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EVALUATION OF ADAPTIVE SIGNAL CONTROL TECHNOLOGY—FINAL REPORT

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16. Abstract

This report presents the results of field evaluation of an adaptive signal-control technology (ASCT) system—SynchroGreen—deployed on the Neil Street corridor in Champaign, Illinois. The Illinois Department of Transportation (IDOT) was interested in field evaluation of an ASCT on a corridor, in terms of traffic safety and operational efficiency. SynchroGreen was selected for field implementation on six intersections along Neil Street. This report is the sixth of the ASCT study, and it provides a brief summary of the other studies and new findings regarding the ASCT performance during heavy traffic from the minor street and heavy traffic due to special events. For the "first year" evaluation, data from 2015 was used; and for the "final year" evaluation, data from 2017 was used. Unlike the outcome of the "first year" evaluation, the "final year" evaluation showed improvements on the performance indicator (PI) in only 5% of the lane groups (cases), no change in 32%, and deterioration in 63%. The system was unable to respond properly to volume increases on the minor street (Kirby Avenue), due to either peak-hour demand or special-event traffic, and failed to allocate the unused green time on the major street to the minor street that had cycle failures. Multiple-vehicle fatal and injury (FI) crashes had a crash-modification factor (CMF) of 0.67, which was not significant at the 95% confidence level but clearly indicated a decreasing trend due to implementation of the ASCT system. Decreasing trends in the angle and rear-end crashes, as well as Type A and Type C injuries, were observed; but they were not statistically significant. The travel times were increased in the preferred directions, which was not a desirable outcome. Several recommendations were made to vendors to provide a more desirable ASCT system.

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EXECUTIVE SUMMARY

This report presents results of the field evaluation of an adaptive signal control technology (ASCT) system—SynchroGreen—deployed on the Neil Street corridor in Champaign, Illinois. The field evaluation has been very important in understanding the system's contribution to traffic safety and operational performance improvements. The Illinois Department of Transportation (IDOT) was interested in field evaluation of an ASCT on a corridor. Through a competitive bidding process, a Trafficware product called SynchroGreen was selected for field implementation. Six intersections along Neil Street were selected for this deployment. To evaluate the SynchroGreen system operational performance, data were collected under four different conditions:

(1) Prior to ASCT deployment, referred as "before" data or 2013 data; (2) the "first year after" ASCT deployment, referred to as the first-year performance, or 2015 data; (3) under time-based coordination (TBC) operation, referred to as TBC 2017, or February/March 2017 data (During this period, the ASCT system was turned off.); and (4) under ASCT operation in 2017, referred to as ASCT 2017, or April 2017 data.

The SynchroGreen system was installed in early 2015 and fine-tuned by the vendor to get the "best" performance. It was fine-tuned for the second time in late 2016 and early 2017. Traffic-operation data for the four conditions at three or four time periods (AM peak, off-peak, noon peak, and PM peak) were analyzed to enable assessment of the performance of the system.

IDOT decided to shut down the system on May 5, 2017, mainly due to the uncertainty in system maintenance and performance should there be a full or partial system failure. The week before the shutdown, IDOT and City of Champaign traffic engineering staff observed that the System continued to run erratically and showed many pattern errors and adjustments that were not explainable. Also, they observed that several times the system improperly split the green time such that it caused unnecessary backups on Windsor Road and Kirby when there was very little traffic on Neil Street.

After the shutdown, the traffic signals were operating under time-based coordination plan, as it was before the ASCT system implementation. The signal coordination and timing plan IDOT had on this corridor was running close to an optimal operation that one could get from a closed loop system. Therefore outperforming or "beating" this existing system is a big challenge for any adaptive system.

Three reports on operational efficiency of the system *(1, 2, 3)* have already been published. Volume 1 of the report series, titled *Evaluation of Adaptive Signal Control Technology—Volume 1: Before-Conditions Data Collection and Analysis,* discussed condition 1 *(1).* Volume 2, titled *Evaluation of Adaptive Signal Control Technology—Volume 2: Comparison of Base Condition to the First Year after Implementation, Revised November 2018,* discussed condition 2 *(2).* Volume three, titled *Evaluation of Adaptive Signal Control Technology—Volume 3: Comparison of TBC 2017 and ASCT 2017,* compared conditions 3 and 4 *(3).* In addition to the three reports, a report on the traffic safety impact of the ASCT, titled *Safety Analysis and Crash Modification Factors of an Adaptive Signal Control Technology along a Corridor (4),* was published. Furthermore, a fifth report, titled *Evaluation of*

Adaptive Signal-Control Technology—Systems Engineering (SE) Document and ASCT Selection Method, has been published *(5)*.

This report is the sixth of the ASCT study, and it provides a brief summary of the other studies, as well as some new information about the corridor travel times and ASCT performance during special heavy traffic from the minor street, as well as heavy traffic due to special events.

The evaluation process for SynchroGreen consists of finding conditions for prior to ASCT deployment as “before” data in 2013, “first year after” ASCT deployment in 2015, TBC in 2017, and “final year” of deployment as ASCT 2017. Two sets of comparisons were made to assess the ASCT system’s operational performance, one based on 2015 data and the other based on 2017 data. The base year for ASCT 2015 is the “before” data in 2013, and the base year for ASCT 2017 is the 2017 TBC data.

For the “first year” evaluation, data for 83 lane groups (also called cases or approaches) were used to find a performance indicator (PI). The PI showed improvements in 41% of the cases, remained unchanged in 30%, and deteriorated in 29%. The “final year” evaluation compared performance of 56 lane groups. (The off-peak data were not used, reducing the number of cases from 83 to 56.) Unlike the outcome of the “first year” evaluation, the “final year” evaluation showed improvements in PI in 5% of the cases, no change in 32%, and deterioration in 63%. Further analyses were performed to find the factors contributing to performance deterioration under 2017 ASCT. Out of the 35 cases (the 63%) that showed PI deterioration, we could find some reasonable explanation for PI deterioration for 20 cases, even though they do not in any way justify the deterioration of the system performance. For the remaining 15 cases, no reasonable explanations were found.

Under the 2017 ASCT operation, PI deterioration was more frequent, compared to the 2015 ASCT for the same lane groups. There were 18 deteriorated cases out of 56 cases in 2015 ASCT, while there were 35 deteriorated cases out of 56 cases in 2017 ASCT. Sixteen cases were common to both data sets. Nineteen cases showed PI deteriorations in the “final year” that were new lane groups, compared to the 2015 ASCT. For 8 of the 19 cases, one could find some reasonable explanation for the deterioration; for 10 cases, no reasonable explanation was found; and for one case, the performance deterioration could be explained by volume increase in 2017. Once again, the reasonable explanations do not justify the deterioration in the system’s PI.

A required feature of the ASCT system (SynchroGreen in this case) was the ability to respond properly and quickly to changes in volume on the minor street. There were two situations that created heavy traffic volumes on the minor street (Kirby Avenue). The system’s performance was evaluated in both cases. The expectation that the system would allocate enough green time to the minor street to process queued vehicles, while providing sufficient green time to the major street, was not materialized. The system did not reallocate the unused green time on the major street (Neil Street) to the minor street (Kirby Avenue) that had heavy traffic volume during the PM peak hour; about 40% to 62% of the cycles were not given enough green time to process the vehicles in queue on the minor street, while there was unused green on the major street. The second situation was a concert by a popular country singer that attracted a lot of people to the University of Illinois (UI) campus. SynchroGreeen was unable to respond properly to volume increases on the minor street (Kirby

Avenue). It failed to reallocate the unused green time on the major street (Neil Street) to the minor street that had cycle failures (vehicles in queue when the minor-street green time ended).

For safety-evaluation, traffic-crash data for 3 years before implementation and 1.5 years after were used to assess traffic-safety impacts of the ASCT. The Crash-modification factor (CMF) for multiple-vehicle fatal and injury (FI) crashes at four-legged intersections was 0.67, which was not statistically significant at the 95% confidence level (It is significant at the 85% confidence level.); however, it clearly indicated a decreasing trend in FI crashes due to the implementation of ASCT. For PDO (property damage only) and total crashes, all crash-modification factors (CMFs) computed were close to one, indicating no crash reduction due to the implementation of ASCT. The results from the paired tests showed decreasing trends in the angle and rear-end crashes, but they were not found to be statistically significant. For the sideswipe same-direction and turning crashes, the test results showed no change. The test results also indicated that for Type A injury and Type C injury crashes, there were reductions; but they were not found to be statistically significant. There was no change in severity of Type B crashes.

In terms of travel time on the corridor, two sets of travel-time comparisons and one set of speed comparisons were made. The 2014 (TBC) vs 2016 (ASCT) travel-time comparisons showed that under ASCT operation the corridor travel time for the preferred directions (NB AM-peak and SB PM-peak directions) increased by 31.8 seconds for NB through traffic during the AM-peak and by 48.3 seconds for the SB through traffic during the PM-peak hours. The comparison of 2017 (TBC) vs 2017 (ASCT) showed that the NB AM-peak travel time increased by 45.0 seconds and SB PM-peak increased by 51.8 seconds. The vehicles were slowing down or stopping due to a red light or queue when the ASCT system was operating, and that mainly caused the increase in travel time. The average speed at the middle-third segment for each link and the average speed of the corridor under 2017 ASCT were compared to the corresponding values under 2017 TBC. The SB traffic during the PM peak showed an average corridor-speed reduction of 6.1 mph, which also contributed to the travel-time increase in the preferred directions, not a desirable outcome. Although travel-time increase and speed decrease may negatively impact the system's efficiency, they may be among the factors contributing to the safety benefits of the ASCT deployment, which showed a decreasing trend in fatal and injury crashes.

Several recommendations were made to vendors to provide a more desirable ASCT system.

CONTENTS

CHAPTER 1: INTRODUCTION

Traffic signals in the United States have evolved from fixed cycle to vehicle actuated operation to the present day advanced signal systems and adaptive signal control technology (ASCT). An adaptive traffic signal adjusts its phase plan and signal timing in response to real time traffic demand. Field evaluation of an ASCT is very important in understanding the system's contribution to traffic safety and performance improvement. The Illinois Department of Transportation (IDOT) was interested in field evaluation of an ASCT on a corridor. Through a competitive bidding process, a Trafficware product called SynchroGreen was selected for field implementation. Installation of the ASCT system began in the spring of 2015 on the Neil Street corridor in Champaign, Illinois, as shown in Figure 1. The six intersections along Neil Street, from north to south, are as follows:

- Neil Street and Stadium Drive
- Neil Street and Kirby Avenue
- Neil Street and St. Mary's Road
- Neil Street and Devonshire Drive
- Neil Street and Knollwood Drive
- Neil Street and Windsor Road

In addition, the traffic signal at Kirby Avenue and State Street was linked to the traffic signal at Kirby and Neil so that they worked in a coordinated manner.

Figure 1. Deployment location on Neil Street in Champaign, Illinois.

In order to evaluate the SynchroGreen system's performance, data were collected under four different conditions:

(1) Prior to ASCT deployment, referred as "before" data, or 2013 data

(2) The “first year after” ASCT deployment, referred to as first-year performance, or 2015 data

(3) Under time-based coordination (TBC) operation, referred to as TBC 2017, or February/March 2017 data (During this period, the ASCT system was turned off.)

(4) Under the ASCT operation in 2017, referred to as ASCT 2017, or April 2017 data

The SynchroGreen system was installed in early 2015 and fine-tuned by the vendor to get the “best” performance. It was further fine-tuned in late 2016 and early 2017 before data collection for this evaluation. Traffic-operation data for the four conditions at three or four time periods (AM peak, off-peak, noon peak, and PM peak) were analyzed to enable assessment of the system performance.

Three reports on operational efficiency of the system (*1, 2, 3*) have already been published. Volume 1 of the report series, titled *Evaluation of Adaptive Signal Control Technology—Volume 1: Before-Conditions Data Collection and Analysis,* discussed condition 1 (*1*). Volume 2, titled *Evaluation of Adaptive Signal Control Technology—Volume 2: Comparison of base condition to the first year after implementation, Revised November 2018,* discussed condition 2 (*2*). Volume three, titled *Evaluation of Adaptive Signal Control Technology—Volume 3: Comparison of TBC 2017 and ASCT 2017,* compared conditions 3 and 4 (*3*). In addition to the three reports, a report on traffic-safety impact of the ASCT, titled *Safety Analysis and Crash Modification Factors of an Adaptive Signal Control Technology along a Corridor* (*4*), was published. Furthermore, a fifth report, titled *Evaluation of Adaptive Signal-Control Technology—Systems-Engineering (SE) Document and ASCT-Selection Method,* was recently published *(5)*.

This report is the sixth of the ASCT study; and it provides a brief summary of the other studies, as well some new information about the corridor travel times and ASCT performance during special-events traffic conditions.

CHAPTER 2: FINDINGS OF PREVIOUS ASCT REPORTS

2.1 SUMMARY OF REPORT VOLUME 1

Field evaluation of ASCT is very important in understanding the system's contribution to traffic safety and performance improvement—and, hence, its effectiveness. To evaluate the SynchroGreen system, the corridor's performance data prior to ASCT deployment were collected. The data were used as a basis to compare the performance of the system after it was deployed.

This report presented the methodology and outcome of data collection, data reduction, and data analysis of the field conditions before implementation of SynchroGreen in Champaign. Traffic characteristics for four time periods (AM peak, off-peak, noon peak, and PM peak) were obtained from field videotapes. Those traffic characteristics include peak hours, hourly volume, saturation flow rate, signal timing, arrival type, field delay, and queue length. The field delay and queue length measured before implementation were used to evaluate the operational performance of the SynchroGreen system by comparing those characteristics after implementation. Those measures of effectiveness in the "before conditions" were also compared with estimations from the *Highway Capacity Manual* (HCM) *(6)* to quantify the effects of volume changes and additional developments at Neil Street and Devonshire Drive through the course of the study.

The *HCM* estimates of stopped delays were significantly different in 58.3% of the cases, representing overestimation in 73.5% of the cases and underestimation in 26.5%. On major streets of typical intersections, *HCM* delay estimates and field data were significantly different in 72% of the cases; in 91% of these cases, *HCM* overestimated the delay on average by 69%. On minor streets of typical intersections, there were significant differences between *HCM* and field data in 56% of the cases; in 94% of these cases, *HCM* overestimated the delay on average by 52%.

HCM estimates of the 50th-percentile queue length was significantly different in 61% of all cases, including overestimations in 56% of the cases and underestimations in 44%. For typical intersections, 52% of the cases had significant differences, including overestimations in 93% and underestimations in 7%. On the major streets of typical intersections, the *HCM* queue lengths were similar to those from the field in 68% of the cases. However, in 28% of the cases, *HCM* overestimated the queue length on average by 66%; in 4% of the cases, it underestimated the queue length on average by 42%. On the minor streets of typical intersections, in only 25% of the cases were the median *HCM* queue lengths similar to those from the field; however, in 70% of the cases, *HCM* overestimated the queue length on average by 44%; and in 5% of the cases, it underestimated it on average by 20%.

In addition, a 95th-percentile queue-length comparison was conducted between *HCM* estimates and field data. In general, it was observed that trends in the 50th- and 95th-percentile queue-length comparisons supported each other.

