FINAL
CONTRACT REPORT
VTRC 11-CR2

QUANTIFYING THE BENEFITS OF COORDINATED ACTUATED TRAFFIC SIGNAL SYSTEMS: A CASE STUDY

BYUNGKYU (BRIAN) PARK, Ph.D.
Associate Professor

YIN CHEN
Graduate Research Assistant

Department of Civil & Environmental Engineering
University of Virginia

VTRC
Virginia Transportation
Research Council

http://www.virginiadot.org/vtrc/main/online_reports/pdf/11-cr2.pdf

Standard Title Page—Report on State Project

Report No.: VTRC 11-CR2	Report Date: September 2010	No. Pages: 30	Type Report: Final Contract	Project No.: 92459
			Period Covered: Jan. 2009 – July 2010	Contract No.:

Title:
Quantifying the Benefits of Coordinated Actuated Traffic Signal Systems: A Case Study

Key Words:
Coordinated Actuated Traffic Signal System, Adaptive Split, Synchro, Traffic Signal Timing, Before-and-After Study

Author(s):
Byungkyu (Brian) Park and Yin Chen

Performing Organization Name and Address:
Virginia Transportation Research Council
530 Edgemont Road
Charlottesville, VA 22903

Sponsoring Agencies' Name and Address:
Virginia Department of Transportation
1401 E. Broad Street
Richmond, VA 23219

Supplementary Notes:

Abstract:

Coordinated actuated traffic signal systems have been widely implemented for the past few decades because they provide better progression along the major corridors through proper coordination. However, little has been done to quantify the benefits that can be obtained from coordinated traffic signal systems. Most efforts reported in the literature focused on system performance estimated from simulation software as opposed to field studies.

The purpose of this study was to quantify the benefits of coordinated actuated traffic signal systems by conducting an analysis of before-and-after data. The travel time on the coordinated arterials and the stopped delay on a few key approaches were selected as measures of effectiveness. Synchro, a macroscopic traffic signal timing evaluation and optimization software, was used to generate the coordinated actuated traffic signal timing plans for comparison purposes. In addition, the performance of an adaptive split feature, implemented within the coordinated actuated traffic signal system, was evaluated through a before-and-after study.

The data showed an improvement in performance of the coordinated actuated system over the actuated isolated system (the before condition), including a 30 percent reduction in travel times on the coordinated corridor. There was a corresponding increase in stopped delay on non-coordinated approaches, but the addition of the adaptive split feature was able to reduce this delay by 40 percent at one site without impacting progression on the coordinated approaches.

The study recommends that the Virginia Department of Transportation regional traffic engineers implement the coordinated actuated traffic signal system over the non-coordinated system and the adaptive split feature with the coordination to reduce delays on side street approaches. Further, a cost/benefit analysis indicated that the coordinated actuated traffic signal system has a benefit/cost ratio of 461.3 when compared to the non-coordinated actuated traffic signal system.

FINAL CONTRACT REPORT

QUANTIFYING THE BENEFITS OF COORDINATED ACTUATED TRAFFIC SIGNAL SYSTEMS: A CASE STUDY

Byungkyu (Brian) Park, Ph.D.
Associate Professor

Yin Chen
Graduate Research Assistant

Department of Civil & Environmental Engineering
University of Virginia

Project Manager
Catherine C. McGhee, P.E., Virginia Transportation Research Council

Contract Research Sponsored by
the Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

September 2010
VTRC 11-CR2

DISCLAIMER

The project that was the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks was for identification purposes only and was not to be considered an endorsement.

Each contract report was peer reviewed and accepted for publication by Research Council staff with expertise in related technical area. Final editing and proofreading of the report were performed by the contractor.

ABSTRACT

Coordinated actuated traffic signal systems have been widely implemented for the past few decades because they provide better progression along the major corridors through proper coordination. However, little has been done to quantify the benefits that can be obtained from coordinated traffic signal systems. Most efforts reported in the literature focused on system performance estimated from simulation software as opposed to field studies.

The purpose of this study was to quantify the benefits of coordinated actuated traffic signal systems by conducting an analysis of before-and-after data. The travel time on the coordinated arterials and the stopped delay on a few key approaches were selected as measures of effectiveness. Synchro, a macroscopic traffic signal timing evaluation and optimization software, was used to generate the coordinated actuated traffic signal timing plans for comparison purposes. In addition, the performance of an adaptive split feature, implemented within the coordinated actuated traffic signal system, was evaluated through a before-and-after study.

The data showed an improvement in performance of the coordinated actuated system over the actuated isolated system (the before condition), including a 30 percent reduction in travel times on the coordinated corridor. There was a corresponding increase in stopped delay on non-coordinated approaches, but the addition of the adaptive split feature was able to reduce this delay by 40 percent at one site without impacting progression on the coordinated approaches.

The study recommends that the Virginia Department of Transportation regional traffic engineers implement the coordinated actuated traffic signal system over the non-coordinated system and the adaptive split feature with the coordination to reduce delays on side street approaches. Further, a cost/benefit analysis indicated that the coordinated actuated traffic signal system has a benefit/cost ratio of 461.3 when compared to the non-coordinated actuated traffic signal system.

FINAL CONTRACT REPORT

QUANTIFYING THE BENEFITS OF COORDINATED ACTUATED TRAFFIC SIGNAL SYSTEMS: A CASE STUDY

Byungkyu (Brian) Park, Ph.D.
Associate Professor

Yin Chen
Graduate Research Assistant

Department of Civil & Environmental Engineering
University of Virginia

INTRODUCTION

Traffic engineers generally assume that coordinated actuated signal systems perform better than isolated traffic signal systems. This is due primarily to the belief that the performance of the signal system can be improved by providing better progression along the major corridor. However, little is known regarding the benefits that can be achieved from coordinated systems over isolated (or non-coordinated) systems. In addition, Buckholz (1993) indicated that coordinated signal systems do not perform very well in certain conditions, including skipped phases that cause early return to green on the coordinated phases resulting in a disruption on the arterial progression. There are many factors affecting the performance of the coordinated traffic signal system including traffic pattern changes (e.g., increased traffic demand or turning movement changes) and traffic signal controller settings (e.g., force off mode, transition mode, and pre-timed or actuated). Traffic engineers have suggested that an adaptive split feature, which allows the signal controller to dynamically adjust split times of non-coordinated phases in response to traffic volume variations, improves the performance of coordinated actuated signal systems. This project intended to investigate how much improvement can be achieved within the coordinated actuated traffic signal system and whether the adaptive split feature can bring additional benefits.

Since the first traffic signal system in the United States was implemented in 1912 to prevent traffic crashes by assigning rights of way, the functions of these systems have greatly changed (Federal Highway Administration [FHWA], 2008). There are more than 272,000 traffic signal systems in the United States (NTOC, 2007). They play an important role in the performance of the transportation system. According to the nationwide personal transportation survey, an individual generally drives 40 miles per day and wastes about 36.1 hours due to traffic delay annually (Texas Transportation Institute, 2009). Obviously the performance of the transportation system has great impact on the quality of life for users of that system. It is estimated that more than a half of the traffic signals in North America are in need of repair, replacement or updating of the timing plan (FHWA, 2008). Outdated and inadequate traffic signal timing accounts for a significant portion of traffic delay on urban arterials. It is noted that the traffic signal system operations are one of the easier ways to improve transportation system performance when compared to adding additional lanes or new routes. For example, the Denver region traffic signal system improvement program resulted in total delay reduction of nearly 36,000 vehicle hours per day and reduction in fuel consumption of 15,000 gallons per day between 2003 and 2008 (FHWA, 2009).

