CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 19-004
UILU-ENG-2019-2004
ISSN: 0197-9191

Evaluation of Adaptive Signal Control Technology— Volume 3: Comparison of TBC 2017 and ASCT 2017

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Research Report No. FHWA-ICT-19-003

A report of the findings of
ICT PROJECT R27-127

Safety and Efficiency Benefits of Implementing Adaptive Signal-Control Technology in Illinois

Illinois Center for Transportation
March 2019

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-19-003	N/A	N/A

4. Title and Subtitle Evaluation of Adaptive Signal Control Technology—Volume 3: Comparison of TBC 2017 and ASCT 2017	**5. Report Date** March 2019 **6. Performing Organization Code** N/A
7. Author(S) Rahim F. Benekohal, Behnoush Garshasebi, Hongjae Jeon, and Mingfeng Shang	**8. Performing Organization Report No.** ICT-19-004 UILU-ENG-2019-2004
9. Performing Organization Name and address Illinois Center for Transportation Department of Civil and Environmental Engineering University of Illinois at Urbana–Champaign 205 North Mathews Avenue, MC-250 Urbana, IL 61801	**10. Work Unit No.** N/A **11. Contract or Grant No.** R27-127
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR) Bureau of Research 126 East Ash Street Springfield, IL 62704	**13. Type of Report and Period Covered** Volume 3 Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Data were collected at five intersections along the Neil Street corridor in Champaign, Illinois, before deployment of SynchroGreen, an adaptive signal control technology (ASCT). The volume, delay, and queue length data from the field for TBC (time based coordination) 2017 conditions were compared to the data from ASCT (adaptive signal control technology) 2017 conditions, at the 97% confidence level. The field volumes were compared for 57 lane groups (approaches). Traffic volume on 7% of the lane groups significantly increased, on 72% remained unchanged, and on only 21% significantly decreased. Stopped delays increased in 56% of the cases, remained unchanged in 40%, and decreased in 4%. Queue length increased in 35% of the cases and remained unchanged in 65%. To determine ASCT performance, the changes in volume, delay, and queue length combined were considered. 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), with 91% confidence. One lane group was excluded from further analysis due to insufficient volume; of the 56 lane groups analyzed, 5% showed improvement, 32% remained unchanged, and 63% (35 cases) showed 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 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.

17. Key Words	18. Distribution Statement
Adaptive traffic signals, ASCT, signalized intersections, corridor travel time, traffic coordination, field data on delay, queue length, HCM, saturation flow, signal timing.	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. PRICE
Unclassified	Unclassified	47 + appendices	N/A

FORM DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT AND DISCLAIMER

This publication is based on the results of **ICT-R27-127, Safety and Efficiency Benefits of Implementing Adaptive Signal Control Technology in Illinois.** ICT-R27-127 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

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We acknowledge the contribution of graduate students: Siao Zhou in queue length data reduction and data cleaning tasks, and Yan Bai in queue length data reduction tasks.

EXECUTIVE SUMMARY

Traffic signal operation in the United States has evolved from pre-timed, to vehicle-actuated, to the present-day advanced traffic signal systems called 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 ASCT is very important in understanding the system's contribution to traffic safety and operational 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. Six intersections along Neil Street in Champaign, Illinois, were selected for this implementation. To evaluate the SynchroGreen system, the corridor's performance was measured during two conditions: under time-based coordination (TBC) in February and March 2017 and under the ASCT condition in April 2017. This report presents the study methodology, data collection, data reduction, and data analysis under the TBC 2017 and ASCT 2017 (implementation of SynchroGreen). The SynchroGreen system was installed in early 2015 and fined 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 different time periods (AM peak, noon peak, and PM peak) were obtained from field videotapes. The traffic characteristics include 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, 65% showed no significant change, and none 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 are Imp (Improved), Unch (Unchanged), and Det (Deteriorated). Because we considered the 97% confidence interval for individual comparisons of volume, delay, and queue length, so 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 contributing factors 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 15 remaining cases, there was no reasonable explanation for the PI deteriorations when ASCT was operating.

CONTENTS

CHAPTER 1: INTRODUCTION

Intersection traffic signal control has evolved from pre-timed operation, to vehicle-actuated, to the present-day adaptive signal systems. Adaptive signal control technologies (ASCT) are used to make traffic signal operation more responsive to real-time traffic demand. These technologies have the potential to provide a more efficient and safer operation. In the United States, adaptive systems are relatively new and are deployed in various parts of the country.

In 2014, as a result of congestion, it is estimated that urban Americans traveled 6.9 billion hours more and purchased an extra 3.1 billion gallons of fuel—resulting in total congestion costs of about $160 billion dollars *(1)*. Thus, increased deployment of more efficient signal systems is necessary to reduce congestion.

The Illinois Department of Transportation (IDOT) has expressed interest in field evaluation of an ASCT for deployment at intersections throughout the state. Through a competitive process, SynchroGreen was selected from available ASCTs for field evaluation. It is a real-time ASCT system from Trafficware, Inc. *(2)*. Field evaluations of ASCTs are very important in understanding their contribution to performance improvement—and, hence, their effectiveness. Some field evaluations of SynchroGreen have been reported in the recent past *(3)*, at locations such as Seminole County, Florida *(4),* and Boca Raton, Florida *(5)*.