The consistency between the results of stopped-delay and the 50th-percentile queue-length comparisons for the 64 overlapping cases was analyzed. In 91% of the cases, the trends in delay and queue comparisons were either consistent or did not have any significant conflicts. However, in 9% of the cases, significant inconsistencies in trends were observed. Thus, to save time, one may compare *HCM* queue-length estimates to field data to assess intersection performance, though the delay comparison is preferred.

2.2 SUMMARY OF REPORT VOLUME 2

This report presented the study methodology, data collection, data reduction, and data analysis of the “first year after” implementation of SynchroGreen (2015 data). The system was installed in early 2015 and fine-tuned by the vendor to get the “best” performance. Traffic characteristics for four time periods (AM peak, off-peak, noon peak, and PM peak) were obtained from field videotapes. The traffic characteristics were peak periods, hourly volumes, saturation flow rates, signal timings, arrival types, field delays, and queue lengths.

The volume, delay, and queue-length data from the field for the 2013 conditions (before) were measured and compared with the data for 2015 conditions (after). The field volumes were compared for 83 lane groups (approaches). Traffic volume on 33% of the lane groups increased significantly, but on 65% did not change significantly, and on only 2% decreased significantly. The field delays were compared for 83 lane groups, out of which 17% showed significant increase, 72% showed no significant change, and 11% showed significant decrease. Queue length was compared for only 63 lane groups because the remaining 20 lane groups either did not have queue data or the queue length was insignificant (no more than two cars). Out of these 63 lane groups, 22% showed significant increase in queue length, 60% showed no significant change, and 18% showed significant decrease in queue length.

Further analysis was carried out to determine ASCT performance at approach, intersection, and corridor levels. Based on the changes in volume, delay, and queue length combined, an overall performance indicator (PI) was determined for each approach of each intersection at each time period. The performance indicators were Imp (improved), Unch (unchanged), Det (deteriorated), or Mix (mixed results). Out of the total of 83 lane groups analyzed, the PI showed improvement in 51%, remained unchanged in 30%, but showed deterioration in 29%. In summary, on 71% of the lane groups, ASCT either improved or performance was unchanged; however, on 29% of the lane groups, performance deteriorated. Out of the 24 deteriorated cases (the 29%), volume significantly increased in 4, did not significantly change in 19, and significantly decreased in 1. Deterioration in the 4 cases can be attributed to the increase in volume and the system’s inability to respond adequately to that increase. However, in the 18 lane groups for which volume did not significantly change, the deterioration in PI was not expected.

The analyses indicated that ASCT made a compromise between the minor- and major-street performances; and in general, the minor-street improvements were correlated with major-street deterioration or unchanged performance.

2.3 SUMMARY OF REPORT VOLUME 3

To evaluate the SynchroGreen system, the corridor’s performance was measured during two conditions: time-based coordination (TBC) in February/March 2017 and ASCT in April 2017. This report presented the study methodology, data collection, data reduction, and data analysis under TBC 2017 and ASCT 2017. The SynchroGreen system was installed in early 2015 and fine-tuned by the vendor to get the “best” performance. It was further fine-tuned in late 2016 and early 2017 before data collection for this evaluation. Traffic characteristics for three time periods (AM peak, noon peak, and PM peak) were obtained from field videotapes. The traffic characteristics were peak periods, hourly volumes, saturation flow rates, signal timings, arrival types, field delays, and queue lengths.

The volume, delay, and queue-length data from the field for TBC 2017 were measured and individually compared with the data for ASCT 2017, at the 97% confidence level. The field data were compared for 57 lane groups (approaches). At the 97% confidence level, traffic volume on 7% of the lane groups significantly increased; but on 72%, it did not change significantly; and on 21%, it significantly decreased. Delay showed significant increase in 56% of the cases, no significant change in 40%, and significant decrease in 4%. Queue length was also compared for the 57 lane groups: 35% showed significant increase in queue length, 65% showed no significant change, and none showed significant decrease.

Further analysis was carried out to determine ASCT performance at approach, intersection, and corridor levels. Based on the changes in volume, delay, and queue length combined, an overall performance indicator (PI) was determined for each approach of each intersection at each time period. The performance indicators were Imp (improved), Unch (unchanged), and Det (deteriorated). Because we considered the 97% confidence interval for individual comparisons of volume, delay, and queue length, the PI would present the results at the 91% confidence level, the product of three individual confidence levels of 97% (0.97*0.97*0.97). One lane group was excluded from further analysis due to insufficient volume; so out of the total of 56 lane groups analyzed, the PI showed improvement in 5%, remained unchanged in 32%, but showed deterioration in 63%. In summary, on 37% of the lane groups, ASCT either improved or did not change performance; however, on 63% (35 cases) of the lane groups, performance deteriorated with ASCT.

Further investigations were performed to find the factors contributing to the ASCT performance deterioration. Out of 35 cases, deterioration in 20 cases could be explained by contributing factors such as frequency of unfavorable arrival types under ASCT 2017, as compared to TBC 2017; a few cases of volume increase under ASCT 2017; ASCT miscount of traffic volumes; signal-timing changes under ASCT 2017; and an increased proportion of vehicles stopped under ASCT 2017. However, in the 15 remaining cases, there was no reasonable explanation for the PI deteriorations when ASCT was operating.

2.4 SUMMARY OF SAFETY ANALYSIS AND CMF REPORT

The main objective of this part of the study was to determine the safety effectiveness of the ASCT SynchroGreen, using an observational before-and-after study applying the Empirical Bayes (EB) method. SynchroGreen was installed at six intersections along the Neil Street corridor in Champaign, Illinois. Five of the intersections were four-legged intersections, and one was a three-legged intersection. Both national (*Highway Safety Manual*) and state-specific (Illinois) safety-performance functions (SPFs) were selected and calibrated for the local conditions for the study period 2012–2016.

Crash data for 2012–2014 were used for the “before” conditions, and the data for May 2015–October 2016 was used for the “after” conditions. A total of fourteen SPFs from the *Highway Safety Manual* (HSM) *(7)* and an additional three from Illinois were calibrated, and crash-modification factors (CMF) were developed. CMFs were developed for each crash severity and type.

For multiple-vehicle fatal and injury (FI) crashes at all intersections (four-legged and three-legged combined), the CMF was 0.67, which was not statistically significant at the 95% confidence level. (It was significant at the 87% confidence level.) For the four-legged intersections only, the CMF was 0.67 as well, which was not significant at the 95% confidence level. (It was significant at the 85% confidence level.) The 87% and 85% confidence levels are not used in practice; however, they clearly indicate a decreasing trend in FI crashes due to the implementation of ASCT. For the three-legged intersection, there was not adequate data to develop CMFs. For PDO (property damage only) and total crashes, all CMFs computed were close to one, indicating no crash reduction due to implementation of ASCT. The above findings are based on SPFs from *HSM (7),* which were chosen over previously developed SPFs for Illinois. Nonetheless, the CMF for Illinois KAB (fatal, type A injury, and type B injury crashes combined) crashes was computed and found to be 0.68, which was not significant at the 95% confidence level. (It was at the 71% confidence level, indicating a decreasing trend in crashes of these types.)

Wilcoxon signed-rank tests were performed. However, due to the small sample size, they were not relied upon for assessing whether there was a shift in the location of crashes. For this reason, paired *t*-tests were performed to further explore which crashes were most affected by the reduction due to the ASCT implementation.

The results from the paired tests showed decreasing trends in crash type and severity, as well as no change on two crash types and no change in severity of type B crashes. For the angle and rear-end crashes, there were reductions; but they were not found to be statistically significant. For sideswipe same-direction and turning crashes, there was no change. In terms of crash severity, Type A injury and Type C injury crashes showed reductions; but they were not found to be statistically significant.

The assumption of medium-level pedestrian volume for midsized cities was supported using local data. (727 pedestrians per day using local data is very close to the medium level of 700 pedestrians per day in *HSM*).

It was recommended to further study ASCT’s long-term (multiyear) safety effects; also, to study the effects of ASCT on three-legged intersections when additional field data are available.

2.5. Summary of SE Document Report

One of the tasks of this study was to use the FHWA’s *Model Systems Engineering Documents for Adaptive Signal-Control Technology (ASCT) Systems—Guidance Document, August 2012* (Fehon et al. 2012) for purchasing an adaptive system. The systems engineering (SE) document prepared for this project was a part of the bidding documents for procurement of the ASCT system. It presents the process of preparing the SE document, developing selection criteria, and preparing a bid document for procurement of the system.

The procurement of the ASCT system was a learning experience for the research team and the Technical Review Panel (TRP). This report was prepared to provide an overview of the process and give an example of the SE document needed for such purchases. Preparing the SE document takes time and must be carefully done to get the right system and features.

The approval process may take significantly longer than expected when other state agencies participate in the process. The team had allocated 3 months for purchasing this system, but it took 14 months to procure it.

An objective process for evaluation and ranking of the competing proposals should be used. This study developed such a procedure and utilized it in selection of a vendor for this study.

It is important to have people with a traffic engineering background involved in preparing the SE document so the system's features and functionalities are appropriately specified.

The system features as advertised by vendors may not function very well in every real-world traffic condition. The expected performance from an ASCT system should be constrained to those that can be achieved in a given condition.

CHAPTER 3: COMPARISON OF FINDINGS IN FIRST YEAR AFTER AND FINAL YEAR OF DEPLOYMENT

Volume 2 of the report series discussed the findings for the “first year after” the ASCT system was deployed (the 2015 data). Similarly, Volume 3 of the report series discussed those for the “final year” the system was deployed (2017 data). IDOT decided to shut down the system on May 5, 2017, mainly due to the uncertainty in system maintenance and performance should there be a full or partial system failure. The week before the shutdown, IDOT and City of Champaign traffic engineering staff observed that the System continued to run erratically and showed many pattern errors and adjustments that were not explainable. Also, they observed that several times the system improperly split the green time such that it caused unnecessary backups on Windsor Road and Kirby when there was very little traffic on Neil Street.

After the shutdown, the traffic signals were operating under time-based coordination plan, as it was before the ASCT system implementation. The signal coordination and timing plan IDOT had on this corridor was running close to an optimal operation that one could get from a closed loop system. Therefore outperforming or “beating” this existing system is a big challenge for any adaptive system. Important dates during the project are presented in the Table 1.

Table 1. Important Dates during the Project

1	Finalized SE document based on feedback from TRP	Oct. 2013
2	SE document sent to UI Purchasing Department	Oct .2013
3	RFP posted on UI website and announcements went out	June 2014
4	UI sent a signed contract to TrafficWare	Dec. 16, 2014
5	System installation started	April 27, 2015
6	System fine-tuning/software update continued	May 4–8, 2015
7	UI sent feedback to TrafficWare	Aug. 11, 2015
8	Final adjustments completed by vendor	Nov. 10, 2015
9	SynchroGreen system was accepted	Nov. 10, 2015
10	System was turned off for further fine tuning	Dec. 8, 2016
11	System was turned on again	April 3, 2017
12	System was permanently turned off	May 5, 2017

Comparisons of the system’s performance indicators (PI) under 2017 ASCT relative to its base, which was 2017 TBC, as well as the PI under 2015 ASCT relative to its base, which was 2013 data, revealed that PI deterioration was more frequent in 2017 data.

In the “final year” data (2017 ASCT, as reported in Volume 3), there were 35 deteriorated cases out of a total of 56 cases. However, there were 18 deteriorated cases out of a total of 56 cases in the “first year after” data (2015 data, as reported in Volume 2). There were 16 cases that showed deterioration in both data sets (the 2017 and 2015 data sets).Thus, 16 out of 18 cases that showed deterioration in the “first year after” data also showed deterioration in the “final year” data, but PI improved in 2 cases. In the “final year” data, 19 additional cases showed performance deterioration, as schematically shown in the Figure 2 Venn diagram.

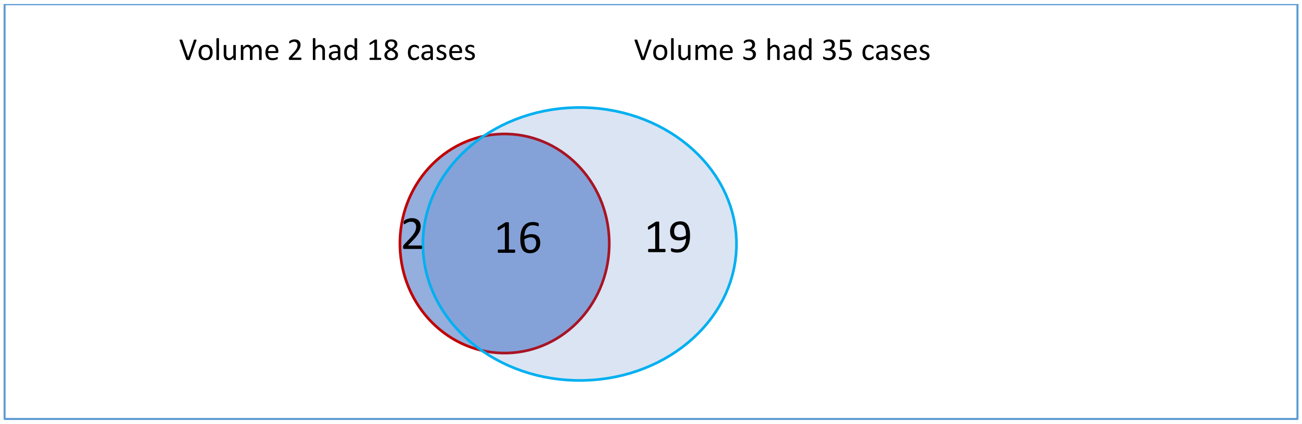

Figure 2. PI deterioration cases in the “first year after” ASCT deployment and the “final year.”

Among the 19 deteriorated cases in the “final year” data, some reasonable explanation for PI deterioration could be found for 8 cases, though not justifying the deterioration of the system performance; but for 11 cases, no reasonable explanation for their PI deterioration was found, (A detailed discussion will be given later.)

Further investigations were conducted to find the possible factors contributing to PI deterioration under 2017 ASCT conditions. Out of the 35 cases that showed PI deterioration under 2017 ASCT, one could find some reasonable explanation for the deterioration for 20 cases. It should be noted that the explanations do not in any way justify the deterioration in system performance, but they help us to understand why it happened and what may have caused it. For the 20 cases, we were able to find some *possible* contributing factor(s), such as frequency of unfavorable arrival types under ASCT 2017 compared to TBC 2017 (8 cases); volume increase under ASCT 2017 (3 cases); ASCT miscount of traffic volumes in some cases; signal-timing changes under ASCT 2017 (6 cases); and increase in the proportion of vehicles stopped under ASCT 2017 (13 cases). Note that these are possible contributing factors; and in 9 cases, more than one possible contributing factor for the deterioration may exist. We examine the deteriorations in detail in the following section. However, for the 15 remaining cases, we were unable to find a reasonable explanation for the PI deteriorations when ASCT was operating in 2017.