Among traffic signal control systems, the coordinated system is the most widely applied by traffic engineers. It provides continuous progression along an arterial with minimum stops, resulting in reduced travel delay on arterial streets. When intersections are closely spaced and volume on the coordinated arterials is large, the coordinated signal system is preferred to the isolated signal system. The *Manual on Uniform Traffic Control Devices* (MUTCD) recommends that traffic signals within 800 m (i.e., 0.5 mile) be coordinated under a common cycle length (FHWA, 2009). Ideally, the traffic signal at an intersection should turn to green as soon as upstream traffic arrives. However, in practice, this is not always the case. There exist many factors that could cause improper vehicle progression on the corridors, including outdated offsets or short-term variations in traffic volume. Under congested conditions, large queues disrupt progression. Under uncongested conditions, a phase skip or a gap-out on non-coordinated phases triggers an earlier return to green on the coordinated phases which can result in a disruption of progression.

PURPOSE AND SCOPE

The purpose of this study was to quantify the benefits of coordinated actuated traffic signal systems by conducting a before-and-after study. The scope of this project involved two sites in Virginia.

METHODS

To accomplish the purpose of this project, the following tasks were undertaken:

1. Examine the previous literature on coordinated actuated traffic signal systems.

2. Develop the coordinated actuated traffic signal timing plan using traffic volume data collected from the field, and evaluate its performance via before-and-after studies.

3. Compare Synchro’s results with field measurements to determine the accuracy of the model results.

4. Evaluate the performance of an adaptive split feature within a coordinated actuated traffic signal system via a before-and-after study.

Literature Review

Literature was reviewed on current and previous research related to the impacts of a coordinated actuated traffic signal system in terms of improved travel time, reduced stopped delay, and impacts of early return to green. The Virginia Transportation Research Council (VTRC) and the University of Virginia libraries were used for this purpose. Some research reports released online were also reviewed.

Site Selection

With the help of traffic engineers in VDOT's Central Operations Region, two study sites were selected for the before and after data collection. One, located in Gloucester County on Route 17, was used for assessing benefits of a coordinated actuated traffic signal system while the other, located in Chesterfield County, was used to investigate benefits of an adaptive split feature within the coordination actuated signal system.

Data Collection and Reduction

A detailed data collection and reduction plan was developed. To develop the optimal non-coordinated actuated traffic signal timing plan and coordinated actuated traffic signal timing plan, network and traffic data were collected. To conduct a before-and-after study, several measures of effectiveness (MOEs) were selected and collected. These included corridor travel time and stopped delay at a few selected key approaches. Manual traffic counters and Sony video cameras were used to collect traffic volume counts at intersections and the stopped delay for selected approaches. Two vehicles equipped with GPS devices were used to collect corridor travel times.

Synchro Model Development

Synchro is a software package that evaluates and optimizes traffic signal timing plans based on traffic volume and geometric conditions. It can optimize isolated and coordinated traffic signal systems. Synchro is one of the most widely used tools in the United States. It includes a user friendly graphical interface and various MOEs. The Synchro model was developed by coding network geometry such as number of lanes, turn bay or link length, lane configuration, and traffic volume data obtained during the data collection. Existing traffic signal timing plans were provided by VDOT. The Synchro model was used to evaluate its traffic signal system performance predictions.

Measures of Effectiveness Comparisons

To quantify the benefits of coordinated actuated traffic signal systems, field measured corridor travel times and stopped delays from key approaches collected before (i.e., non-coordinated) and after (i.e., coordinated) were compared. To assess the reliability of Synchro, the changes in MOEs measured in the field and reported by Synchro for the before-and-after conditions were compared. Finally, to examine benefits of an adaptive split feature, field measured stopped delays were compared before-and-after the adaptive split features were implemented.

RESULTS

Literature Review

In the literature, methods to demonstrate impacts of the coordinated actuated traffic signal systems fall into three categories: simulation, which estimates the benefits through a calibrated simulation model; field study, where benefits are measured directly through a before-and-after study; and theory, which focuses on the principle of the coordinated actuated traffic signal systems.

Benefits Estimated from Simulation Studies

The City of Syracuse implemented a traffic signal interconnect design project in 1993 to improve air quality. In their project, Synchro was used to assess the performance of the coordinated actuated traffic signal timing plans. The results showed that vehicle delay was reduced by 14 to 19 percent and total stops were reduced by 11 to 16 percent (DMJM Harris, 2003).

Skabardonis (2001) summarized the benefits of optimizing traffic signal timing plans for coordinated signal control and implementing adaptive signal control. TRANSYT-7F was used in the evaluation. TRANSYT-7F results showed a 7.7 percent reduction in travel time, a 13.8 percent reduction in delays, and a 12.5 percent reduction in stops.

Four consecutive intersections about 0.5 mile apart were coordinated to quantify benefits of a coordinated actuated traffic signal system. TRANSYT-7F results showed that the average delay decreased from 68.3 sec/veh to 37.2 sec/veh for morning peak hour and from 65.1 sec/veh to 35.6 sec/veh during evening peak hour (Nesheli et al., 2009).

The Denver region traffic signal system improvement program, which included 19 traffic timing and coordination projects between 2003 and 2008, improved more than 1,100 traffic signals and reduced delay by 36,000 vehicle hours per day and saved 15,000 gallons (FHWA, 2009).

A traffic signal coordination study conducted by the Traffic Engineering Division of Colorado Springs, Colorado (2005), reported 10 to 30 percent improvement in travel time and potential benefits such as improved mobility, reduced vehicular crashes, reduced fuel consumption, and increased travel speed.

The adaptive split feature (or adaptive maximum feature) in an actuated traffic signal operation was evaluated via microscopic simulation. Yun et al. (2007) evaluated an actuated traffic signal system with the adaptive maximum feature via hardware-in-the-loop simulation (HILS). VISSIM was used as the simulation model, and an EPAC300 traffic controller was used to implement the adaptive split feature. The results showed that the adaptive maximum feature outperformed the normal maximum green intervals. The average delay was reduced from 31.30 sec/veh to 28.07 sec/veh.

Zimmerman (2000) indicated that traffic signal coordination across two jurisdictions in Arizona resulted in a 21 percent delay reduction using the INTEGRATION simulation program (Zimmerman, 2000).

Benefits Measured from Field Studies

A field study on the coordinated traffic signal timings across two jurisdictions in Arizona resulted in a 6.2 percent increase in vehicle speeds and 1.6 percent reduction in fuel consumption (Zimmerman, 2000).

Skabardonis (2001) conducted a field floating car study to assess the benefits of optimizing a traffic signal timing plan for coordinated traffic signal control and implementing adaptive traffic signal control. The field study results showed a 11.4 percent travel time reduction, a 24.9 percent delay reduction, and a 27 percent reduction in stops.

The City of Richmond, Virginia, installed an advanced signal system at 262 signalized intersections in the central business district area. The system coordinated four routes of isolated intersections. A test vehicle equipped with an automatic data collection system was used to collect field travel time data. The results showed that travel time decreased by 9 to 14 percent, total delay decreased by 14 to 30 percent, and stops decreased by 28 to 39 percent (Hetrick et al.., 1996).

Basic Principles of Coordinated Actuated Traffic Signal Systems

Buckholz (1993) discussed a few potential pitfalls of coordinated traffic signal systems.

- *The failure to consider "anchor points" early on in the analysis process.* In some cases, the special characteristics of certain intersections may restrict the size of the cycle length that can be used for providing better progression or may require special timing phases. The common characteristics are close spaced intersection and over-capacity intersection.

- *Selection of the wrong cycle length.* The natural cycle length for each intersection within the proposed corridor may vary greatly, so choosing a proper cycle length may have great impact on the performance of the coordinated signal system. A shorter cycle length may result in poor progression while a longer cycle length may result in queue blockage problems.

The traffic signal timing manual published by FHWA provides the basic theory behind coordinated actuated signal systems. The manual identified several components which must be considered to achieve an acceptable coordination plan. These include hardware limitations, pedestrians, phase sequences, an early return to green, heavy side street volumes, turn bay intersections, and oversaturated conditions (Koonce et al., 2008).

