: April 2012.

Authors information:

Jim Clark, P.E.
Southeast Territory Engineering Manager
Rhythm Engineering
12351 W. 96th Terrace, Suite 107
Lenexa, KS 66215
Phone +1-913-227-0603
Mobile +1-703-300-4147
Fax +1-913-227-0674
Email: Jim.Clark@rhythmtraffic.com

Jim Clark, PE is a Senior Project Manager for HNTB Corporation and President of the Central Florida Chapter of ITE. Jim has over 34 years of experience in both the public and private sector of traffic engineering after earning has degree of Master of Science in Civil Engineering. His career and research pursuits concentrate on intelligent transportation systems including advanced traffic simulation and optimization methods, transportation management systems, standards development, systems integration and the research, development, implementation and evaluation of traffic adaptive traffic control systems. Jim's work consists of direct or supporting engagements with the Federal Highway Administration, US Department of Transportation, state and local governments including Florida and Virginia DOTs, Institute of Transportation Engineers, American Society of Civil Engineers, Intelligent Transportation Society of America and the Transportation Research Board/National Cooperative Highway Research Program.