For each approach of each intersection, the PIs for the “first year after” (Volume 2) and the “final year” (Volume 3) are given in Table 2. There are 56 cases common to both years (a pair) that are analyzed. [Volume at Stadium Drive westbound through (WBT) during AM peak was not sufficient in the 2017 data, so it is not used.] The PIs are different in 50% of the cases (28 out of 56 cases) but remain the same in the other half. Among the cases for which the PI was different, in 92.9% (26 cases out of 28), the PI worsened (red-highlighted cells in Table 2); and in only 7.1% (2 cases, meaning 2 pairs of cases), the PI improved (green-highlighted cells in Table 2). Blue-highlighted cells in Table 2 show 16 cases with deterioration in both years.

Table 2. Performance-Indicator (PI) Comparison for Each Lane Group (PI at 91% Confidence Level)

Intersections	Approach	AM Peak		Noon Peak		PM Peak	
		1st year after	Final year	1st year after	Final year	1st year after	Final year
Stadium	NBT	Unch	Det	Imp	Det	Imp	Det
	SBT	Imp	Det	Imp	Unch	Imp	Det
	EBT	Imp	Det	Imp	Det	Det	Det
	WBT	Imp	NA	Unch	Det	Det	Det
Kirby	NBT	Imp	Det	Imp	Imp	Imp	Imp
	SBT	Unch	Det	Unch	Unch	Det	Det
	EBT	Det	Det	Imp	Det	Unch	Unch
	WBT	Imp	Det	Imp	Det	Imp	Det
St. Mary's	NBT	Det	Unch	Det	Det	Unch	Unch
	SBT	Imp	Unch	Det	Det	Det	Unch
	EBT	Imp	Unch	Unch	Unch	Unch	Unch
	WBT	Unch	Det	Det	Det	Unch	Det
Devonshire	NBT	Det	Det	Det	Det	Det	Det
	SBT	Unch	Unch	Det	Det	Det	Det
	EBL	Unch	Unch	Imp	Unch	Imp	Imp
Windsor	NBT	Det	Det	Imp	Det	Imp	Unch
	SBT	Det	Det	Unch	Unch	Det	Det
	EBT	Det	Det	Imp	Unch	Imp	Det
	WBT	Unch	Unch	Imp	Unch	Unch	Det

Furthermore, in the "final year" data, 7 cases showed no change in PI (Unchanged category); but they had shown improvement in PI in the "first year after" data. So the traffic operation for these 7 cases worsened; however, we did not include them among the 35 deteriorated cases.

One may suspect that traffic-volume increase from 2015 to 2017 played a big role in explanation of the higher frequency of PI deterioration in 2017 data. This topic is explored further here. It should be noted that data collected for "first year after" implementation of ASCT (2015 data) was done after the first fine-tuning of the system to perform its "best." However, the "final year" (ASCT 2017 data) data was collected after the system was further fine-tuned to perform even better than the "best." So the system operation in 2017 was not the same as it was in 2015. This difference prevented us from making direct volume comparisons. Furthermore, we had used the 2013 data already the base for the 2015 data—and similarly, the 2017 TBC as the base for 2017 ASCT—as the most appropriate bases for the comparisons. So we decided not to make a direct volume comparison between 2015 and 2017 data. Instead, we looked at the changes in volume with respect to the respective bases.

Among 56 pairs of cases, there were only 4 pairs of cases in which traffic volume in 2017 ASCT data increased compared to its base but did not increase in the 2015 data compared to its base. These 4 pairs of cases are highlighted in red in Table 3.

Table 3. Volume Comparison for Each Lane Group at 97% Confidence Level

Intersections	Approach	AM Peak		Noon Peak		PM Peak	
		1st year after	Final year	1st year after	Final year	1st year after	Final year
Stadium	NBT	Unch	Unch	Inc	Unch	Unch	Unch
	SBT	Inc	Unch	Inc	Unch	Unch	Unch
	EBT	Inc	Dec	Inc	Dec	Inc	Dec
	WBT	Unch	NA	Unch	Dec	Unch	Unch
Kirby	NBT	Unch	Unch	Inc	Unch	Unch	Unch
	SBT	Unch	Dec	Unch	Unch	Unch	Unch
	EBT	Unch	Unch	Inc	Unch	Unch	Unch
	WBT	Inc	Dec	Inc	Unch	Inc	Dec
St. Mary's	NBT	Unch	Unch	Unch	Inc	Unch	Unch
	SBT	Unch	Unch	Unch	Inc	Unch	Unch
	EBT	Inc	Unch	Unch	Unch	Unch	Dec
	WBT	Unch	Dec	Dec	Dec	Unch	Dec
Devonshire	NBT	Unch	Unch	Unch	Inc	Inc	Unch
	SBT	Unch	Unch	Unch	Unch	Unch	Unch
	EBL	Unch	Unch	Inc	Unch	Inc	Inc
Windsor	NBT	Unch	Unch	Unch	Unch	Inc	Unch
	SBT	Unch	Dec	Unch	Unch	Unch	Unch
	EBT	Unch	Unch	Unch	Unch	Dec	Unch
	WBT	Unch	Unch	Unch	Unch	Unch	Unch

One of the 4 cases that volume changes could provide an explanation for the worsening of PI was eastbound through (EBT) of Windsor Road. Volume decrease in the 2015 data contributed to PI improvement, whereas the volume's remaining unchanged in the 2017 data resulted in PI deterioration. For the other 3 cases, the volume was unchanged in the 2015 data but increased in the 2017 data. However, the performance did not worsen at these three locations.

The 8 cases we discussed before plus the one case in which volume could play a role (discussed above) are presented in Table 4. Explanations for PI deterioration can be provided for the two green-highlighted cells due to undesirable arrival type; for the three blue-highlighted cells, due to signal-timing changes; and for the three yellow-highlighted cells, due to a higher proportion of stopped vehicles. For the red-highlighted cells, the volume increase could provide a reasonable explanation for PI’s worsening. One of the 9 cases could have more than one reasonable explanation, and that is identified with a star (*).

Table 4. Explained Worsened Cases

Intersections	Approach	AM Peak		Noon Peak		PM Peak	
		Vol 2	Vol 3	Vol 2	Vol 3	Vol 2	Vol 3
Stadium	NBT	Unch	Det	Imp	Det	Imp	Det
	SBT	Imp	Det	Imp	Unch	Imp	Det
	EBT	Imp	Det	Imp	Det	Det	Det
	WBT	Imp	NA	Unch	Det	Det	Det
Kirby	NBT	Imp	Det	Imp	Imp	Imp	Imp
	SBT	Unch	Det	Unch	Unch	Det	Det
	EBT	Det	Det	Imp	Det	Unch	Unch
	WBT	Imp	Det	Imp	Det*	Imp	Det
St. Mary’s	NBT	Det	Unch	Det	Det	Unch	Unch
	SBT	Imp	Unch	Det	Det	Det	Unch
	EBT	Imp	Unch	Unch	Unch	Unch	Unch
	WBT	Unch	Det	Det	Det	Unch	Det
Devonshire	NBT	Det	Det	Det	Det	Det	Det
	SBT	Unch	Unch	Det	Det	Det	Det
	EBL	Unch	Unch	Imp	Unch	Imp	Imp
Windsor	NBT	Det	Det	Imp	Det	Imp	Unch
	SBT	Det	Det	Unch	Unch	Det	Det
	EBT	Det	Det	Imp	Unch	Imp	Det
	WBT	Unch	Unch	Imp	Unch	Unch	Det

CHAPTER 4: TRAVEL TIME AND SPEED

4.1 TRAVEL-TIME DATA COLLECTION

Travel-time data were collected under good weather conditions using the floating-car method. A GPS unit (mobile phone) was used to record the trajectory data for the test vehicle using GPS Tracks for iPhone and GeoTracker for Android phones. These recorded files were later processed to obtain travel time for each link and for the corridor. GPS Track Editor was the computer software used to process the .gpx files recorded in the field. The data were collected on six days in 2014, five days in 2015 (feedback data), six days in 2016, and six days in 2017. In 2017, data collected in March was for the traffic-signal operation with time-base coordination (TBC) plans; but the April data was when the ASCT system controlled the traffic-signal operation. Round trips along the Neil Street corridor were made by a floating car to estimate average travel time on the corridor. A run was defined as the travel time of going from one end of the corridor to the other end in the same direction. In one run, the floating car traversed five links. A link is the distance from the middle of one intersection to the middle of the adjacent downstream intersection. A link travel time was determined as the time it took for the floating car to travel from the middle of an upstream intersection to the middle of the downstream intersection. Thus, it includes travel time on the link and the downstream intersection. Table 5 presents the days and the total number of runs on those days. The research team collected data on three days in May and two days in July 2015 to provide the corridor travel-time feedback to the vendor. The vendor used the feedback data to improve the system performance. Therefore, the feedback data were excluded from the analysis in this report.

Table 5. Data-Collection Days and Total Number of Runs

Year	Day of Data Collection	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Oct. 28, 29; Nov. 18, 19; Dec. 3, 4	24	24	16	16	17	16	17	15
2016 (ASCT)	March 16, 30, 31; April 7, 12, 13	19	19	17	18	17	18	20	21
2017 (TBC)	March 9, 15, 16	8	8	-	-	9	9	12	12
2017 (ASCT)	April 12, 18, 19	8	8	-	-	7	7	11	11
2015 (Feedback)	May 5–7; July 14, 15	20	20	18	18	19	19	20	20

4.2 TRAVEL-TIME CALCULATION

The GPS unit in the floating car recorded the latitude, longitude, elevation, and vehicle speed at one-second increments. These data were processed, and travel-time data for each link (segment) and the entire corridor (five links and six intersections) were obtained. The travel time was determined so it would include the link travel time plus the delay experienced at the intersection at the end of that link. In Appendix A, the specifics of how travel times were recorded and processed are presented. Additionally, Appendix A presents the travel-time data utilized in the analysis in the following sections.

4.2.1 Data analysis and comparisons

Three main comparisons were made between the travel time of 2014 (TBC) versus 2016 (ASCT) data, travel time between the 2017 (TBC) versus 2017 (ASCT) data, and the speed of the 2017 (TBC) versus 2017 (ASCT) data. To determine whether the mean travel times were statistically different, *t*-tests were performed. Please recall that the ASCT system was operating until November of 2016. After the vendor's second round of improvements, it was turned on again at the beginning of April 2017. However, ASCT operation lasted about a month; and IDOT shut it down permanently on May 5, 2017. The following sections present the travel-time comparisons for runs at the 90% confidence level. The green-highlighted cells indicate reduction in travel time, and the red-highlighted cells indicate increase in travel time. The white cells indicate that the changes were not significant at the 90% confidence level.

4.2.2 Travel-time comparison between 2016 ASCT and 2014 TBC

The average travel time for each segment, as well as for all five segments combined (corridor level), was compared for the 2014 (TBC) and 2016 (ASCT) conditions. Table 6 presents the difference in average travel times. A negative (positive) value indicates the travel time decreased (increased) under 2016 ASCT compared to 2014 TBC. To determine if the increases or decreases were significant, *t*-tests with 90% confidence level were conducted. In some conditions, the variation in travel time from run to run was very small. Consequently, the standard deviation of travel time was very small. For these cases, a small difference in the average travel time became statistically significant. Regarding the individual segments, there were ten cases in which the segment travel times significantly decreased in ASCT 2016. Six of these were in AM or PM in the opposite of the preferred directions. (The preferred directions were NB in AM and SB in PM.) In the other four cases, they were in NP (noon-peak) or OP (off-peak) periods when there was no preferred direction. In contrast, there were ten cases in which the link travel times were significantly increased in ASCT 2016. Four of the increases were in the preferred directions (not a desirable outcome), two in the opposite to the preferred direction, and four in the OP and NP periods.

Changes in the corridor travel time are more indicative of the system performance than the segment travel times. Corridor travel time indicates the total time it would take to travel from one end to the corridor to the other (total travel time on all five segments combined). The corridor travel time (last row in the table) shows that the travel time increased in three cases and decreased in one.

Table 6. Comparing Average Travel Times of 2016 ASCT vs 2014 TBC (sec)

Segment between	AM		OP		NP		PM	
	SB	NB	SB	NB	SB	NB	SB	NB
Stadium and Kirby	-11.0	3.3	-9.8	-6.4	5.5	-3.2	17.6	-4.4
Kirby and St. Mary’s	-13.9	19.9	7.7	-19.1	3.6	-4.0	14.7	-11.8
St. Mary’s and Devonshire	-2.1	6.7	2.6	8.0	3.3	7.7	5.8	13.7
Devonshire and Knollwood	-1.0	0.4	0.6	0.9	-0.5	-3.2	2.3	-3.1
Knollwood and Windsor	21.3	1.5	3.4	0.0	7.4	0.4	7.9	1.2
Corridor (all 5 segments)	-6.8	31.8	4.5	-16.7	19.3	-2.3	48.3	-4.4

It is worth noting that the two largest statistically significant increases in the average corridor travel time occurred in the northbound (NB) direction during the AM-peak hour and the southbound (SB) direction during the PM-peak hour. These two directions had the heaviest traffic volumes because the morning rush-hour traffic goes NB toward the central business district (CBD), and the evening SB rush-hour traffic goes away from it. These decreases could be an indication of deterioration in the system performance in the heavy-volume directions. In addition, the travel time increased by 19.3 seconds on the SB direction during the noon-peak hour.

In contrast, the system performed better, on average by 16.7 seconds decrease in travel time, for NB traffic during off-peak hour.

4.2.3 Travel-time comparison between 2017 ASCT and 2017 TBC

Table 7 shows the comparison results for March 2017 versus April 2017. In the 2017 runs, no runs were made during the off-peak period, mainly due to lower traffic volumes. Here, the results are less likely to be statistically significant due to the lower number of data points; but the overall trend can still be captured. At the segment level, travel time increased in seven cases in April when the ASCT was operating, as compared to TBC 2017; and it decreased in four cases. Unfortunately, four out of the seven increases occurred in the preferred directions.

At the corridor level, the NB AM-peak and SB PM-peak traffic experienced a statistically significant increase in travel time, which is an undesirable outcome. The NB AM-peak-hour traffic experienced a 45.0-second increase, and the SB PM-peak-hour traffic experienced a 51.8-second increase. The SB AM and SB NP periods also showed significant increase in travel time, with 41.8 seconds and 34.7 seconds, respectively. In this comparison, no significant corridor level travel-time reduction occurred.

Table 7. Comparing Travel Times from 2017 ASCT vs 2017 TBC (sec)

Segment between	AM		NP		PM	
	SB	NB	SB	NB	SB	NB
Stadium and Kirby	18.8	3.0	-3.5	2.7	5.5	8.4
Kirby and St. Mary's	3.1	21.9	14.0	-18.5	7.3	-18.1
St. Mary's and Devonshire	-0.1	20.3	7.4	19.7	8.3	2.9
Devonshire and Knollwood	1.5	0.1	2.3	-3.9	8.6	-2.5
Knollwood and Windsor	18.5	-0.3	14.5	-0.5	22.1	-1.3
Corridor (all 5 segments)	41.8	45.0	34.7	-0.5	51.8	-10.8

When analyzed closely, the major contributors to the increase in corridor travel time on the SB AM peak were the segment between Stadium Drive and Kirby Avenue and the one between Knollwood Drive and Windsor Road. The runs showed that, under ASCT 2017, vehicles stopped consistently on that approach due to either a queue or a red light, which translated into increased travel time. The increase in travel time is in contrast with the performance of the SB AM-peak traffic in the 2016-to-2014 comparison, in which four out of the five segments resulted in a significant decrease in travel time. For all other directions, the behavior was very similar, in which the system caused an increase in travel time on the preferred heavy-volume directions and a decrease in travel time on the opposite lighter-volume directions. The SB AM-peak traffic was the only direction that showed the opposite trend in both comparisons.