Site Selection

Two study sites were selected. Site 1 contained 5 actuated isolated signalized intersections in Gloucester County on Route 17 and Site 2 contained 6 coordinated actuated signalized intersections in Chesterfield County on US 60. Site 1 was used to quantify the benefits of coordination by comparing corridor travel times and approach delays with and without coordination. Site 2 assessed impacts of an adaptive split feature within the coordinated actuated signal system.

Site 1 - Gloucester County, Virginia

Site 1 (Figure 1) has five non-coordinated actuated signalized intersections:

1. Route 17 & Hospital Drive
2. Route 17 & Route 619 (Main Street)
3. Route 17 & Route 616 (Belroi Rd.)
4. Route 17 & Routes 3 & 14 (Main Street)
5. Route 17 & Beehive Drive (1024 Zooms).

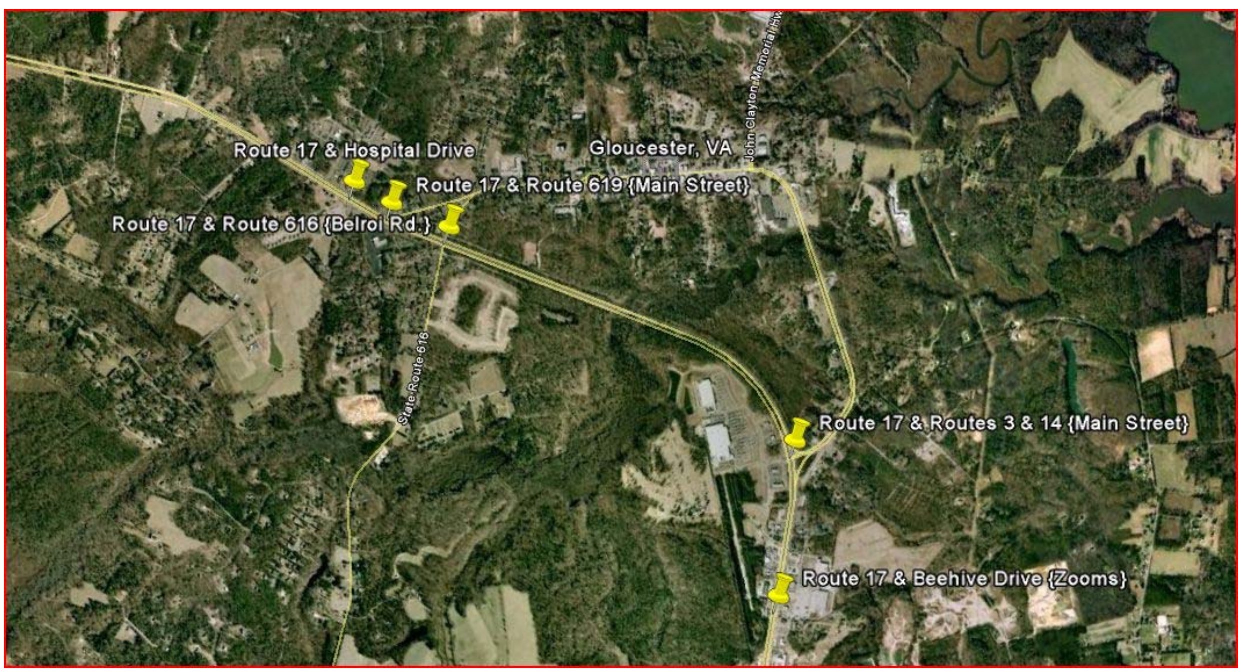

Figure 1. The location and geological features of Site 1 in Gloucester, Virginia (Google Earth).

The total length of this site is about 2.4 miles, and the distance between the intersections varies from 0.15 mile to 1.5 miles. The peak hour traffic volume on the main arterial is about 600 vehicles per hour per lane. Thus, this site is considered to be uncongested.

Site 2 - Chesterfield County, Virginia

Site 2 (see Figure 2) is located in Chesterfield County on US 60. Compared to Site 1, this site is more congested. The total length of this site is about 3 miles, and the distance between adjacent intersections varies from 0.15 mile to 1.4 miles. There are two T-intersections within the site and several schools access the main corridor. Thus, traffic volume within this corridor varies by time of day based on school operations. The average traffic volume on the main arterials was around 750 vehicles per hour per lane. This site, consisting of six signalized intersections, has been operated as a coordinated actuated signal system. The intersections within this site are:

1. US 60 & Otterdale
2. US 60 & Winterfield
3. US 60 & Chater Colony Pkwy
4. US 60 & Coalfield Rd
5. US 60 & Crowder Rd
6. US 60 & Old Buckingham Rd.

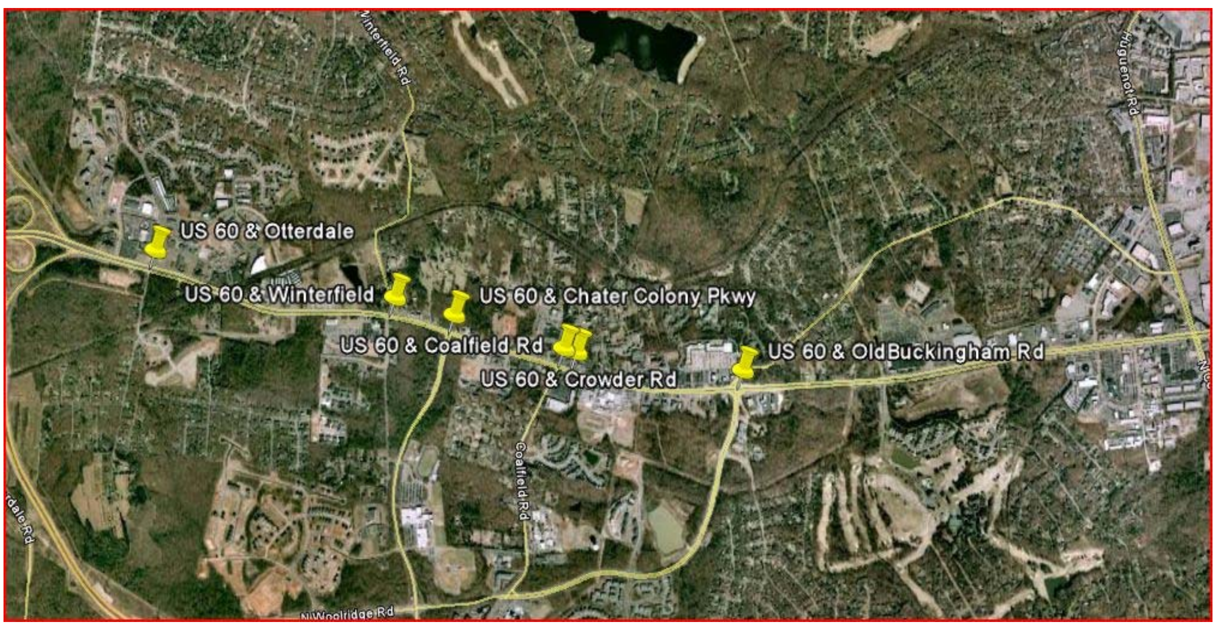

Figure 2. The location and geological features of Site 2 in Chesterfield, Virginia. *Source:* Google Earth.

Data Collection and Reduction

Traffic volume, geometry and MOEs (i.e., stopped delay and travel time) data were collected from each of the two sites. Traffic volume and geometry data were used to develop the

Synchro models, and stopped delay and travel time were used as MOEs of the before-and-after study.

Data Collection: Site 1: Gloucester County

Data was collected twice; once for the before condition (i.e., the non-coordinated actuated timing plan) and the other for the after condition (i.e., the coordinated actuated timing plan). Detailed data collection dates and times are shown in Table 1.