Comparing the increase in corridor travel time for the SB PM peak under the 2016-to-2014 comparison to the increase in corridor travel time under the 2017-to-2017 comparison, it reveals that the increases are not coming from the same links. Although the travel-time increase was of similar magnitude in both cases, the distribution was different among the segments. In the 2014-to-2016 comparison, the majority of the travel-time increase was coming from the northernmost segments (between Stadium Drive and Kirby Avenue, and Kirby Avenue and St. Mary's Road). However, in the 2017-to-2017 comparison, the majority of the delay was coming from the southernmost segments (Devonshire Drive and Knollwood Drive, and Knollwood Drive and Windsor Road).

Another interesting result is the NP behavior in both comparisons. In the NP hour, there is no preferred direction of travel, as there is no clearly heavier-volume direction. Despite this fact, the system favored the NB direction over the SB. In both comparisons (2014-to-2016 and 2017-to-2017), the SB direction experienced a statistically significant increase (19.3 seconds and 34.7 seconds, respectively), while the NB direction experienced a small decrease or no change in travel time.

4.3 SPEED IN MIDDLE OF THE LINK VERSUS "DELAY SPEED"

To quantify the effects of the ASCT system on the travel speed of the link and corridor, one has to be careful not to use the travel times discussed in the previous sections. If the speeds were to be calculated from these travel times, then the time in which the vehicles were stopped at the intersection due to a red light or queue is also taken into account ("delay speed"). This "delay speed" fluctuates greatly and does not correctly capture the effects of the ASCT system in the after period compared to the TBC. For this reason, each segment was divided into three parts, and the speed was recorded in only the middle-third of each segment (i.e., actual traveling speed). The segmentation was done to correctly capture the speed of the vehicle when it was actually moving and to minimize the effects of the stoppages.

To portray why this distinction is important, the following illustrative example is presented. Let us consider both average travel times between St. Mary's Road and Devonshire Drive in the NB AM-peak direction for March and April 2017. In March 2017 (TBC) the average travel time was 28.6 seconds, while the average travel time in April 2017 (ASCT) was 48.9 seconds. If we compute speeds based on these travel times and the length of the segment (1,848 ft), their respective speeds would be the following:

$$\text{Delay Speed } in\ March\ 2017\ (TBC) = \frac{1{,}848\ ft}{28.6\ sec} = 64.6\frac{ft}{sec} = 44.0\ mph$$

$$\text{Delay Speed } in\ April\ 2017\ (ASCT) = \frac{1{,}848\ ft}{48.9\ sec} = 37.8\frac{ft}{sec} = 25.8\ mph$$

$$Difference\ in\ \text{Delay Speeds} = 25.8\ mph - 44.0\ mph = -18.2\ mph$$

If the travel times were used for speed calculations (i.e., "delay speeds"), the average speed difference in the segment between St. Mary's Road and Devonshire Drive in 2017 would have been –18.2 mph. Although this reduction seems very considerable, in reality the speed difference when comparing the middle-third speeds among these two periods is only –0.6 mph (as shown in Table 8); indicating that utilizing "delay speeds" instead of actual speeds could provide misleading information by greatly overestimating the speed difference in the before and after periods. For this reason, the following section presents only the speed comparisons based on the middle-third speeds.

4.4 SPEED COMPARISON

The average speed for each link and the average speed of the corridor under 2017 ASCT are compared to the corresponding values under 2017 TBC. As mentioned in the previous section, only the speeds in the middle-third of each link were compared to eliminate the potential bias due to acceleration or deceleration of vehicles and the influence of queued vehicle at intersections. The average speed for the corridor is computed as the simple average of the middle-third speeds of the five links. Appendix B presents the speed data per segment utilized in this analysis.

Table 8 presents the comparison between the average link speeds between March and April 2017 based on the middle-third segment speeds. Then, the last row presents the average change in the entire corridor. Unlike the travel times, the corridor average speed was computed by taking the average middle-third speeds of the five segments per run. Similar to the previous comparisons, colors are used to indicate average change at the 90% confidence level, with red for speed increase and green for speed decrease.

Table 8. Comparing Speeds from 2017 ASCT vs 2017 TBC (mph)

Segment between	AM		NP		PM	
	SB	NB	SB	NB	SB	NB
Stadium and Kirby	-2.2	2.0	2.6	2.1	-4.7	1.3
Kirby and St. Mary's	-0.5	0.9	-2.3	3.1	-6.7	3.3
St. Mary's and Devonshire	0.5	-0.6	0.9	-1.5	-2.3	1.9
Devonshire and Knollwood	0.0	-0.2	-0.5	3.2	-6.1	4.6
Knollwood and Windsor	-6.8	0.9	-2.7	-4.1	-10.8	3.4
Average change (all 5 segments)	-1.8	0.6	-0.4	0.6	-6.1	2.9

From Table 8, it can be seen that, contrary to the travel times, the speed in the NB AM peak remained practically unchanged; indicating that the travel-time increases were primarily due to an increased delay in the ASCT, as compared to the TBC. On the contrary, the travel-time reduction in the SB PM peak was not primarily due to increased delay but to speed reduction. Table 8 shows that the entire corridor experienced an average of 6.1-mph speed reduction. Similarly, the PM NB direction also agrees with the travel-time trends, meaning that the reduction in travel time was due to an increase in speed along the NB PM peak. For all other peak directions, the fluctuations in travel times could be due to an increase in delay. The recorded travel speeds were very similar, and no clear increasing or decreasing trend was observed.

It is important to quantify speed change because speed is a factor in safety analysis. Given that the SB PM-peak direction is one of the heavier directions of travel, the speed reduction along this peak hour could be one of the safety benefits from implementing ASCT. The safety report for this project *(4)* showed a decreasing trend in the fatal and injury crashes. Additionally, lower speeds have been shown to be strongly related to lower fatal and injury crashes *(8).* Therefore, one of the potential contributors for the crash reduction in this project could be speed reduction in the peak hour, when volumes are expected to be high. However, crash data did not show a noticeably different reduction in frequency or severity of the crashes in the SB Neil Street.

CHAPTER 5: SYSTEM RESPONSE TO HEAVY TRAFFIC VOLUME ON MINOR STREET

Further investigations were conducted to determine how the second round of major fine-tuning of the SynchroGreen software handled the demand from the minor street. The intersection that needed the most operational improvements was Kirby Avenue and Neil Street. Kirby Avenue is labeled as the minor street to indicate that the signal coordination was not along it but on the crossing street (Neil Street). The WB traffic volume during part of the PM-peak hour is heavy as people leave the U of I campus to go home to the west side of Champaign. The WB direction needs more green time during the PM peak, and the vendor was told about it right from the beginning of the project. Operation of traffic WB had to be synchronized with the traffic-signal operation at Kirby Avenue and State Street. This synchronization was required in the contract and was known to be a challenging issue. One of the vendor's engineers spent about 5 days on the site, and a senior engineer also was there for 2 days to get the ASCT system to provide the best performance possible. They spent some of that time at the Kirby Avenue and Neil Street intersection. So the vendor had 4 months (December 2016 to March 2017) to improve the system operation. The SynchroGreen system was turned on the beginning of April 2017 after the second fine-tuning was completed by the vendor.

5.1 DATA COLLECTION

After the vendor fine-tuned the system and improved its operation the second time, field data on the number of vehicles in queue on the WB approach of Kirby Avenue were collected. Field data were collected on WB Kirby Avenue at Neil Street on three weekdays. The number of vehicles in queue was observed in the field—for 75 minutes on April 10, 2017; 66 minutes on April 11; and 25 minutes on April 12—during PM-peak-hour demand conditions. We also video recorded traffic operation during the PM peak on April 11 and 12 to have actual images of operation of the signal. In addition, we obtained the signal-timing data from the archived files in the system.

5.2 SYSTEM RESPONSE TO QUEUE AND GREEN-TIME ALLOCATION

During the field observation, it was noticed that the system did not respond to the queue on the minor street. Each day, there were multiple cycles when the WB queue could not clear during the green time (cycle failure) the system had allocated to the minor street. Before looking at detailed analysis for performance of ASCT system, cycle failure for time-based coordination (TBC) was determined. Field-observation of cycle failures for TBC are shown in Table 9 and 10, representing February 15 and March 1, 2017, respectively. Orange-highlighted rows indicate observed cycle failures. About one-half (48 – 52 %) of the cycles failed to process all queued vehicles on WB Kirby Avenue.

Table 9. Observed TBC Cycle Failures during PM Peak on February 15, 2017

Beginning of Cycle	Cycle Length (Seconds)	WBT Green Time (Seconds)	Field Observation	
			No. of Veh in Queue on WBT at the Beginning of Green	No. of Veh in Queue on WBT at the End of Green
4:46:00 PM	120	35.1	8+	0
4:48:00 PM	120	35.1	8+	0
4:50:00 PM	120	35.1	8+	0
4:52:00 PM	120	45.1	2	0
4:54:00 PM	120	49.1	7	0
4:56:00 PM	120	35.1	7	0
4:58:00 PM	120	35.1	0	0
5:00:00 PM	120	35.1	8+	0
5:02:00 PM	120	35.1	8+	4
5:04:00 PM	120	49.1	7+	7
5:06:00 PM	120	35.1	8+	7
5:08:00 PM	120	35.1	8+	7
5:10:00 PM	120	35.1	9+	5
5:12:00 PM	120	34.1	8+	7
5:14:00 PM	120	35.1	8+	8
5:16:00 PM	120	35.1	8+	7
5:18:00 PM	120	35.1	8+	5
5:20:00 PM	120	35.1	8+	8
5:22:00 PM	120	35.1	9+	9+
5:24:00 PM	120	35.1	9+	9+
5:26:00 PM	120	35.1	9+	8+
5:28:00 PM	120	35.1	8+	2
5:30:00 PM	120	49.1	7+	0
5:32:00 PM	120	35.1	8+	0
5:34:00 PM	120	35.1	8+	0
5:36:00 PM	120	35.1	7+	0
5:38:00 PM	120	35.1	5	0
5:40:00 PM	120	35.1	7	0
5:42:00 PM	120	38.1	7	0
Number of observed cycle failures with more than 1 vehicle in queue on minor street				**14**
Number of cycle failures with 1 vehicle in queue				**0**
Number of cycles without a failure				**15**

Table 10. Observed TBC Cycle Failures during PM Peak on March 1, 2017

Beginning of Cycle	Cycle Length (Seconds)	WBT Green Time (Seconds)	Field Observation	
			No. of Veh in Queue on WBT at the Beginning of Green	No. of Veh in Queue on WBT at the End of Green
4:44:00 PM	120	35.1	8+	0
4:46:00 PM	120	35.1	8+	0
4:48:00 PM	120	38.1	7+	0
4:50:00 PM	120	35.1	4	0
4:52:00 PM	120	35.1	7	0
4:54:00 PM	120	36.1	4	0
4:56:00 PM	120	35.1	7+	1
4:58:00 PM	120	35.1	8+	8
5:00:00 PM	120	35.1	9+	5
5:02:00 PM	120	35.1	9+	5
5:04:00 PM	120	35.1	8+	6
5:06:00 PM	120	35.1	8+	7
5:08:00 PM	120	35.1	8+	7
5:10:00 PM	120	35.1	8+	6
5:12:00 PM	120	35.1	9+	8
5:14:00 PM	120	35.1	8+	5
5:16:00 PM	120	35.1	8+	5
5:18:00 PM	120	49.1	8+	0
5:20:00 PM	120	35.1	8+	4
5:22:00 PM	120	35.1	8+	0
5:24:00 PM	120	35.1	7+	0
5:26:00 PM	120	35.1	8+	2
5:28:00 PM	120	35.1	9+	1
5:30:00 PM	120	35.1	8+	0
5:32:00 PM	120	35.1	6	0
5:34:00 PM	120	35.1	4	0
5:36:00 PM	120	35.1	8+	3
5:38:00 PM	120	35.1	7+	0
5:40:00 PM	120	35.1	5+	0
Number of observed cycle failures with more than 1 vehicle in queue on minor street				**13**
Number of cycle failures with 1 vehicle in queue				**2**
Number of cycles without a failure				**14**

Field-observation data for ASCT are shown in Tables 11, 12, and 13, representing April 10, 11, and 12, 2017, respectively. Orange-highlighted rows indicate observed cycle failures. About 40 % to 62 % of the cycles failed to process all vehicle in the queue on WB Kirby Avenue. This performance was much worse than one reasonably expects from an adaptive signal system that should respond to traffic demand compared with a TBC system. A similar failure was observed during special-event traffic (to be discussed later in this report).

Table 11. Observed Cycle Failures during PM Peak on April 10, 2017

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Field Observation	
			Number of Vehicles in Queue at Start of Green	Number of Vehicles in Queue at End of Green
4:30:22 PM	115	46.1	10	0
4:32:17 PM	117	34.1	3	0
4:34:14 PM	115	39.1	5	0
4:36:09 PM	130	46.1	10	0
4:38:19 PM	132	47.1	15	0
4:40:31 PM	134	55.1	16	0
4:42:45 PM	134	55.1	14	0
4:44:59 PM	120	46.1	15	0
4:46:59 PM	114	27.1	10	0
4:48:53 PM	115	47.1	8	0
4:50:48 PM	110	24.1	18	3
4:52:38 PM	111	24.1	13	5
4:54:29 PM	117	35.1	17	3
4:56:26 PM	128	43.1	18	0
4:58:34 PM	134	49.1	13	0
5:00:48 PM	119	33.1	13	1
5:02:47 PM	112	44.1	10	0
5:04:39 PM	110	41.1	14	0
5:06:29 PM	119	34.1	15	1
5:08:28 PM	128	43.1	21	1
5:10:36 PM	126	41.1	21	1
5:12:42 PM	125	39.1	20	1
5:14:47 PM	135	47.1	25	4
5:17:02 PM	120	33.1	25	10
5:19:02 PM	135	53.1	26	8
5:21:17 PM	124	40.1	26	10
5:23:21 PM	135	49.1	22	0
5:25:36 PM	135	53.1	18	0
5:27:51 PM	134	49.1	13	0
5:30:05 PM	134	61.1	5	0
Number of observed cycle failures with more than 1 vehicle in queue on minor street				**7**
Number of cycle failures with 1 vehicle in queue				**5**
Number of cycles without a failure				**18**

Table 12. Observed Cycle Failures during PM Peak on April 11, 2017

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Field Observation: Number of Vehicles in Queue at Start of Green	Field Observation: Number of Vehicles in Queue at End of Green
4:31:18 PM	112	33.1	7	0
4:33:10 PM	108	33.1	15	0
4:34:58 PM	114	33.1	16	4
4:36:52 PM	117	32.1	19	5
4:38:49 PM	119	34.1	24	13
4:40:48 PM	117	48.1	25	8
4:42:45 PM	121	36.1	22	2
4:44:46 PM	132	47.1	24	0
4:46:58 PM	117	30.1	11	0
4:48:55 PM	110	26.1	16	5
4:50:45 PM	118	34.1	21	5
4:52:43 PM	119	38.1	17	1
4:54:42 PM	126	41.1	22	2
4:56:48 PM	126	41.1	15	0
4:58:54 PM	119	45.1	19	4
5:00:53 PM	117	34.1	23	3
5:02:50 PM	115	34.1	25	8
5:04:45 PM	117	32.1	22	6
5:06:42 PM	112	43.1	21	0
5:08:34 PM	127	42.1	18	0
5:10:41 PM	126	41.1	17	1
5:12:47 PM	135	57.1	12	0
5:15:02 PM	120	36.1	25	5
5:17:02 PM	122	25.1	24	10
5:19:04 PM	125	36.1	28	14
5:21:09 PM	122	43.1	28	12
5:23:11 PM	128	33.1	35	15
5:25:19 PM	128	39.1	32	17
5:27:27 PM	135	45.1	26	7
5:29:42 PM	135	49.1	18	0
5:31:57 PM	126	39.1	12	0
5:34:03 PM	116	36.1	10	0
5:35:59 PM	116	33.1	6	0
5:37:55 PM	117	32.1	5	0
Number of observed cycle failures with more than 1 vehicle in queue on minor street				**19**
Number of cycle failures with 1 vehicle in queue				**2**
Number of cycles without a failure				**13**

Table 13. Observed Cycle Failures during PM Peak on April 12, 2017

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Field Observation	
			Number of Vehicles in Queue at Start of Green	Number of Vehicles in Queue at End of Green
4:35:09 PM	112	33.1	10	4
4:37:01 PM	115	33.1	18	6
4:38:56 PM	119	38.1	13	1
4:40:55 PM	110	42.1	15	0
4:42:45 PM	125	40.1	11	0
4:44:50 PM	131	30.1	15	4
4:47:01 PM	118	33.1	15	5
4:48:59 PM	114	29.1	14	4
4:50:53 PM	111	24.1	13	5
4:52:44 PM	110	24.1	11	0
4:54:34 PM	110	24.1	10	0
4:56:24 PM	110	24.1	8	0
4:58:14 PM	112	37.1	6	0
5:00:06 PM	126	41.1	8	0
Number of observed cycle failures with more than 1 vehicle in queue on minor street				**6**
Number of cycle failures with 1 vehicle in queue				**1**
Number of cycles without a failure				**7**

We further analyzed how the system performed during heavy-volume conditions, by reducing the data from our recorded videos in the field. We watched the videos recorded, to determine if there were unused green times on the major-street direction; and their duration. Basically, unused green time was the time duration with no demand on NB or SB directions (major street). We also determined how many vehicles were in queue on the WB Kirby approach that could not clear by the end of each green time because the green time ended while they were still waiting in queue. This data reduction was needed to assess the system's ability (or inability) to respond to heavy demand from the minor street while providing excess green time to the major street. Table 14 shows data reduced for Tuesday, April 11. There were cycle failures on the minor street, while there were unused green times on the major street. This was happening while there was space for additional vehicles on receiving lanes of WB Kirby. Orange-highlighted rows indicate 20 cycle failures. Out of the 20 cycles, there were 14 cycles (red-highlighted cells) when the system could allocate more green time to the minor street by reallocating the unused green time on the major street. However, the system failed to allocate enough green time to process vehicles on the minor street although there was unused green on the competing major-street directions (NBT and SBT). Blue-highlighted cells show the condition of unused green on NBT and SBT, but the receiving link was full and could not receive more vehicles. Pink highlighted cells show when green time was not available from competing direction

(NBT/SBT). One might argue that when the receiving link of WBT is full, there is no benefit to allocate more green time to WBT; and we agree with this argument. However, this argument is not valid when the receiving link is not full. Allocating the unused green time in SBT/NBT to WBT would allow processing of a few more cars from the queue, which could accelerate recovery to the normal state of traffic.

Table 14. Detailed Analysis for Cycle Failure on WBT with Unused Green Time on Competing Directions (NBT and SBT) on April 11, 2017

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Field Observation		Video Observation	
			Number of Vehicles in Queue on WBT at Start of Green	Number of Vehicles in Queue on WBT at End of Green	Receiving Link	Unused Green Time on NBT/SBT (seconds)
4:25:48 PM	110	24.1	6	0	Not recorded	
4:27:38 PM	110	41.1	13	0		
4:29:28 PM	110	33.1	12	0	EMPTY	7
4:31:18 PM	112	33.1	7	0	EMPTY	0–5
4:33:10 PM	108	33.1	15	0	EMPTY	14
4:34:58 PM	114	33.1	16	4	EMPTY	7–8
4:36:52 PM	117	32.1	19	5	EMPTY	11
4:38:49 PM	119	34.1	24	13	EMPTY	0
4:40:48 PM	117	48.1	25	8	EMPTY	12–15
4:42:45 PM	121	36.1	22	2	EMPTY	16
4:44:46 PM	132	47.1	24	0	EMPTY	0
4:46:58 PM	117	30.1	11	0	EMPTY	0
4:48:55 PM	110	26.1	16	5	EMPTY	10–13
4:50:45 PM	118	34.1	21	5	EMPTY	13–15
4:52:43 PM	119	38.1	17	1	EMPTY	0
4:54:42 PM	126	41.1	22	2	EMPTY	0
4:56:48 PM	126	41.1	15	0	HALF FULL	0–4
4:58:54 PM	119	45.1	19	4	HALF FULL	7–8
5:00:53 PM	117	34.1	23	3	EMPTY	8
5:02:50 PM	115	34.1	25	8	EMPTY	11
5:04:45 PM	117	32.1	22	6	EMPTY	0
5:06:42 PM	112	43.1	21	0	EMPTY	8–10
5:08:34 PM	127	42.1	18	0	EMPTY	0
5:10:41 PM	126	41.1	17	1	HALF FULL	0
5:12:47 PM	135	57.1	12	0	HALF FULL	0
5:15:02 PM	120	36.1	25	5	EMPTY	5
5:17:02 PM	122	25.1	24	10	EMPTY	10
5:19:04 PM	125	36.1	28	14	EMPTY	3–5
5:21:09 PM	122	43.1	28	12	EMPTY	15–18

5:23:11 PM	128	33.1	35	15	EMPTY	0
5:25:19 PM	128	39.1	32	17	FULL	5–8
5:27:27 PM	135	45.1	26	7	HALF FULL	9
5:29:42 PM	135	49.1	18	0	EMPTY	18–20
5:31:57 PM	126	39.1	12	0	EMPTY	5–7
5:34:03 PM	116	36.1	10	0	EMPTY	10
5:35:59 PM	116	33.1	6	0	EMPTY	0
5:37:55 PM	117	32.1	5	0	EMPTY	0

Similarly, Table 15 shows data reduced for Tuesday, April 12, 2017. Field observation was limited to 25 minutes, so only those times were analyzed. Unfortunately, the video recording was poor on that day with 12–13 minutes' stoppage in the video. In that limited time period of six cycles, there were two cycles when the competing direction had unused green time, while there was room for demand on the minor street.

Table 15. Detailed Analysis of Cycle Failure on WBT with Unused Green Time on Competing Directions (NBT and SBT) on April 12, 2017

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Field Observation		Video Observation	
			Number of Vehicles in Queue on WBT at Start of Green	Number of Vehicles in Queue on WBT at End of Green	WBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
4:35:09 PM	112	33.1	10	4	Not recorded	
4:37:01 PM	115	33.1	18	6		
4:38:56 PM	119	38.1	13	1		
4:40:55 PM	110	42.1	15	0		
4:42:45 PM	125	40.1	11	0		
4:44:50 PM	131	30.1	15	4		
4:47:01 PM	118	33.1	15	5		
4:48:59 PM	114	29.1	14	4		
4:50:53 PM	111	24.1	13	5	EMPTY	0
4:52:44 PM	110	24.1	11	0	EMPTY	6–8
4:54:34 PM	110	24.1	10	0	EMPTY	6
4:56:24 PM	110	24.1	8	0	HALF FULL	0
4:58:14 PM	112	37.1	6	0	HALF FULL	0
5:00:06 PM	126	41.1	8	0	HALF FULL	0

The above analyses indicated that the the ASCT system was not able to respond to the heavy-traffic demand during the PM peak on the minor street and did not reallocate unused green time available on the major-street direction. This inability of the ASCT system was not expected.

CHAPTER 6: SYSTEM RESPONSE TO SPECIAL-EVENT TRAFFIC

Traffic volumes may change when there is an special event on the UI campus. Usually, a spike in traffic volume for the inbound direction before the event and a spike in volume for the outbound direction after the event are expected. These high-demand traffic volumes can create some congestion. It is important for the ASCT system to handle spikes in demand in a timely manner to avoid creating gridlock in the nearby network. To assess the performance of the ASCT system, SynchroGreen, we recorded video footage and observed the system's operation during the Illinois Marathon and concerts by country singer Garth Brooks at UI's State Farm Center.

6.1 DATA COLLECTION

Garth Brooks gave three concerts in two days. Two of the concerts were held on April 29, 2017 (around 3 pm and 7 pm), and one concert on April 30 (around 7 pm).

Pre-marathon activities took place on the evening of the day before the marathon. The research team attempted to collect data during the pre-marathon and the marathon, but the data were not helpful for assessing system performance. During the pre-marathon activities, both traffic pattern and traffic-signal operation were not normal. In particular, the traffic signal at Kirby Avenue and Neil Street was controlled and operated by police officers; so the system was not allowed to function without police interruption. On marathon day, the signal at Stadium Drive was set on flashing mode, and Neil Street was closed to through traffic between Kirby Avenue and Stadium Drive. As a result, the traffic pattern had changed; and the system was not operating in adaptive mode. Therefore, data analysis for marathon day traffic was not performed. In contrast, three sets of data were collected and analyzed for the Garth Brooks concerts.

6.2 SYSTEM-RECORDING ISSUES

The ASCT system had some data-recording issues when the cycle length became greater than 255 seconds. An observed long cycle on the videotapes of the intersection was recorded as two cycles by the system (see examples in Table 16). The Cycle Length column under Video Observation shows how two cycles recorded by the system match with the cycle length observed on the video. Video images were updated every 3–5 seconds, so a difference of 6–10 seconds at most could happen between the times observed on the video and the times recorded by the system. This difference is not important for matching the cycle number in the video to those recorded by the system. In Table 16, exact cycle-matched cases are indicated with "="; approximately matched cases with "≈"; and nonmatching cases with "≠." Fixes to Table 16 are presented in Table 17.

Table 16. Inaccurate Cycle Recording

System Record		Video Observation	
Beginning of Cycle	Cycle Length (seconds)	Beginning of Cycle	Cycle Length (seconds)
5:51:50 PM	255	5:44:46 PM	342 = 255 + 87
5:56:05 PM	87		
5:57:32 PM	255	5:50:23 PM	291 ≈ 255 + 37
6:01:47 PM	37		
6:02:24 PM	255	5:55:14 PM	317 ≈ 255 + 59
6:06:39 PM	59		
6:07:38 PM	255	6:00:31 PM	-
6:11:53 PM	111	-	-
6:13:44 PM	255	No recording	-
6:17:59 PM	5	-	-
6:18:04 PM	255	6:10:57 PM	266 ≈ 255 + 12
6:22:19 PM	12		
6:22:31 PM	255	6:15:23 PM	404 ≈ 255 + 147
6:26:46 PM	147		
6:29:13 PM	255	6:22:07 PM	313 ≈ 255 + 61
6:33:28 PM	61		
6:34:29 PM	255	6:27:20 PM	357 ≠ 255 + 200
6:38:44 PM	200	6:33:17 PM	

Table 17. Fixed System-Cycle Recording

Inaccurate Cycle			Fixed Cycle	
Beginning of Cycle	Cycle Length (seconds)	Green Time	Cycle Length (seconds)	Green Time
17:51:50 PM	255	83.1	342	170.1
17:56:05 PM	87	87	-	-
17:57:32 PM	255	72.1	292	109.1
18:01:47 PM	37	37	-	-
18:02:24 PM	255	113.1	314	172.1
18:06:39 PM	59	59	-	-
18:07:38 PM	255	39.1	366	150.1
18:11:53 PM	111	111	-	-
18:13:44 PM	255	115.1	260	120.1
18:17:59 PM	5	5	-	-
18:18:04 PM	255	141.1	267	153.1
18:22:19 PM	12	12	-	-
18:22:31 PM	255	112.1	402	259.1
18:26:46 PM	147	147	-	-
18:29:13 PM	255	56.1	316	117.1
18:33:28 PM	61	61	-	-
18:34:29 PM	255	57.1	255	57.1
18:38:44 PM	200	93.1	200	93.1

6.3 GREEN TIME ALLOCATION

The Garth Brooks' concerts were held at the UI State Farm Center, so inbound traffic was EBT and outbound traffic WBT at the Kirby Avenue and Neil Street intersection. For the first concert on April 29, 2017, the inbound traffic started around 1:30 pm and lasted nearly until 3:00 pm. During this time, inbound traffic was mostly heavy; but there were some cycles with unused green on the competing directions (NBT and SBT), while there was leftover queue on EBT. These are shown in Table 18 with red- and orange-highlighted cells. Orange-highlighted cells show cycle failures. Red-highlighted cells show when there was space to store more vehicles on the receiving link on EBT. Blue-highlighted cells show when the EBT receiving link was full and could not receive more vehicles. Pink-highlighted cells show when green time was not available from competing direction (NBT/SBT).