Table 1. Data Collection at Site 1: Gloucester

	Date	Control Mode	Off Peak	PM Peak
Before Study	12/15/2008	Actuated Isolated	1:30pm to 3:00 pm	4:30pm to 6:00 pm
After Study	3/5/2009	Actuated Coordination	1:30pm to 3:00 pm	4:30pm to 6:00 pm

Data Collection: Site 2: Chesterfield County

Data were collected three times at Site 2: one for VDOT's coordinated actuated without adaptive split feature, another for VDOT's coordinated actuated with adaptive split feature, and the other for Synchro optimized coordinated actuated without adaptive split feature. Table 2 summarizes the detailed data collection dates and times. It is noted that the project team developed non-coordinated actuated timing plans and considered the possibility of implementing them with VDOT. The decision was made not to implement the plans due to concerns over the potential negative operational impacts.

Table 2. Data Collection Time Plan at Chesterfield, Virginia

	Date	Off Peak	PM Peak
Base coordinated actuated without adaptive split feature	8/5/2009	1:30pm to 3:00 pm	4:30pm to 6:00 pm
Base coordinated actuated with adaptive split feature	9/2/2009	1:30pm to 3:00 pm	4:30pm to 6:00 pm
Synchro optimized coordinated actuated without adaptive split feature	10/22/2009	1:30pm to 3:00 pm	4:30pm to 6:00 pm

Data Category

To develop a Synchro model, input data, such as traffic counts on each approach, length of each approach lane, posted speed limit, and geometric characteristics were required. In general, these data were collected at the first data collection. During the second or third data collections, only a few selected intersection volumes were collected. These volume data were used to ensure traffic volumes did not significantly change during the data collection periods. The traffic signal timing plans implemented in the field were obtained from VDOT. The MOEs including corridor travel times and stopped delays on selected coordinated and non-coordinated approaches were also collected. The approaches were selected on the basis of the feasibility of safely collecting stopped delays using video cameras. Table 3 shows an example of traffic volume data collected in Gloucester County.

Table 3. A before-and-after traffic volume data collection example at Gloucester County

	Southbound (veh/hr)			Westbound (veh/hr)			Northbound (veh/hr)			Eastbound (veh/hr)		
Movements	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**
Off-Peak Before	28	464	20	16	12	84	72	588	60	56	8	60
Off-Peak After	68	544	72	16	28	56	72	688	44	52	12	40
	Southbound (veh/hr)			**Westbound (veh/hr)**			**Northbound (veh/hr)**			**Eastbound (veh/hr)**		
Movements	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**	**Right**	**Thru**	**Left**
Peak Before	64	672	40	16	28	96	36	820	60	76	8	72
Peak After	40	592	36	36	36	116	48	896	48	68	0	104

Data Collection and Reduction Device

Two vehicles equipped with a Dell PDA with GPS navigation were used for travel time data collection. To collect travel time in both directions at the same time, the two vehicles started at the two end points of the arterial and continued to travel through both directions during the data collection.

Both Jammar traffic counters and Sony video cameras were used for collecting traffic volume and stopped delay. A person using a Jammar traffic counter counted the traffic volume for all approaches at an intersection. However, when a person could not cover all four approaches due to high traffic volume, a video camera was used to record the traffic volumes. The video cameras were also used to capture the stopped delay at the same time. In most cases, a person covered one major approach and one minor approach while the video camera covered the other major and minor approaches and the stopped delay of a minor street. Data were later reduced to obtain traffic volumes and stopped delays.

Data Summary

Appendix A summarizes the traffic counts obtained during each data collection for both sites in Gloucester and Chesterfield. For Site 1 in Gloucester County, the traffic counts were collected for both before-and-after periods. For Site 2 in Chesterfield County, the traffic counts were fully collected at the first data collection. During the 2nd and 3rd data collections at Site 2, traffic volumes were collected only on selected intersections of coordinated approaches due to limitation in personnel. Traffic volume comparison of Site 1 showed that traffic volumes did not change much. Detailed comparison results are provided in Appendix B. Table 4 shows an example of the comparison.

Table 4. A before-and-after traffic volume data comparison example at Gloucester County

Traffic Counts (vph)		Left Turn		Through		Right Turn	
		Before	After	Before	After	Before	After
Route 17 & Route 616 (Belroi Rd.)	Southbound	0	0	484	520	16	48
	Northbound	40	64	576	600	36	80
	Eastbound	32	48	72	92	88	76
	Westbound	104	96	72	72	0	8

Synchro Model Development

Evaluation of Synchro

Measure of Effectiveness

Synchro provides a variety of numerical MOEs, which can be specific to each approach, each intersection, or network wide. The main MOEs include:

- Delays per vehicle: the delays include Synchro's control delay, queue delay, and total delay
- Number of stops: a count of the number of vehicles forced to come to a stop at the intersection or network
- Level of service: for each intersection, the level of service is calculated from the intersection delay

In this study, delay was chosen as the measure of effectiveness.

Synchro Network

Using the collected traffic counts and geometry, the Synchro models of the two study sites were developed. Figures 6 and 7 show the two study sites' Synchro Network.

Comparisons of Measures of Effectiveness

Benefits of Coordinated Actuated Traffic Signal Systems

Traffic volume conditions for before-and-after study

A before-and-after study was conducted in Gloucester County (Site 1) to compare the performance of the non-coordinated actuated signal system and the coordinated actuated signal system. It is noted that the hypothesis of the before-and-after comparison was that the traffic volumes would not change much between the before-and-after study periods. The traffic volumes between before-and-after study showed no significant difference as shown in Appendix B.

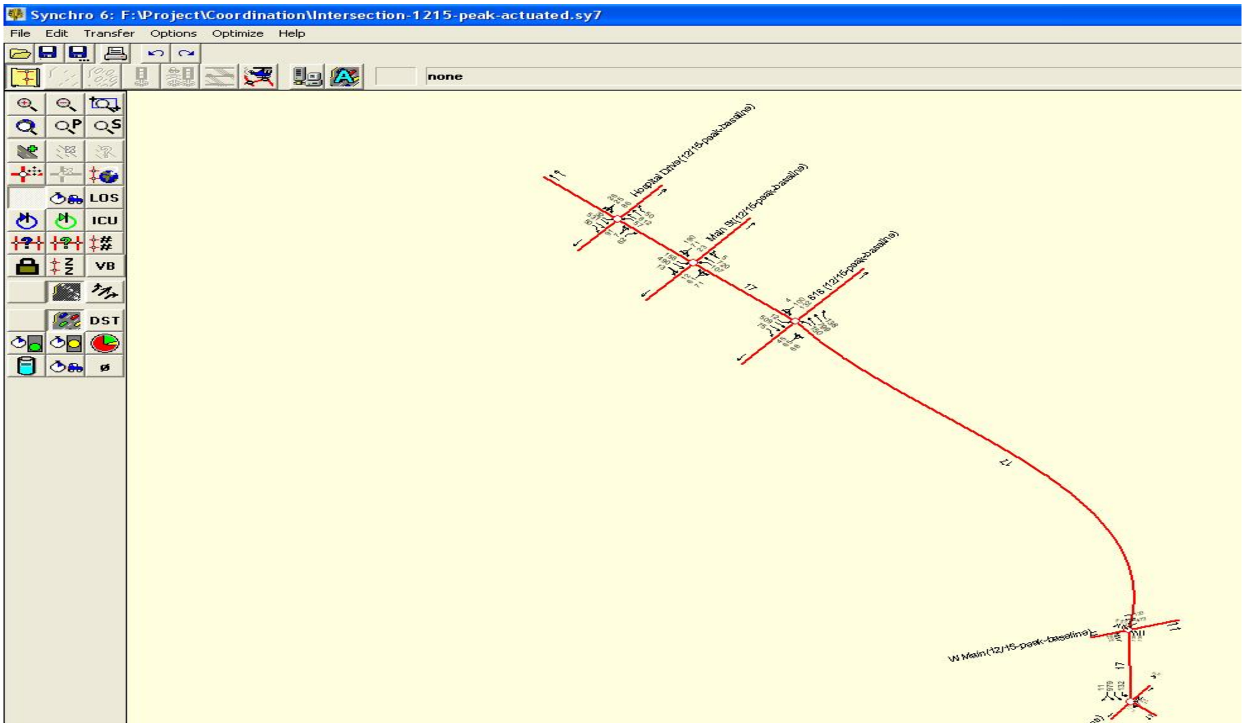

Figure 6. Gloucester County's Synchro Network

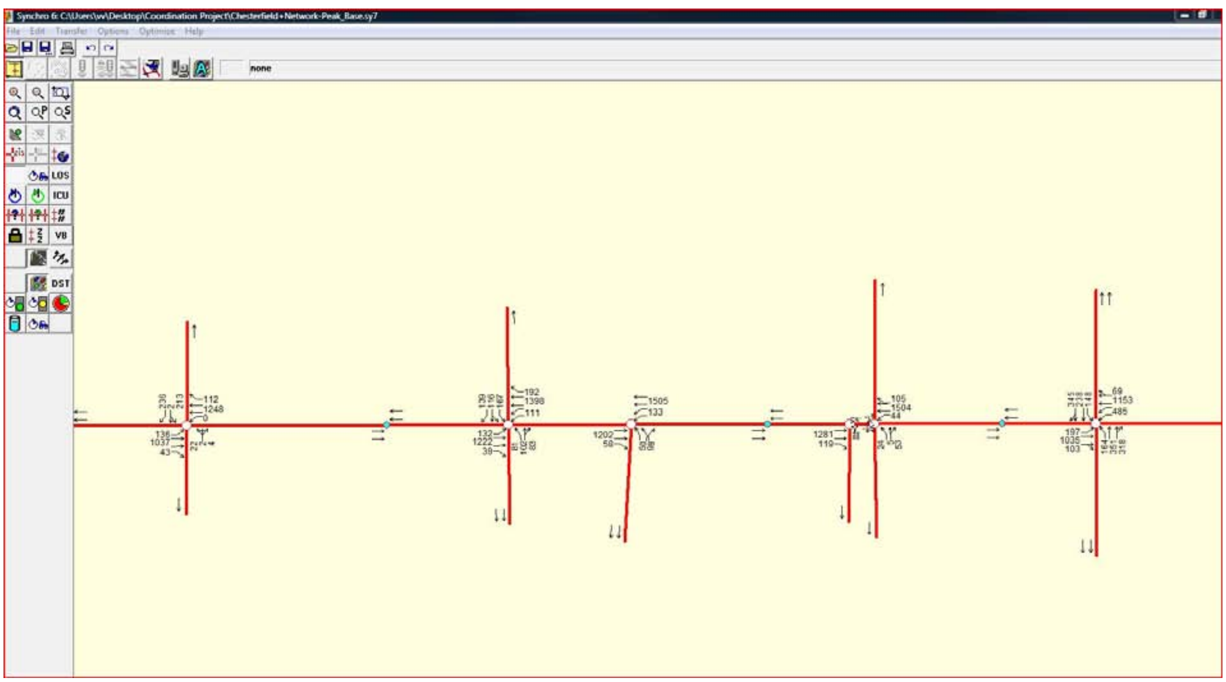

Figure 7. Chesterfield County's Synchro Network

Stopped Delay

Stopped delay was used to quantify the benefits of the coordinated actuated traffic signal system. Tables 5 and 6 show the stopped delay comparison results from Site 1. It is noted that the comparable stopped delays were only collected during the peak hour.

Table 5. Field Stopped Delay Comparison for Selected Mainline Coordinated Approaches at Site One

Intersection	Non-coordinated Actuated (sec/veh)	Coordinated Actuated (sec/veh)	Improvement
Route 17 & Hospital Dr	9.4	8.3	12%
Route 17 & Main St (619)	21.2	4.7	78%

Table 6. Field Stopped Delay Comparison for Selected Non-Coordinated Cross Street Approaches at Site One

Intersection	Non-coordinated Actuated (sec/veh)	Coordinated actuated (sec/veh)	Improvement
Route 17 & Main St (619)	34	39	-15%
Route 17 & 616	44.6	59.7	-34%
Route 17 & W Main (Through)	26	26	0%
Route 17 & W Main (Left)	49	53	-8%

As shown in Tables 5 and 6, when compared to the non-coordinated actuated system, the coordinated actuated traffic signal system showed large improvements in stopped delays on coordinated approaches with increases in stopped delays on non-coordinated approaches. The intersection of Route 17 and Hospital Dr., which is the first intersection of the corridor's western end, showed relatively small improvement when compared to the intersection on Route 17 and Main St. (619), which is an intersection within the arterial. It is reasonable to expect large improvements on coordinated approaches within the arterial as opposed to those on the outer edges. It is noted that traffic volumes on non-coordinated approaches were much lower than those on coordinated approaches. Given that the objective of traffic signal timing optimization is to minimize total system delay, it makes sense to seek improvements on approaches carrying higher traffic volumes even when some lower volume approaches are made worse in the process.

Travel Time

Travel time was also used to assess the impacts of coordination on the network. Table 7 shows the travel times obtained during the before-and-after study at Site 1.

Table 7. Field Travel Time Comparison (Site 1: Mainline Through Traffic Only)

Gloucester County	Non-coordinated Actuated System (Before)		Coordinated Actuated System (After)		Improvements (sec, %)	
	Average (sec)	STDEV	Average (sec)	STDEV		
Off Peak	663	63	465	28	198	30%
PM Peak	713	115	473	40	240	34%

When compared to the non-coordinated actuated system, the travel times of the coordinated actuated system were decreased by 30 and 34 percent for off-peak and PM-peak hours, respectively. These results were consistent with those of the stopped delay comparisons on the selected coordinated approaches.

Evaluation of the Synchro Model

Synchro is a widely adopted engineering tool to evaluate and optimize traffic signal timing plans. However, its validity in replicating field measurements has not been well-investigated. This project evaluated whether Synchro can effectively reflect the traffic signal optimization impacts or not. That is, delta changes between the before-and-after field measurements were compared to those of the before-and-after Synchro estimates. Comparing the differences in before-and-after values for both field data and Synchro removes concerns about legitimate difference in absolute values. If the delta changes from the field and Synchro are similar, it would indicate that Synchro is a valid tool for evaluating the impacts of optimization.

Synchro evaluations were conducted at both sites. At Site 1 (US 17, Gloucester), the comparisons were made between non-coordinated and coordinated conditions. At Site 2 (US 60, Chesterfield), the comparisons were made between coordinated actuated signal systems developed by VDOT and Synchro.

Evaluation Results from Site 1

At study Site 1, both the non-coordinated actuated and the coordinated actuated timing plans were implemented in the field. These timing plans were evaluated in Synchro. Tables 8 and 9 summarized the comparison results using stopped delay measures. It is clear that the delta changes of the before-and-after measurements indicate that Synchro generally well reflects field changes.

Table 8. Delta Changes in Stopped Delay between Field and Synchro (Coordinated Approaches)

Coordinated Approaches	Field measurements (sec/veh)			Synchro estimates (sec/veh)		
	Before	After	[B – A]	Before	After	[B – A]
Route 17 & Hospital Dr	9.4	8.3	+1.1	17.2	13.4	+3.8
Route 17 & Main St. (619)	21.2	4.7	+16.5	21.1	5.7	+15.4

Table 9. Delta Changes in Stopped Delay between Field and Synchro (Non-Coordinated Approaches)

Non-coordinated Approaches	Field measurements (sec/veh)			Synchro estimates (sec/veh)		
	Before	After	[B – A]	Before	After	[B – A]
Route 17 & Main St (619)	34	39	–5	19.1	19.9	–0.8
Route 17 & 616	44.6	59.7	–15	40.7	40.5	+0.2
Route 17 & W Main (Through)	26	26	0	29.6	29.4	+0.2
Route 17 & W Main (Left)	49	53	–4	36.2	47.7	–11.5

Evaluation Results from Site 2

As noted, three sets of timing plans were implemented at Site 2. These include VDOT's coordinated actuated traffic signal timing plans with and without adaptive split feature, and a

Synchro optimized coordinated traffic signal timing plan. As Synchro does not model the adaptive split feature, the delta comparisons were made between VDOT's timing plan without an adaptive split feature and the Synchro optimized timing plan. Tables 10 and 11 show the delta changes in stopped delay on these two timing plans. In general, delta changes of before-and-after stopped delays from Synchro well reflected those from the field (i.e., VDOT timing plan without adaptive split feature) measurements.