Table 18. Inability to Respond to Queue Length on EBT Traffic

Beginning of Cycle	Cycle Length (seconds)	EBT Green Time (seconds)	Video Observation			
			Number of Vehicles in Queue on EBT at Start of Green	Number of Vehicles in Queue on EBT at End of Green	EBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
1:35:46 PM	121	17.1	7+	6+	EMPTY	0
1:37:47 PM	115	33.1	8+	4	EMPTY	3–5
1:39:42 PM	121	21.1	8+	4	EMPTY	20
1:41:43 PM	125	28.1	5+	1	EMPTY	0
1:43:48 PM	125	28.1	7+	5+	HALF FULL	0
1:45:53 PM	128	38.1	5+	7+	HALF FULL	0
1:48:01 PM	122	29.1	8+	2	EMPTY	0
1:50:03 PM	125	25.1	8+	4	EMPTY	5–6
1:52:08 PM	125	24.1	7+	7+	HALF FULL	0
1:54:13 PM	125	28.1	No recording			
1:56:18 PM	125	18.1				
1:58:23 PM	125	17.1				
2:00:28 PM	126	28.1				
2:02:34 PM	124	21.1	8+	5	FULL	0
2:04:38 PM	125	28.1	7+	4	HALF FULL	0
2:06:43 PM	125	28.1	8+	6+	HALF FULL	0
2:08:48 PM	125	28.1	9+	6+	FULL	0
2:10:53 PM	127	28.1	8+	5	HALF FULL	0
2:13:00 PM	123	28.1	7+	7+	FULL	0
2:15:03 PM	115	37.1	7+	6+	HALF FULL	0
2:16:58 PM	127	28.1	7+	6+	FULL	0
2:19:05 PM	112	33.1	7+	8+	FULL	0
2:20:57 PM	114	36.1	8+	5+	FULL	0
2:22:51 PM	117	31.1	7+	8+	FULL	7
2:24:48 PM	107	22.1	8+	9+	FULL	0
2:26:35 PM	117	32.1	9+	7+	FULL	0
2:28:32 PM	110	29.1	7+	8+	FULL	0
2:30:22 PM	125	35.1	8+	8+	FULL	0
2:32:27 PM	114	28.1	8+	7+	FULL	0
2:34:21 PM	110	28.1	7+	5+	FULL	5–10
2:36:11 PM	114	28.1	8+	6+	FULL	5–10
2:38:05 PM	117	28.1	No recording			4–6
2:40:02 PM	116	31.1	7+	6+	HALF FULL	0
2:41:58 PM	233	95.1	7+	1	HALF FULL	30
2:45:51 PM	153	47.1	8+	0	EMPTY	3–6
2:48:24 PM	186	54.1	7+	0	EMPTY	40

The second Garth Brooks concert happened on the evening of April 29, 2017. This event created congestion for both inbound and outbound traffic. Outbound traffic included those leaving the State Farm Center after the first concert. During this busy time, the police arrived around 5:34 pm and took control of the signal. They increased the cycle length by pushing the pedestrian signal, which is shown as yellow-highlighted cells in Table 19. They stayed until 6:40 pm. Once the police left, the system took control of signal operation but failed to adapt to the condition. It allocated more green time to the NBT/SBT direction, which resulted in unused green time for NBT/SBT, as shown in Table 19 by the orange-highlighted cells. One might argue that because the receiving link of the EBT is full, there is no benefit in allocating more green time on EBT. However, if the 5–10 seconds of unused green time in SBT/NBT were allocated to EBT, then a couple more queued vehicles could have been processed in each cycle, which could help recovery to the normal state of traffic. Yellow-highlighted rows indicate when the police were present to control the signal.

Table 19. Inability to Respond to Queue Length on EBT Traffic When Demand Volume on Both EBT and WBT Were Heavy

Beginning of Cycle	Cycle Length (seconds)	EBT Green Time (seconds)	Video Observation			
			Number of Vehicles in Queue on EBT at Start of Green	Number of Vehicles in Queue on EBT at End of Green	EBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
5:29:41 PM	115	28.1	7+	3	HALF FULL	3–5
5:31:36 PM	174	61.1	7+	0	EMPTY	0
5:34:30 PM	184	70.1	2	1	EMPTY	0
5:37:34 PM	209	86.1	7+	0	EMPTY	0
5:41:03 PM	242	99.1	8+	4	EMPTY	0
5:45:05 PM	210	84.1	7+	2	HALF FULL	0
5:48:35 PM	195	55.1	6+	7+	HALF FULL	0
5:51:50 PM	342	170.1	8+	8+	FULL	0
5:57:32 PM	292	109.1	8+	8+	FULL	0
6:02:24 PM	314	172.1	8+	8+	FULL	0
6:07:38 PM	366	150.1	10+	No recording	FULL	0
6:13:44 PM	260	120.1	7+	7+	FULL	0
6:18:04 PM	267	153.1	7+	7+	FULL	0
6:22:31 PM	402	259.1	7+	7+	FULL	0
6:29:13 PM	316	117.1	6+	7+	FULL	0
6:34:29 PM	255	57.1	7+	7+	FULL	0
6:38:44 PM	200	93.1	7+	7+	FULL	0
6:42:04 PM	158	50.1	6+	7+	FULL	0
6:44:43 PM	146	40.1	7+	6+	FULL	0
6:47:09 PM	126	15.1	6+	7+	FULL	0
6:49:15 PM	125	13.1	6+	6+	FULL	5–8
6:51:20 PM	125	14.1	7+	7+	FULL	10
6:53:25 PM	125	13.1	8+	6+	FULL	10
6:55:30 PM	125	14.1	6+	6+	FULL	0

6:57:35 PM	125	13.1	7+	7+	FULL	0
6:59:40 PM	125	20.1	7+	7+	FULL	0
7:01:45 PM	125	16.1	7+	6+	FULL	0
7:03:50 PM	125	23.1	6+	7+	FULL	0
7:05:55 PM	130	28.1	7+	7+	FULL	0
7:08:05 PM	128	28.1	7+	7+	FULL	3
7:10:13 PM	117	20.1	7+	7+	FULL	0
7:12:10 PM	125	16.1	7+	7+	FULL	10–12
7:14:15 PM	125	28.1	6+	7+	FULL	8
7:16:20 PM	126	27.1	7+	7+	FULL	0
7:18:26 PM	124	46.1	7+	8+	FULL	8–9
7:20:30 PM	125	40.1	8+	6+	FULL	0

Similarly, Table 20 shows the traffic condition for WBT when demand was heavy in both directions, EBT and WBT. During this time, police officers were present to operate signals during most of heavy-volume condition. Yellow-highlighted cells indicate when the police were operating the traffic signal.

Table 20. WBT Traffic-Operation Condition When Demand Volume on Both EBT and WBT Were Heavy

Beginning of Cycle	Cycle Length (seconds)	WBT Green Time (seconds)	Video Observation			
			Number of Vehicles in Queue on WBT at Start of Green	Number of Vehicles in Queue on WBT at End of Green	WBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
5:29:41 PM	115	34.1	7+	3	EMPTY	0
5:31:36 PM	174	62.1	7+	0	EMPTY	0
5:34:30 PM	184	70.1	7+	2	EMPTY	3
5:37:34 PM	209	86.1	7+	5	EMPTY	0
5:41:03 PM	242	99.1	6+	6+	EMPTY	0
5:45:05 PM	210	84.1	7+	4	EMPTY	0
5:48:35 PM	195	55.1	8+	5+	EMPTY	0
5:51:50 PM	342	170.1	5+	2	HALF FULL	0
5:57:32 PM	292	109.1	6+	6+	EMPTY	0
6:02:24 PM	314	172.1	6+	4+	FULL	0
6:07:38 PM	366	150.1	7+	No recording	HALF FULL	0
6:13:44 PM	260	120.1	6+	0	EMPTY	0
6:18:04 PM	267	153.1	7+	3	EMPTY	0
6:22:31 PM	402	259.1	7+	2	EMPTY	0
6:29:13 PM	316	117.1	7+	0	HALF FULL	0
6:34:29 PM	255	57.1	5+	2	FULL	0
6:38:44 PM	200	93.1	5+	5	HALF FULL	0

The third Garth Brooks concert was on Sunday, April 30, 2017. During this time, there was room for ASCT to make some improvement on signal operation. There was unused green time on NBT/SBT, which could have been allocated to EBT to process more vehicles when the receiving link of EBT was half-full. If the system had allocated more green time to EBT, it would have mitigated the congestion to some degree. In Table 21, orange-highlighted cells show cycle failures. Red-highlighted cells show when there was some space for more vehicles on the EBT receiving link. Blue-highlighted cells show the possibility for a small improvement by allocating unused green time on EBT rather than the major street (NBT and SBT). A combination of these two adjustments could have reduced congestion due to the concert on Sunday evening. Additionally, pink-highlighted cells show when green time was not available on the major street.

Table 21. Inability to Respond to Queue Length of EBT Traffic When Demand Volume Was Heavy

Beginning of Cycle	Cycle Length (seconds)	Green Time (seconds)	Video Observation			
			Number of Vehicles in Queue on EBT at Start of Green	Number of Vehicles in Queue on EBT at End of Green	EBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
5:52:56 PM	125	28.1	6+	2	EMPTY	0
5:55:01 PM	125	29.1	7+	3	HALF FULL	15
5:57:06 PM	120	19.1	7+	5+	HALF FULL	20
5:59:06 PM	125	25.1	6+	7+	HALF FULL	8
6:01:11 PM	125	29.1	9+	7+	HALF FULL	18
6:03:16 PM	119	28.1	8+	4+	HALF FULL	8
6:05:15 PM	121	26.1	7+	7+	FULL	7
6:07:16 PM	125	40.1	9+	6+	FULL	12
6:09:21 PM	125	28.1	7+	7+	FULL	0
6:11:26 PM	125	36.1	8+	5+	FULL	10
6:13:31 PM	125	28.1	6+	5+	FULL	3
6:15:36 PM	125	29.1	7+	6+	FULL	8
6:17:41 PM	125	37.1	7+	7+	FULL	10
6:19:46 PM	120	19.1	8+	6+	FULL	15
6:21:46 PM	125	28.1	7+	8+	FULL	0
6:23:51 PM	122	30.1	8+	6+	HALF FULL	20
6:25:53 PM	114	29.1	8+	6+	FULL	0
6:27:47 PM	125	31.1	6+	5+	FULL	0
6:29:52 PM	125	28.1	7+	8+	FULL	5–7
6:31:57 PM	125	29.1	8+	8+	FULL	12–14
6:34:02 PM	125	28.1	8+	7+	HALF FULL	16
6:36:07 PM	120	43.1	9+	7+	FULL	28
6:38:07 PM	119	27.1	8+	5+	FULL	0
6:40:06 PM	110	34.1	7+	6+	FULL	15
6:41:56 PM	117	23.1	8+	4	FULL	0
6:43:53 PM	125	25.1	7+	7+	FULL	0

6:45:58 PM	125	28.1	8+	7+	FULL	0
6:48:03 PM	125	29.1	7+	5	FULL	10
6:50:08 PM	125	28.1	8+	6	FULL	12
6:52:13 PM	127	30.1	6+	7+	FULL	0
6:54:20 PM	112	34.1	7+	7+	FULL	12
6:56:12 PM	125	28.1	8+	7+	FULL	5
6:58:17 PM	110	28.1	7+	6+	FULL	17
7:00:07 PM	119	28.1	8+	6+	HALF FULL	0
7:02:06 PM	120	28.1	7+	6	FULL	0
7:04:06 PM	119	30.1	6+	7	FULL	0
7:06:05 PM	238	73.1	No recording			0
7:10:03 PM	120	32.1	7+	4	HALF FULL	13
7:12:03 PM	112	28.1	6+	2	EMPTY	8
7:13:55 PM	117	21.1	6	0	EMPTY	12
7:15:52 PM	110	16.1	4	0	EMPTY	15

The outbound traffic condition on Sunday, April 30, 2017, can be divided into two categories. In the first condition, NBT/SBT has a small volume, so volume on both lanes (median lane and shoulder lane) on NBT and SBT are reported, as shown in Table 22. Orange cells indicate cycle failure on WBT. Red cells indicate that the ASCT system could have allocated more green time to WBT, where heavy inbound traffic existed on WBT due to the end of the concert.

Table 22. Inability to Respond to Queue Length on WBT When Demand Volume on NBT and SBT Was Light

Beginning of Cycle	Cycle Length (seconds)	Green Time (Seconds)			Video Observed				
		WBT	SBT	NBT	No. of SBT (two lanes) Departing Vehicles During Green	No. of NBT (two lanes) Departing Vehicles During Green	No. of Vehicles in Queue on WBT at Start of Green	No. of Vehicles in Queue on WBT at End of Green	WBT Receiving Link
10:30:23 PM	83	17.1	32	43	1	1	5	0	EMPTY
10:31:46 PM	56	29.1	15	15	1	0	0	0	EMPTY
10:32:42 PM	65	23.1	18	30	5	3	0	0	EMPTY
10:33:47 PM	75	45.1	18	18	3	3	0	0	EMPTY
10:35:02 PM	56	28.1	16	16	9	3	3	No recording	EMPTY
10:35:58 PM	46	14.1	20	20	2	4	0	1	EMPTY
10:36:44 PM	56	28.1	16	16	2	1	4	1	EMPTY
10:37:40 PM	90	29.1	32	33	2	1	3	0	EMPTY
10:39:10 PM	66	14.1	27	15	4	3	4	0	EMPTY
10:40:16 PM	69	28.1	17	29	4	5	0	0	EMPTY
10:41:25 PM	96	40.1	32	44	5	6	3	0	EMPTY
10:43:01 PM	98	28.1	30	30	1	8	3	0	EMPTY
10:44:39 PM	87	30.1	17	17	4	3	6	0	EMPTY
10:46:06 PM	89	14.1	32	34	5	4	5	1	EMPTY
10:47:35 PM	88	33.1	22	15	3	0	5	0	EMPTY
10:49:03 PM	84	45.1	15	27	2	0	6	1	EMPTY
10:50:27 PM	67	14.1	28	15	2	4	1	0	EMPTY
10:51:34 PM	84	32.1	29	29	4	6	7+	0	EMPTY
10:52:58 PM	52	14.1	26	15	5	3	1	3	EMPTY
10:53:50 PM	65	24.1	18	29	5	2	3	0	EMPTY
10:54:55 PM	56	14.1	16	30	5	3	4	0	EMPTY
10:55:51 PM	66	28.1	15	26	2	2	5	3	EMPTY
10:56:57 PM	73	29.1	15	32	2	7	8+	6	EMPTY
10:58:10 PM	65	32.1	21	21	3	9	7+	2	EMPTY

The second condition was a continuation of time-period analysis when the demand volume on NBT and SBT increased, so we analyzed to find unused green time on the competing WBT direction. Color coding here is similar to when inbound traffic was heavy during 5:50 pm to 7:15 pm, as shown in shown in Table 23. Orange-highlighted cells indicate cycle failure. Red-highlighted cells indicate possibility for significant improvements, and blue-highlighted cells show room for small improvements. Pink-highlighted cells indicate when there is no available green time on the major street (NBT and SBT).

Table 23. Inability to Respond to Queue Length on WBT Traffic When Demand Volume Was Heavy, with Increasing Demand on NBT and SBT

Beginning of Cycle	Cycle Length (seconds)	Green Time (seconds)	Video Observation			
			Number of Vehicles in Queue on WBT at Start of Green	Number of Vehicles in Queue on WBT at End of Green	WBT Receiving Link	Unused Green Time on NBT/SBT (seconds)
10:59:15 PM	63	24.1	8+	6+	EMPTY	5-8
11:00:18 PM	103	32.1	7+	6+	HALF FULL	16
11:02:01 PM	105	43.1	8+	7+	FULL	0
11:03:46 PM	96	33.1	8+	6+	FULL	0
11:05:22 PM	106	45.1	7+	7+	FULL	10
11:07:08 PM	106	34.1	8+	5+	FULL	3
11:08:54 PM	107	35.1	6+	6+	HALF FULL	5
11:10:41 PM	106	45.1	7+	4+	HALF FULL	0
11:12:27 PM	106	45.1	6+	6+	HALF FULL	0
11:14:13 PM	94	33.1	9+	6+	EMPTY	12
11:15:47 PM	86	41.1	7+	6+	EMPTY	0
11:17:13 PM	81	39.1	8+	3	FULL	0
11:18:34 PM	106	45.1	7+	6+	FULL	5
11:20:20 PM	78	14.1	7+	5+	EMPTY	10
11:21:38 PM	232	130.1	6+	5+	FULL	6
11:25:30 PM	176	91.1	9+	6+	EMPTY	0
11:28:26 PM	158	80.1	No recording			
11:31:04 PM	169	78.1	No recording			
11:33:53 PM	159	70.1	No recording			

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 MAIN FINDINGS OF VOLUME 1 OF REPORT

Traffic characteristics for four different time periods (AM peak, off-peak, noon peak, and PM peak) were obtained from field videotapes taken in 2013. The field delay and queue length were measured in the "before conditions," to be used later for evaluating SynchroGreen.