Table 10. Delta Changes in Stopped Delay between Field and Synchro (Peak period)

Peak	Field measurements (sec/veh)			Synchro estimates (sec/veh)		
	Before	After	[B – A]	Before	After	[B – A]
Otterdale Coord. East	7	11	–4	6	7	–1
Coalfield Coord. West	6	4	+2	8	9	–1
Crowder Minor North	36	32	+4	43	32	+11
Winterfield Minor North	51	40	+11	51	51	+0

Table 11. Delta Changes in Stopped Delay between Field and Synchro (Off-Peak period)

Off-Peak	Field measurements (sec/veh)			Synchro estimates (sec/veh)		
	Before	After	[B – A]	Before	After	[B – A]
Coalfield Coord. West	4	4	0	9	7	+2
Crowder Minor North	43	28	+15	53	35	+18

Benefits of Adaptive Split Feature

The before-and-after study from Site 2 on US 60 evaluated the performance of adaptive split feature under the coordinated actuated signal system. In addition, the field performance of VDOT and Synchro optimized timing plans without adaptive split feature were compared. Thus, field data collections were conducted for three traffic signal timing plans as shown below.

1. VDOT coordinated actuated traffic signal without adaptive split feature
2. VDOT coordinated actuated traffic signal with adaptive split feature
3. Synchro optimized coordinated actuated traffic signal without adaptive split feature

Again, Synchro optimized timing plan for adaptive split feature was not implemented since Synchro does not optimize such features.

Traffic Volume conditions for before-and-after study

To ensure unbiased assessments, the before-and-after study must be conducted under similar volume conditions. Traffic volume comparison results showed no significant difference during the off-peak hour. However, traffic volumes were slightly increased during the peak hour. This might have been caused by additional traffic generated from nearby schools. It is noted that the increased traffic volumes were mostly on the coordinated approaches and did not have significant impacts on cross street non-coordinated approaches where the adaptive split features were implemented.

Stopped Delay

The stopped delay comparison between VDOT's coordinated signal system with and without adaptive split feature was shown in Table 12.

Table 12. Stopped Delay Comparison between VDOT Coordinated System With and Without Adaptive Split Feature

Period	Approach	VDOT Coordinated with Adaptive Split (sec/veh)	VDOT Coordinated without Adaptive Split (sec/veh)	Adaptive Split Feature Improvement
Peak	US 60 & Crowder Minor South	38	58	34%
	US 60 & Winterfield Minor North	40	51	22%
Off-Peak	US 60 & Crowder Minor North	28	43	35%
	US 60 & Crowder Minor South	31	38	18%
	US 60 & Old Buckingham Minor South	40	51	22%

It is clear that significant improvements were made on stopped delay of the non-coordinated approaches with the implementation of the adaptive split feature. The stopped delay improvements ranged from 18 to 35 percent.

The Synchro optimized timing plan was also implemented in the field. Table 13 shows the comparison of field measured stopped delays between the Synchro optimized timing plan and VDOT optimized coordinated actuated timing plan with adaptive split feature. The comparison results show that no significant performance differences were found.

Table 13. Stopped Delay Comparison between the Synchro Optimized and VDOT Coordinated with Adaptive Split Feature

Period	Approach	Synchro Optimized Coordinated (sec/veh)	VDOT Coordinated with Adaptive Split (sec/veh)	Synchro Improvement
Peak	US 60 & Old Buckingham Minor South	49	44	-10%
	US 60 & Winterfield Minor North	40	40	0%
Off-Peak	US 60 & Crowder Minor North	28	28	0%
	US 60 & Old Buckingham Minor South	36	36	0%
	US 60 & Winterfield Minor South	33	39	+18%

The performance of the Synchro optimized coordinated timing plan and VDOT coordinated timing plan without adaptive split was compared. As shown in Table 14, while the results were somewhat mixed, the Synchro timing plan performed slightly better than VDOT coordinated system without adaptive split feature.

Table 14. Stopped Delay Comparison the Synchro Optimized Coordinated System and VDOT Coordinated System Without Adaptive Split Feature

Period	Approach	Synchro Optimized Coordinated (sec/veh)	VDOT Coordinated without Adaptive Split (sec/veh)	Synchro Improvement
Peak	US 60 & Otterdale Coordinated East	11	7	-57%
	US 60 & Coalfield Coordinated West	4	6	33%
	US 60 & Crowder Minor North	32	36	11%
	US 60 & Winterfield Minor North	40	51	22%
Off-Peak	US 60 & Coalfield Coordinated West	4	4	0%
	US 60 & Crowder Minor North	28	43	35%

Travel Time

Travel times along the corridor were collected during the operations of these three traffic signal timing plans. Table 15 shows summary statistics of travel times. It shows that the corridor travel times were similar regardless of the use of adaptive split feature and VDOT versus Synchro optimized timing plans. This was expected as all three timing plans considered coordination. The only exception was the PM peak travel time under the Synchro optimized timing plan. It shows a statistically significant increase in travel time. However, it is likely that this was due to slightly increased traffic volume on the corridor.

Table 15. Summary of the Travel Time Comparison among Three Timing Plans

	VDOT Coordinated without Adaptive Split (sec)		VDOT Coordinated with Adaptive Split (sec)		Synchro Optimized Coordinated (sec)	
	Average	**STDEV**	**Average**	**STDEV**	**Average**	**STDEV**
Off-Peak (sec)	505	49	489	43	501	54
PM Peak (sec)	505	63	498	65	540	49

CONCLUSIONS

- Based on field measurements at Site 1, the corridor travel times under the coordinated system were improved by 30 to 34 percent over the non-coordinated system, while stopped delays on non-coordinated approaches were increased about 14 percent. Thus, it can be concluded that the coordinated actuated signal system outperforms actuated isolated signal system.

- Traffic signal system coordination was well maintained even over 1-mile spacing between the intersections. Conventional wisdom says the coordination is not necessary when the spacing between intersections is longer than ¾ mile.

- VDOT’s coordinated actuated timing plan (without adaptive split feature) and the Synchro optimized coordinated actuated timing plan showed very similar performance. However, the adaptive split feature implemented under VDOT’s coordinated actuated timing plan resulted in significant savings on non-coordinated cross street movements. The stopped delay savings ranged between 18 and 35 percent. Thus, it can be concluded that an adaptive split feature improves traffic performance on cross street movements.

- Although the absolute performance between Synchro and field measurement is quite different, their performance changes during the before-and-after conditions were very similar. Thus, VDOT regional traffic engineers may trust Synchro in assessing the performances of before-and-after studies (e.g., expected performance between non-coordinated and coordinated traffic signal systems).

RECOMMENDATIONS

1. *VDOT regional traffic engineers should implement the coordinated actuated traffic signal system over the non-coordinated actuated traffic signal system.* It is noted that the coordinated actuated signal system might increase delays at non-coordinated approaches. However, improvements in coordinated approaches outweigh small increases in non-coordinated approaches.

2. *VDOT regional traffic engineers should implement the adaptive split feature (or similar features in other controller types) with coordination to reduce delays on side street approaches when the intersections are being operated within a coordinated system.* As illustrated in this project, delay saving benefits of the adaptive split feature could be as high as 40 percent reductions in delay on cross street movements.