The "before conditions" data were used to compute delay and queue length following the procedures given in the *Highway Capacity Manual 2010* (HCM) *(6)* to quantify the effects of volume changes anticipated due to additional developments at the intersection of Neil Street and Devonshire Drive.

The *HCM* estimates of stopped delays were significantly different from field data in 58.3% of the cases, representing overestimations in 73.5% of the cases and underestimations in 26.5%. On major streets of typical intersections, *HCM* delay estimates and field data were significantly different in 72% of the cases; in 91% of these cases, *HCM* overestimated the delay on average by 69%. On minor streets of typical intersections, there were significant differences between *HCM* and field data in 56% of the cases; in 94% of these cases, *HCM* overestimated the delay on average by 52%.

HCM estimates of the 50th-percentile queue length was significantly different in 61% of all cases, including overestimations in 56% and underestimations in 44% of the cases. For typical intersections, 52% of the cases had significant differences, including overestimations in 93% and underestimations in 7%. On the major streets of the typical intersections, the *HCM* queue lengths were similar to those from the field in 68% of the cases. However, in 28% of the cases, *HCM* overestimated the queue length on average by 66%; in 4% of the cases, it underestimated the queue length on average by 42%. On the minor streets of typical intersections, in only 25% of the cases were the median *HCM* queue lengths similar to those from the field; however, in 70% of the cases, *HCM* overestimated the queue length on average by 44%; and in 5% of the cases, it underestimated it on average by 20%.

In addition, a 95th-percentile queue-length comparison was conducted between *HCM* estimates and field data. In general, it was observed that trends in the 50th- and 95th-percentile queue-length comparisons supported each other.

The consistency between the results of stopped delay and the 50th-percentile queue-length comparisons for the 64 overlapping cases was analyzed. In 91% of the cases, the trends in delay and queue comparisons were either consistent with each other or did not have any significant conflicts. However, in 9% of the cases, significant inconsistencies in trends were observed. Thus, to save time, one may compare *HCM* queue-length estimates to field data to assess intersection performance, though the delay comparison is preferred.

7.2 MAIN FINDINGS OF VOLUME 2 OF REPORT

Volume 2 of the report presented the system performance for the "first year after" implementation of SynchroGreen (also called 2015 data). The system was installed in early 2015. The research team provided extensive feedback on how the system was performing. Then, the vendor fine-tuned the system to get the "best" possible performance. Traffic characteristics for four time periods (AM peak, off-peak, noon peak, and PM peak) were obtained from field videotapes.

The volume, delay, and queue-length information in 2015 (first year after implementation) were compared with the data for the 2013 conditions. The field volumes were compared for 83 lane groups (also called cases, or approaches). Traffic volume on 33% of the lane groups significantly increased; but on 65%, it did not change significantly; and on only 2%, it significantly decreased. The field delays were compared for 83 lane groups, out of which 17% showed significant increase, 72% showed no significant change, and 11% showed significant decrease. Queue length was compared for only 63 lane groups because the remaining 20 lane groups either did not have queue data or the queue length was insignificant (no more than two cars). Out of these 63 lane groups, 22% showed significant increase in queue length, 60% showed no significant change, and 18% showed significant decrease.

Further analysis was carried out to determine ASCT performance at approach, intersection, and corridor levels. Based on the changes in volume, delay, and queue length combined, an overall performance indicator (PI) was determined for each approach of each intersection at each time period. The performance indicators were Imp (improved), Unch (unchanged), det (Deteriorated), or Mix (mixed results). Out of the total 83 lane groups analyzed, the PI showed improvement in 41% of them; the PI remained unchanged in 30%; but in 29%, the PI showed deterioration. In summary, on 71% of the lane groups, ASCT either improved or performance was unchanged; however, on 29% of the lane groups, ASCT deteriorated the performance. Out of the 24 deteriorated cases (the 29%), volume significantly increased in 4, did not change significantly in 19, and significantly decreased in one. Deterioration in the 4 cases can be attributed to the increase in volume and the system's inability to respond adequately to the volume increase. However, in the 18 lane groups for which volume did not significantly change, the deterioration in PI was not expected.

The analyses indicated that ASCT made a compromise between the minor- and major-street performances; and in general, minor-street improvements were correlated with major-street deterioration or unchanged performance.

7.3 MAIN FINDINGS OF VOLUME 3 OF REPORT

To evaluate the SynchroGreen system, the corridor's performance was measured during two conditions: under time-based coordination (TBC) in February/March 2017 and under the ASCT condition in April 2017. It was further fine-tuned in late 2016 and early 2017 before data collection for this evaluation. Traffic characteristics for three time periods (AM peak, noon peak, and PM peak) were obtained from field videotapes.

The volume, delay, and queue-length data from the field for TBC 2017 were measured and individually compared with the data for ASCT 2017, at the 97% confidence level. The field data were compared for 57 cases (also called lane groups, or approaches). At the 97% confidence level, traffic volume on 7% of the lane groups significantly increased; but on 72%, it did not change significantly; and on 21%, it significantly decreased. Delay showed significant increase in 56% of the cases, no significant change in 40%, and significant decrease in 4%. Queue length was also compared for the 57 lane groups: 35% showed significant increase, 65% showed no significant change, and none showed significant decrease.

Further analysis was carried out to determine ASCT performance at approach, intersection, and corridor levels. Based on the changes in volume, delay, and queue length combined, an overall performance indicator (PI) was determined for each approach of each intersection at each time period. The performance indicators are Imp (improved), Unch (unchanged), and Det (deteriorated). Because we considered the 97% confidence interval for individual comparisons of volume, delay, and queue length, the PI would present the results at the 91% confidence level, the product of three individual confidence levels of 97% (0.97*0.97*0.97). One lane group was excluded from further analysis due to insufficient volume; so out of the total of 56 lane groups analyzed, the PI showed improvement in 5%, remained unchanged in 32%, but showed deterioration in 63%. In summary, on 37% of the lane groups, ASCT either improved or did not change performance; however, on 63% (35 cases) of the lane groups, performance deteriorated with ASCT.

Further investigations were performed to find the factors contributing to the ASCT performance deterioration. Out of 35 cases, deterioration in 20 cases could be explained by contributing factors such as frequency of unfavorable arrival types under ASCT 2017, as compared to TBC 2017; a few cases of volume increase under ASCT 2017; ASCT miscount of traffic volumes; signal-timing changes under ASCT 2017; and an increased proportion of vehicles stopped under ASCT 2017. However, in the 15 remaining cases, there was no reasonable explanation for the PI deteriorations when ASCT was operating.

7.4 MAIN FINDINGS FROM COMPARISON OF FIRST-YEAR-AFTER AND FINAL-YEAR-AFTER DEPLOYMENT

Volume 2 of the report series discussed the findings for the “first year after” the ASCT system was deployed (the 2015 data). Similarly, Volume 3 of the report series discussed the findings for the “final year” the system was deployed (2017 data). IDOT decided to shut down the system on May 5, 2017, mainly due to the uncertainty in system maintenance and performance should there be a full or partial system failure. The week before the shutdown, IDOT and City of Champaign traffic engineering staff observed that the System continued to run erratically and showed many pattern errors and adjustments that were not explainable. Also, they observed that several times the system improperly split the green time such that it caused unnecessary backups on Windsor Road and Kirby when there was very little traffic on Neil Street.

After the shutdown, the traffic signals were operating under time-based coordination plan, as it was before the ASCT system implementation. The signal coordination and timing plan IDOT had on this corridor was running close to an optimal operation that one could get from a closed loop system. Therefore outperforming or “beating” this existing system is a big challenge for any adaptive system.

Comparisons of system performance indicators (PI) under 2017 ASCT relative to its base, which was 2017 TBC—as well as the PI under 2015 ASCT relative to its base, which was 2013 data—revealed that PI deterioration was more frequent in 2017 data.

In the “final year” data (2017 ASCT, as reported in Volume 3), there were 35 deteriorated cases out of a total of 56 cases. However, there were 18 deteriorated cases out of a total of 56 cases in the “first year after” data (2015 data as reported in Volume 2). There were 16 cases that showed deterioration in both data sets (the 2017 and 2015 data sets), indicating that 16 out of 18 cases that showed deterioration in the “first year after” data also showed deterioration in the “final” year data; but in 2 cases, PI improved.

Out of the 35 cases that showed PI deterioration under 2017 ASCT, one could find some reasonable explanation for the deterioration for 20 cases; yet it should be noted that the explanations do not in any way justify the deterioration in system performance; but they help us to understand why it happened and what may have caused it. However, for the 15 remaining cases, we were unable to find a reasonable explanation for the PI deterioration when ASCT was operating in 2017.

In the “final year” data, there were 19 additional cases that showed performance deterioration. Among the 19 deteriorated cases in the “final year” data, some reasonable explanation for PI deterioration could be found for 8 cases, though not justifying the deterioration of the system performance; but for 11 cases, no reasonable explanation for PI deterioration was found.

Furthermore, in the “final year” data, 7 cases showed no change in PI (Unch category); but they had shown improvement in PI in the “first year after” data. So the traffic operation for these 7 cases worsened; however, we did not include them among the 35 deteriorated cases.

One may suspect that traffic-volume increase from 2015 to 2017 played a big role in explaining the higher frequency of PI deterioration in the 2017 data. We looked at the changes in volume with respect to their proper bases and found that volume should be a contributing factor in only one case.

7.5 MAIN FINDINGS OF SAFETY ANALYSIS AND CMF REPORT

For multiple-vehicle fatal and injury (FI) crashes at all intersections (four-legged and three-legged combined), the CMF was 0.67, which was not statistically significant at the 95% confidence level. (It was significant at 87% confidence level.) For four-legged-only intersections, the CMF was 0.67 as well, which was not significant at the 95% confidence level. (It was significant at the 85% confidence level.) The 87% and 85% confidence levels are not used in practice; however, they clearly indicate a decreasing trend in FI crashes due to the implementation of ASCT. For the three-legged intersection, data were not adequate to develop CMFs. For PDO and total crashes, all CMFs computed were close to one, indicating no crash reduction due to implementation of ASCT. The above findings are based on SPFs from *HSM (7)*, which were chosen over previously developed SPFs for Illinois. Nonetheless, the CMF for Illinois KAB (fatal, type A injury, and type B injury crashes combined) crashes was computed and found to be 0.68, which was not significant at the 95% confidence level. (It was at 71%, indicating a decreasing trend in these types of crashes.)

The results from the paired tests showed decreasing trends in angle and rear-end crashes, but they were not found to be statistically significant. For the sideswipe same-direction and turning crashes, the test results showed no change. The test results also indicated that for Type A injury and Type C injury crashes, there were reductions; but they were not found to be statistically significant. There was no change in severity of Type B crashes.

7.6 TRAVEL-TIME FINDINGS

Two sets of travel-time comparisons and one set of speed comparisons were made. The 2014 (TBC) vs 2016 (ASCT) travel-time comparisons showed that under ASCT operation the corridor travel time for the preferred directions (NB AM-peak and SB PM-peak directions) increased by 31.8 seconds for NB through traffic during the AM peak and by 48.3 seconds for the SB through traffic during the PM-peak hours. For the OP and NP, no desirable direction exists; but the system still experienced a significant increase of 19.3 seconds in the NP SB direction and a significant decrease in the OP NB direction. Similar trends were observed in 2017 (TBC) vs 2017 (ASCT) data comparison. For the NB AM peak, travel time increased by 45.0 seconds; and for the SB PM peak, it increased by 51.8 seconds. Also, for the SB traffic during the AM peak, travel time increased by 41.8 seconds in the 2017-to-2017 comparison. The vehicles were slowing down or stopping due to a red light or a queue when the ASCT system was operating, which mainly caused the increase in travel time. The average speed at the middle-third segment for each link and the average speed of the corridor under 2017 ASCT were compared to the corresponding values under 2017 TBC. The SB during PM peak showed an average corridor-speed reduction of 6.1 mph. Thus, under 2017 ASCT operation, the travel times in the preferred directions were significantly increased and corridor travel speed significantly decreased in the SB direction, which are not desirable outcomes.

Although travel-time increase and speed decrease may negatively impact the system's efficiency, the combination may be one of the factors contributing to the safety benefits of ASCT deployment. Lower speeds have been shown to be related to lower fatal and injury crashes *(8)*. In this project, the safety benefits include a decreasing trend in fatal and injury crashes, as shown in the ASCT safety-analysis report study *(4)*.

7.7 MAIN FINDINGS OF SYSTEM RESPONSE TO HEAVY TRAFFIC ON MINOR STREET AND SPECIAL-EVENT TRAFFIC.

It is important for an ASCT system, SynchroGreen in this case, to respond properly and quickly to changes in volume on the minor street. There were two cases that created heavy-volume conditions on the minor street, and the system's performance was evaluated in both cases.

The expectation that the system would allocate enough green time to the minor-street direction while providing sufficient green time to the major street to avoid cycle failure was not materialized. The system did not reallocate the unused green time on the major street to the heavy traffic on the minor street during the PM-peak hour of normal traffic conditions.

The field data showed that during normal traffic conditions, about 40% to 62% of the cycles were not given enough green time to process the vehicles in queue on the minor street, while there was unused green time on the major street.

Adapting to volume changes under special-event conditions is expected for an ASCT system. However, SynchroGreeen was unable to respond properly to volume increases on the minor street. It failed to reallocate the unused green time on the major street to the minor street that had cycle failures (queue remaining at the end of the green time).

7.8 HIGHLIGHTS OF THE FINDINGS

Operational efficiency

In the first year after implementation, Performance Indicator (PI) improved on 41%, unchanged on 30%, and deteriorated on 29% of the approaches. On the major street approaches, PI on 34% improved, on 26% unchanged, and on 40% deteriorated. On the minor streets, PI on 50% improved, 36% unchanged, and 14% deteriorated. The ASCT system improved the traffic operation on more cases than it deteriorated, but favored minor streets over the major street.

In the final year of implementation, PI improved on 5%, unchanged in 32%, and deteriorated in 63% of the approaches. On the major street aproaches, PI on 7% improved, on 30% unchanged, and on 63% deteriorated. On the minor streets, PI on 4% improved, on 35% unchanged, and on 61% deteriorated. The ASCT system improved a few, unchanged about 1/3, and deteriorated operation on more than 60% of approaches; on both major and minor streets.

Among the 56 approaches (cases) that were common in the first year and the final year of implementation, PI deteriorated in 18 cases in first year, but in 35 cases in final year. Sixteen of the cases were on both years, but 19 more cases deteriorated in final year of implementation. In addition to the 19 cases, comparing PI of the first to the final year, in 7 additional approaches the operation got worse.

Average corridor travel time increased in preferred directions, which is not desireable, mainly due to increases in delay at intersections.

When there was heavy demand on the minor street approach (WB of Kirby during PM peak), about 40%-62% of cycles failed to process all the vehicles in queue while in most cases there was unused green on SBT/NBT which could be reallocated to the WB approach.