3. *VDOT regional traffic engineers should consider implementing coordination even when signal spacings exceed ¾ mile.*

COSTS AND BENEFITS ASSESSMENT

Benefit-cost analysis (BCA) was conducted to evaluate the economic benefits of implementing the coordinated actuated traffic signal system in place of a non-coordinated actuated traffic signal system.

Assumptions

To conduct a benefit-cost analysis for implementing the coordinated actuated traffic signal system in place of the non-coordinated actuated traffic signal system, the following assumptions were made:

- The existing traffic signal controller does not need to be updated to implement the coordinated actuated traffic signal system.

- The annual costs of traffic signal controller maintenance are $200 and $300 for non-coordinated and coordinated, respectively.

- The value of travel time is $15.47 per hour (Texas Transportation Institute, 2009).

- The analysis period and annual interest rate were set as 10 years and 5 percent, respectively.

- Only the peak hour is considered.

Scenarios

Two scenarios were considered:

1. Base Case: a non-coordinated actuated traffic signal control system
2. Alternative: a coordinated actuated traffic signal control system

Analysis Results

Based on the field measured travel time and stopped delay savings during the before-and-after study at Site 1, the travel time saving of 9.94 vehicle-hours per intersection are estimated during the PM peak hour. Annual travel time saving is estimated to be over 2,982 vehicle-hours. As shown in Table 16, with the expected additional maintenance cost for coordinated actuated signal system and travel time savings for the next 10 years, the benefit cost ratio exceeds 461:1.

Table 16. Benefit-Cost Analysis Calculation

	Category	**Base (non-coordinated)**	**Alternative (coordinated)**
Cost	Annual traffic controller maintenance cost ($)	$200	$300
	NPV maintenance costs for 10 years ($) [note: net present value for 10 years annual maintenance costs]	$1621. 6	$2432.4
	Net costs for implementing coordinated signal system	$2432.4 – $1621. 6 = $810.8	
Benefits from coordinated movements	Peak hour volume for coordinated approaches (veh/hour)	2000	
	Corridor round trip travel time (sec/veh) (from Table 7)	713	473
	Travel time savings per coordinated movements vehicle at each intersection (sec/veh) [note: a corridor with five intersections has 6 links per direction]	(713 – 473) ÷ (6 links ×2 directions) = 20	
	Travel time savings per hour, coordinated movements per intersection (veh-hour)	2000 × 20 ÷ 3600 (sec/hr) = 11.11	

Benefits from non-coordinated movements	Peak hour volume for non-coordinated approaches (veh-hour)	700	
	Peak hour stopped delay at non-coordinated approaches (sec/veh) (weighted average from Table 6)	38.4	44.43
	Travel time saving per non-coordinated movements vehicle at each intersection (sec/veh)	–6.0	
	Travel time savings per hour, non-coordinated movements per intersection (veh-hour)	700 × (–6) ÷ 3600 (sec/hr) = –1.17	
Combined Benefits	Travel time savings per intersection (veh-hour)	11.11 + (–1.17) = 9.94	
	Annual total peak hour savings per intersection	9.94 × 300 weekdays = 2,982 hours	
	Annual peak hour savings ($)	2982 × 15.47 ($/hour) = $46,131.54	
	NPV Travel time savings over 10 years per intersection [note: net present value for 10 years annual savings]	$374,026.30	
B/C Analysis	Benefit cost ratio (net benefit / net costs)	$370,025.3 ÷ $810. 8 = 461.3	

ACKNOWLEDGMENTS

The authors acknowledge Mr. Mike Goodman for his guidance and support throughout the project and Mr. Lewis Woodson and a group of graduate students who helped the field data collection.

REFERENCES

Buckholz, J.W. The 10 Major Pitfalls of Coordinated Signal Timing. *ITE Journal*, Vol. 63, No. 8, 1993, pp. 27-29.

DMJM Harris. *Syracuse Signal Interconnect Project: Before-and-after Analysis Final Report.* New York State Department of Transportation, Syracuse, September 2003.

Denver Regional Council of Government. *The Denver Region Traffic Signal System Improvement Program*. FHWA-HOP-09-046. Federal Highway Administration, Washington, DC, 2009.

Federal Highway Administration. *Manual on Uniform Traffic Control Devices.* Washington, DC, 2009.

Hetrick, S., and McCollough, C.B. How to save $4.2 Million a Year. *ITS International Newsletter*, June 1996.

Husch, D., and Albeck, J. *Synchro 6: Traffic Signal Software, User Guide.* Trafficware, Inc., Albany, CA.

Koonce, P., L. Rodegerdts, K. Lee, S. Quayle, S. Beaird, C. Braud, J. Bonneson, P. Tarnoff, and T. Urbanik. *Traffic Signal Timing Manual*. FHWA-HOP-08-024. Federal Highway Administration, Washington, DC, 2008.

Nesheli, M.M., Puan, O.C.H.E., and Roshandeh, A.M. Optimization of Traffic Signal Coordination System on Congestion: A Case Study. *WSEAS Transportations on Advances in Engineering Education*, Issue 7, Vol. 6, July 2009.

National Transportation Operations Coalition. *2007 National Traffic Signal Report Card: Technical Report*. Institute of Transportation Engineers, Washington, DC, 2007.

Park, B., and Chang, M. Realizing Benefits of Adaptive Signal Control at an Isolated Intersection. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1811*. Transportation Research Board of the National Academies, Washington, DC, 2002, pp. 115-121.

Schrank, D., and Lomax, T. *2009 Urban Mobility Report*. Texas Transportation Institute, Texas A&M University System, College Station, 2009.

Skabardonis, A. ITS Benefits: The Case of Traffic Signal Control Systems. In *The 80th Annual Transportation Research Board Meeting.* Washington, DC, 2001.

Skabardonis, A., R.L. Bertini, and B.R. Gallagher. Development and Application of Control Strategies for Signalized Intersections in Coordinated Systems. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1634.* Transportation Research Board of the National Academies, Washington, DC, 1998, pp. 100-117.

Traffic Engineering Division of Colorado Springs, Colorado. *Traffic Signal Coordination Planning Effort.* City of Colorado Springs, 2005.

Yun, I., Best, M., and Park, B. Evaluation of Adaptive Maximum Feature in Actuated Traffic Controller: Hardware-in-the-Loop Simulation. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2035.* Transportation Research Board of the National Academies, Washington, DC, 2007, pp. 134-140.

Zimmerman, C., J. Marks, J. Jenq, C. Cluett, A. DeBlasio, J. Lappin, H. Rakha, and K. Wunderlich. *Phoenix Metropolitan Model Deployment Initiative Evaluation Report.* FHWA-OP-00-015. Federal Highway Administration, Washington, DC, 2000.

APPENDIX A

TRAFFIC VOLUME SUMMARY AT EACH INTERSECTION

Table A-1: Traffic Counts Summary of Intersection-Route 17 & Hospital Drive

Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Off-Before	28	464	20	16	12	84	72	588	60	56	8	60
Off-After	68	544	72	16	28	56	72	688	44	52	12	40
Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Peak-Before	64	672	40	16	28	96	36	820	60	76	8	72
Peak-After	40	592	36	36	36	116	48	896	48	68	0	104

Table A-2: Traffic Counts Summary of Intersection- Route 17 & Route 619 (Main Street)

Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Off-Before	12	464	144	148	60	24	8	512	88	64	48	4
Off-After	0	464	132	108	48	20	4	488	108	64	44	4
Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Peak-Before	4	556	240	176	76	8	8	716	104	64	64	8
Peak-After	8	532	184	292	108	36	12	820	120	76	76	16

Table A-3: Traffic Counts Summary of Intersection- Route 17 & Route 616 (Belroi Rd.)

Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Off -Before	16	484	0	0	72	104	36	576	40	88	72	32
Off -After	48	520	0	8	72	96	80	600	64	76	92	48
Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Peak-Before	64	584	12	4	92	188	76	748	108	60	88	52
Peak-After	80	536	0	4	88	132	172	888	188	88	76	44

Table A-4: Traffic Counts Summary of Intersection- Route 17 & Route 3 & 14 (Main Street)

Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Off-Before	52	500	8	64	188	532	460	556	280	296	180	180
Off-After	80	444	16	28	144	452	512	500	324	240	240	204
Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Peak-Before	84	660	32	36	148	560	572	792	264	196	164	184
Peak-After	140	612	24	56	188	572	760	716	300	280	240	204

Table A-5: Traffic Counts Summary of Intersection- Route 17 & Beehive Drive (Zooms)

Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Off-Before	52	1116	108	68	8	156	96	1188	20	32	4	16
Off-After	4	988	64	104	16	100	0	1472	12	52	4	8
Street Name	Southbound			Westbound			Northbound			Eastbound		
Start Time	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left
Peak-Before	32	1216	108	96	12	184	192	1924	16	60	0	16
Peak-After	12	1200	152	120	0	128	188	2036	8	44	0	12

Table A-6: Traffic Counts Summary of Intersection- US 60 & Otterdale

Street Name	Otterdale Woods			US 60 W			Otterdale			US 60 E		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	21	4	**4**	110	851	18	118	2	93	5	1010	158
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	22	2	4	136	1037	43	213	2	236	0	1248	112

Table A-7: Traffic Counts Summary of Intersection- US 60 & Winterfield

Street Name	LE Gordon Dr			US 60 W			Winterfiled			US 60 E		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	49	62	67	96	1160	32	177	71	108	113	1260	191
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	81	102	83	132	1222	39	167	116	139	111	1398	192

Table A-8: Traffic Counts Summary of Intersection- US 60 & Charter Colony Pkwy

Street Name	Charter Colony			US 60 W			None			US 60 E		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	71		132		1125	56				159	1276	
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	50		98		1202	58				133	1505	

Table A-9: Traffic Counts Summary of Intersection- US 60 & Coalfield Rd

Street Name	Coalfield			US 60 W			None			US 60 E		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	98		77		1116	88				106	1328	
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	104		100		1281	119				116	1611	

Table A-10: Traffic Counts Summary of Intersection- US 60 & Crowder Rd

Street Name	Shopping Center			US 60 West			Crowder Dr			US 60 East		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	15	13	61	45	983	41	193	7	65	60	1269	101
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	24	5	53	41	1120	39	193	17	47	44	1504	105

Table A-11: Traffic Counts Summary of Intersection- US 60 & Old Buckingham

Street Name	Old Buckingham			US 60 W			Woolridge			US 60 E		
OFF-Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	153	192	120	360	1054	78	137	134	252	168	1041	
PM Peak	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Volume	164	351	318	485	1153	69	148	238	345	197	1035	103

APPENDIX B

TRAFFIC VOLUME COMPARISON FOR BEFORE-AND-AFTER STUDY

Table B-1: The Before-and-after Study Traffic Volume Comparison For Off-Peak Hour

Traffic Counts (vph)		Left Turn		Through		Right Turn	
		Before	After	Before	After	Before	After
Route 17 & Hospital Drive	Southbound	20	72	464	544	28	68
	Northbound	60	44	588	688	72	72
	Eastbound	60	40	8	12	56	52
	Westbound	84	56	12	28	16	16
Route 17 & Route 619 (Main Street)	Southbound	144	132	464	464	12	0
	Northbound	88	108	512	488	8	4
	Eastbound	4	4	48	44	64	64
	Westbound	24	20	60	48	148	108
Route 17 & Route 616 (Belroi Rd.)	Southbound	0	0	484	520	16	48
	Northbound	40	64	576	600	36	80
	Eastbound	32	48	72	92	88	76
	Westbound	104	96	72	72	0	8
Route 17 & Routes 3 & 14 (Main Street)	Southbound	8	16	500	444	52	80
	Northbound	280	324	556	500	460	512
	Eastbound	180	204	180	240	296	240
	Westbound	532	452	188	144	64	28
Route 17 & Beehive Drive (Zooms)	Southbound	108	64	1116	988	0	0
	Northbound	20	12	1188	1472	0	0
	Eastbound	8	16	4	4	32	52
	Westbound	156	100	8	16	68	104

Table B-2: The Before-and-after Study Traffic Volume Comparison For Pm-Peak Hour

Traffic Counts (vph)		Left Turn		Through		Right Turn	
		Before	After	Before	After	Before	After
Route 17 & Hospital Drive	Southbound	40	36	672	592	64	40
	Northbound	60	48	820	896	36	48
	Eastbound	72	104	8	0	76	68
	Westbound	96	116	28	36	16	36
Route 17 & Route 619 (Main Street)	Southbound	240	184	556	532	4	8
	Northbound	104	120	716	820	8	12
	Eastbound	8	16	64	76	64	76
	Westbound	8	36	76	108	176	192
Route 17 & Route 616 (Belroi Rd.)	Southbound	12	0	584	536	64	80
	Northbound	108	188	748	888	76	172
	Eastbound	52	44	88	76	60	88
	Westbound	188	132	92	88	4	4
Route 17 & Routes 3 & 14 (Main Street)	Southbound	32	24	660	612	84	140
	Northbound	264	300	792	716	572	760
	Eastbound	184	204	164	240	196	280
	Westbound	560	572	148	188	36	56
Route 17 & Beehive Drive (Zooms)	Southbound	108	152	1216	1200	32	12
	Northbound	16	8	1924	2036	192	188
	Eastbound	16	12	0	0	60	44
	Westbound	184	128	12	0	96	120

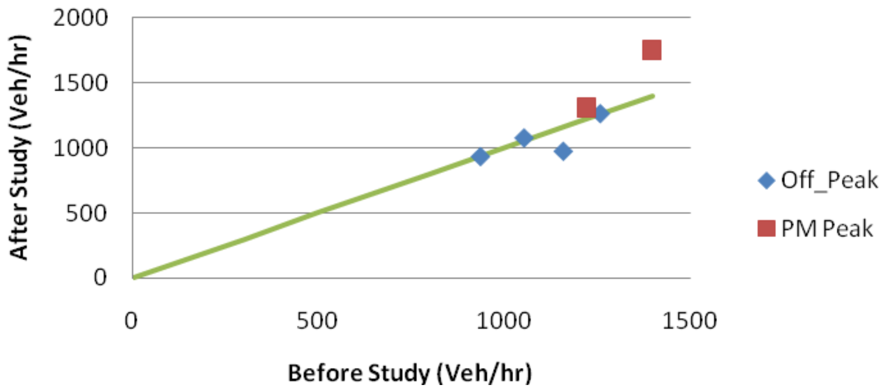

Figure B-1: Traffic Volume Comparison Between Base Coordinated Signal System With And Without Adaptive Split Feature

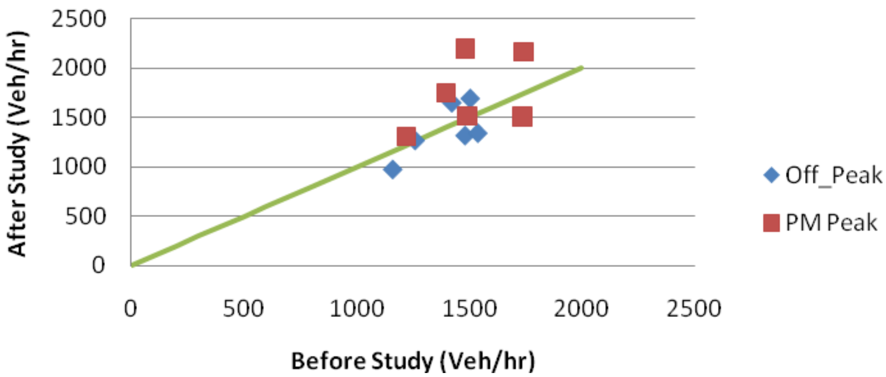

Figure B-2: Traffic Volume Comparison Between Base Coordinated Signal System With And Without Adaptive Split Feature