During the special event traffic (Garth Brooks concerts) the ASCT sytem was unable to respond to volume increases on Kirby Avenue.

Safety

For multi-vehicle fatal and injury crashes the CMF was not significant at 95% confidence level, but clearly showed a decreasing trend (it was significant only if the confidence level was lowered to 85%). Similarly, the CMF for Type A and type C injury crashes indicated a decreasing trend, but was not significant at 95% (it was significant if the confidence level is lowered to 71). The angle and rear-end crashes also showed a decreasing trend, but they were not statistically significant.

7.9 RECOMMENDATIONS:

The vendor needs to clearly understand the client's expectations and priorities so the system is modified and fine-tuned to meet the expectations. The system should be thoroughly tested before putting it out to face the challenges of real-world traffic. The system should have a small set of parameters to make it suitable to a given condition, instead of having a large combination of features but no clear guidelines on how a feature should be used and when and where it is applicable. The system needs to be robust, accurate and reliable; and there should not be much uncertainty about how the system would perform if a failure occurs in some of its components. The system operation and changing parameters should not be a "mystery"; rather it should be intuitive, logical, and simple for the users. It is not desirable to take a "continuous" fine-tuning approach with many small improvements. The vendor should make sure that the components used as a part of the system are reliable, accurate, and tough to withstand real-world conditions of the project.

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APPENDIX A: TRAVEL TIMES

Travel times were determined from GPS data. Specifically, a segment was defined as the distance from the middle of one intersection to the middle of the adjacent downstream intersection. Figure A1 presents an example of travel time between Windsor Road and Knollwood Drive. Each arrow represents the distance that the vehicle traveled in one second, if it was not stopped.

Figure A1. Car trajectory recorded in one-second increments.

The travel time was computed so that the arrow of trajectory represents the one-second distance traveled pass the middle point of the intersection. Figure A2 presents the trajectory of a vehicle going north on Neil Street near the intersection with Knollwood Drive, to indicate the beginning of the travel time between Knollwood Drive and Devonshire Drive.

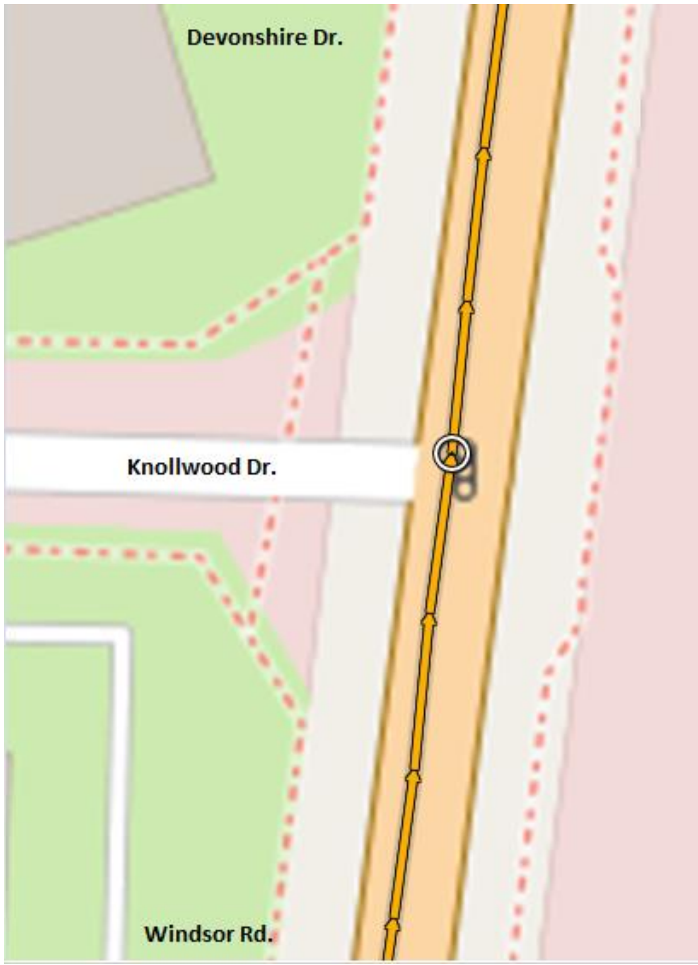

Figure A2. Vehicle trajectory when one-second travel distance is within the intersection.

The intersection in Figure A2 shows a situation when a one-second travel distance in the previous increment has not yet reached the middle of the intersection, and one-second travel distance at the next time increment falls outside of the intersection. In situations like this, the beginning of the travel time for the link starts where the white circle is located. This action was made consistent because it is the closest second interval after the vehicle passes the midpoint of the intersection. Similarly, Figure A3 shows the case in which the vehicle passes the intersection within the one-second interval. The same rule applied in which the travel time begins in the nearest second interval pass the midpoint of the intersection. This process was consistent among all runs recorded.

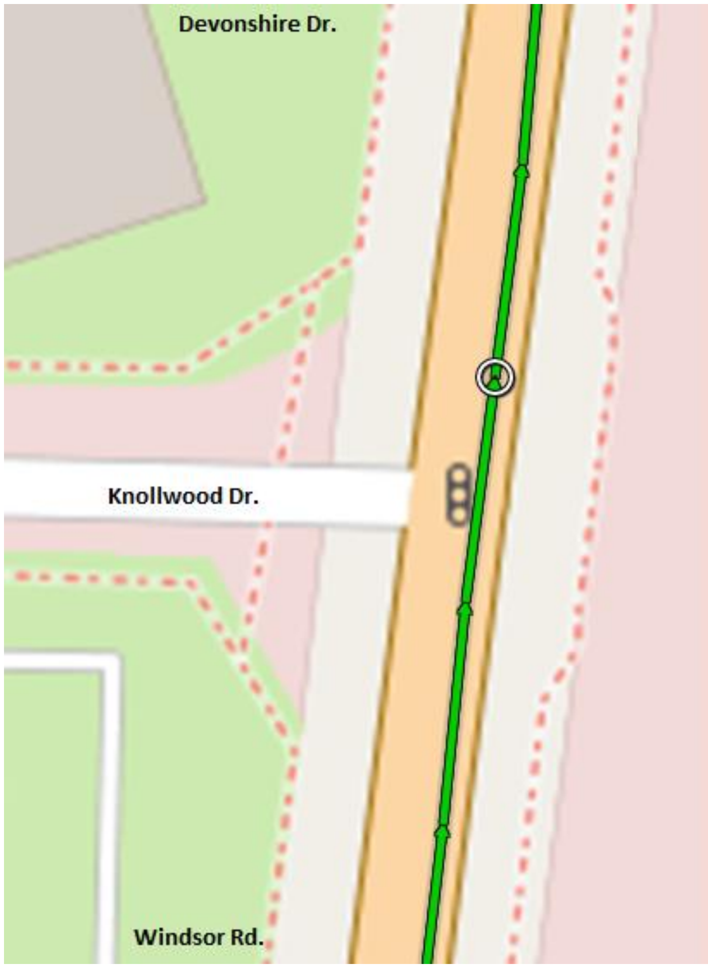

Figure A3. Vehicle trajectory when one-second travel distance passes the intersection.

After finding all travel times, their means and standard deviations were computed for further analysis. They are shown in Table A1 for the entire corridor, and for each individual link in Tables A2 to A6.

Table A1. Corridor Average Travel Time and Standard Deviation (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	172.1	153.4	156.3	180.6	152.6	179.2	175.5	184.4
	Std Dev	32.9	14.9	27.6	17.6	28.5	29.0	39.1	12.2
2016 (ASCT)	Mean	165.3	165.3	185.2	160.8	163.8	171.9	176.9	223.8
	Std Dev	717.6	26.7	33.8	36.8	36.9	34.0	31.5	34.4
2017 (TBC)	Mean	144.8	149.6	—	—	158.6	184.2	167.3	184.8
	Std Dev	29.4	24.6	—	—	25.0	25.1	24.0	9.0
2017 (ASCT)	Mean	186.5	194.9	—	—	193.3	183.7	219.2	174.0
	Std Dev	40.1	31.4	—	—	39.6	31.8	54.4	29.1

Table A2. Average Travel Time and Standard Deviation Between Stadium Drive and Kirby Avenue (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	50.1	41.8	57.1	44.4	50.5	40.0	61.6	40.2
	Std Dev	23.7	10.5	25.4	11.9	23.9	6.7	29.4	6.3
2016 (ASCT)	Mean	39.1	45.1	47.3	38.0	56.1	36.8	79.2	35.8
	Std Dev	9.4	9.9	21.9	7.9	20.8	3.3	23.4	2.6
2017 (TBC)	Mean	39.0	37.6	—	—	55.8	43.8	66.8	41.2
	Std Dev	15.1	3.5	—	—	22.3	12.5	19.9	5.8
2017 (ASCT)	Mean	57.8	40.6	—	—	52.3	46.4	72.4	49.5
	Std Dev	27.7	9.4	—	—	29.3	8.7	19.3	12.9

Table A3. Average Travel Time and Standard Deviation Between Kirby Avenue and St. Marys Road (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	47.4	37.5	28.4	58.3	29.7	57.6	30.4	65.9
	Std Dev	11.1	8.3	2.8	12.1	4.5	23.5	4.0	9.7
2016 (ASCT)	Mean	33.5	57.5	36.1	39.1	33.3	53.6	45.1	54.0
	Std Dev	11.4	18.9	13.5	14.9	6.3	16.4	9.3	24.2
2017 (TBC)	Mean	38.0	45.9	—	—	30.3	59.3	29.4	71.5
	Std Dev	12.9	24.1	—	—	3.9	11.3	3.8	5.9
2017 (ASCT)	Mean	41.1	67.8	—	—	44.3	40.9	36.7	53.4
	Std Dev	11.8	12.5	—	—	14.5	11.5	7.3	16.7

Table A4. Average Travel Time and Standard Deviation Between St. Mary's Road and Devonshire Drive (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	33.3	31.5	31.1	32.3	31.4	34.1	31.6	31.9
	Std Dev	2.0	3.2	2.1	2.8	1.4	7.0	1.8	2.7
2016 (ASCT)	Mean	31.2	38.2	33.7	40.3	34.7	41.7	37.4	45.6
	Std Dev	1.7	19.2	6.2	17.7	8.3	21.4	10.8	23.3
2017 (TBC)	Mean	31.1	28.6	—	—	33.0	33.6	32.7	29.6
	Std Dev	2.4	1.4	—	—	2.6	5.2	2.9	2.0
2017 (ASCT)	Mean	31.0	48.9	—	—	40.4	53.3	41.0	32.5
	Std Dev	1.8	27.1	—	—	15.6	28.0	13.7	16.0

Table A5. Average Travel Time and Standard Deviation Between Devonshire Drive and Knollwood Drive (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	22.7	23.5	21.9	25.1	23.3	26.3	22.7	26.1
	Std Dev	2.0	3.8	0.7	6.3	4.1	5.5	1.0	7.2
2016 (ASCT)	Mean	21.7	23.9	22.5	26.0	22.8	23.1	25.0	23.0
	Std Dev	1.9	7.4	2.7	10.3	1.8	2.7	6.0	4.8
2017 (TBC)	Mean	20.4	20.6	—	—	22.2	26.8	21.3	24.0
	Std Dev	1.3	1.3	—	—	1.7	4.1	1.6	2.3
2017 (ASCT)	Mean	21.9	20.8	—	—	24.6	22.9	29.9	21.5
	Std Dev	4.8	2.3	—	—	2.6	2.1	6.9	2.5

Table A6. Average Travel Time and Standard Deviation Between Knollwood Drive and Windsor Road (sec)

Year	Statistic	AM		OP		NP		PM	
		SB	NB	SB	NB	SB	NB	SB	NB
2014 (TBC)	Mean	18.6	19.1	17.8	20.4	17.7	21.3	29.2	20.4
	Std Dev	3.7	2.3	1.8	1.8	2.3	4.2	23.6	1.7
2016 (ASCT)	Mean	39.9	20.6	21.2	20.4	25.1	21.7	37.1	21.7
	Std Dev	13.9	6.9	10.0	5.3	14.3	8.8	15.2	7.3
2017 (TBC)	Mean	16.3	17.1	—	—	17.2	20.8	17.1	18.5
	Std Dev	3.0	1.8	—	—	2.5	7.1	1.9	1.7
2017 (ASCT)	Mean	34.8	16.9	—	—	31.7	20.3	39.2	17.2
	Std Dev	11.5	2.4	—	—	20.5	2.8	29.3	2.8

APPENDIX B: MIDDLE-THIRD AVERAGE SPEEDS

Travel speeds were determined for the middle-third of each link. Each segment was divided into three parts, and the data points falling within the middle-third were used. Table B1 presents the data utilized in the speed analysis.

Table B1. Segments and Corridor Average Speeds and Standard Deviations (mph)

Segment between	Year	Statistic	AM		NP		PM	
			SB	NB	SB	NB	SB	NB
Stadium Dr. and Kirby Ave.	2017 (TBC)	Mean	38.9	34.0	34.3	32.0	32.4	31.7
		Std Dev	4.5	2.6	4.1	2.3	4.8	3.5
	2017 (ASCT)	Mean	36.7	36.0	36.8	34.1	27.7	33.0
		Std Dev	3.1	3.5	5.4	3.9	3.5	2.5
Kirby Ave. and St. Mary's Rd.	2017 (TBC)	Mean	35.2	30.9	32.5	28.7	33.4	30.3
		Std Dev	4.5	4.5	2.9	7.3	2.6	4.2
	2017 (ASCT)	Mean	34.7	31.8	30.2	31.8	26.7	33.6
		Std Dev	2.8	4.2	3.6	5.0	6.1	4.0
St. Mary's Rd. and Devonshire Dr.	2017 (TBC)	Mean	39.3	42.2	36.0	38.0	35.5	40.0
		Std Dev	3.4	2.1	3.6	2.7	4.0	2.4
	2017 (ASCT)	Mean	39.8	41.6	36.9	36.5	33.2	41.9
		Std Dev	3.4	4.4	4.8	5.3	3.6	4.5
Devonshire Dr. and Knollwood Dr.	2017 (TBC)	Mean	43.6	42.8	39.8	36.0	41.7	37.5
		Std Dev	3.2	2.8	3.5	2.5	2.9	3.4
	2017 (ASCT)	Mean	43.6	42.6	39.3	39.2	35.6	42.0
		Std Dev	3.4	5.3	3.5	3.8	4.6	5.4
Knollwood Dr. and Windsor Rd.	2017 (TBC)	Mean	42.2	41.0	38.5	37.7	39.2	37.4
		Std Dev	4.9	4.7	6.2	3.8	4.5	4.1
	2017 (ASCT)	Mean	35.4	41.9	35.9	33.6	28.3	40.8
		Std Dev	3.9	5.6	5.5	4.5	8.5	5.4
5-segment average	2017 (TBC)	Mean	39.8	38.2	36.2	34.5	36.4	35.4
		Std Dev	3.2	5.4	3.0	4.0	3.9	4.2
	2017 (ASCT)	Mean	38.0	38.8	35.8	35.0	30.3	38.2
		Std Dev	3.7	4.7	3.4	2.9	3.9	4.6