Therefore, this study was undertaken on behalf of IDOT to evaluate the performance of the SynchroGreen system—in terms of traffic safety and traffic operational efficiency.

This report presents the data analysis results for the April 2017 conditions in which the adaptive signal-control technology (ASCT 2017) was in place, compared to the February and March 2017 conditions in which time-based coordination (TBC 2017) was in place. Volume 1 *(6)* of this report discusses the base conditions in 2013, before the ASCT was implemented. Volume 2 *(7)* compares the performance of the ASCT system in 2015 to the base conditions in 2013, to document the performance of ASCT during the first year after implementation. The base condition in 2013 was also operating as a TBC system.

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.

This report is organized as follows: Chapter 2 contains a description of the study area and the data-collection methodology used in the study. Chapter 3 presents the methodology and outcomes of data reduction performed following collection of the traffic data for 2017. Chapter 4 discusses statistical comparisons between February/March 2017 and April 2017 (TBC versus ASCT conditions) in terms of volume, stopped delay, and queue length—as well as the relationships between delay and volume performance, and queue and volume performance. This chapter also evaluates the traffic performance at both corridor and intersection levels by analyzing the comparison results and presents a detailed analysis of the cases with deteriorated performances. Chapter 5 presents the main findings and conclusions.

CHAPTER 2: DATA COLLECTION

This chapter describes the study area and presents the methodology used for data collection.

2.1 DESCRIPTION OF STUDY AREA

The study area consisted of six intersections along the Neil Street corridor, Champaign, Illinois (Figure 2). For this report, we used data for five intersections on Neil Street that were operating through an active ASCT system. The Knollwood intersection was not used because the operation there is heavily influenced by the nearby signal at Windsor Road; also, the traffic on minor streets was so low that some cycles were skipped. The traffic pattern on Neil Street has higher volume northbound in the morning (toward downtown Champaign) and southbound in the afternoon. Four of the crossing streets that create typical four-legged intersections are Stadium Drive, Kirby Avenue, St. Mary's Road, and Windsor Road. On the cross streets, the heavy volume direction in the morning is eastbound toward the campus of the University of Illinois at Urbana–Champaign. In the afternoon, the heavy-volume direction is westbound, away from campus. Schematic geometries of the five intersections are shown in Figures 2 to 7 (drawings not to scale).

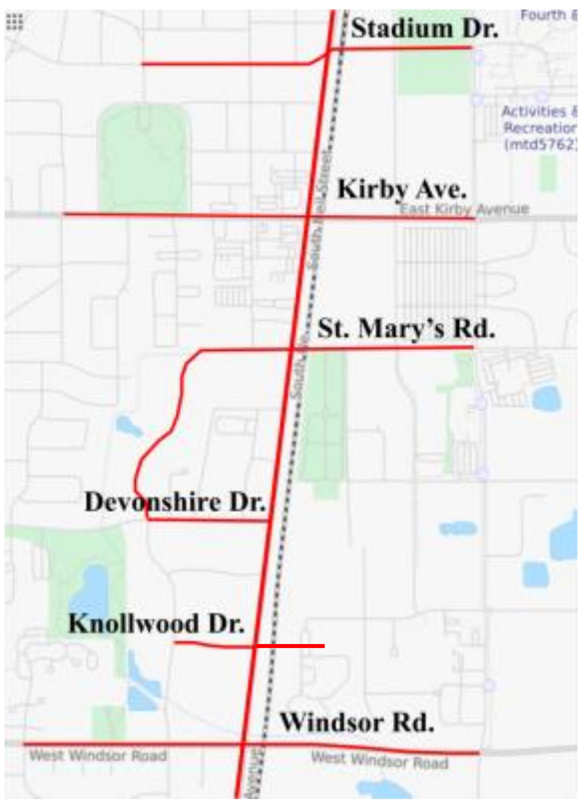

Figure 2. Five intersections were studied along the Neil Street corridor, Champaign, Illinois: Stadium Drive, Kirby Avenue, St. Mary's Road, Devonshire Drive, and Windsor Road.

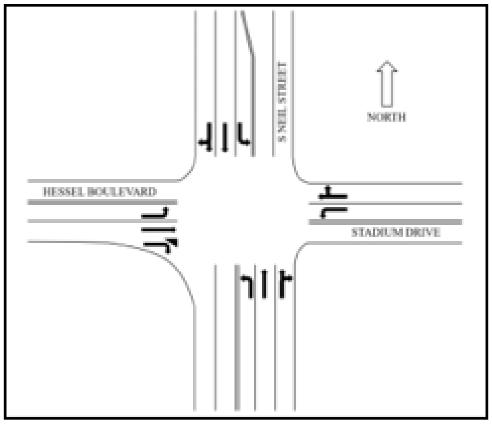

Figure 3. Geometry of the intersection of Neil Street and Stadium Drive.

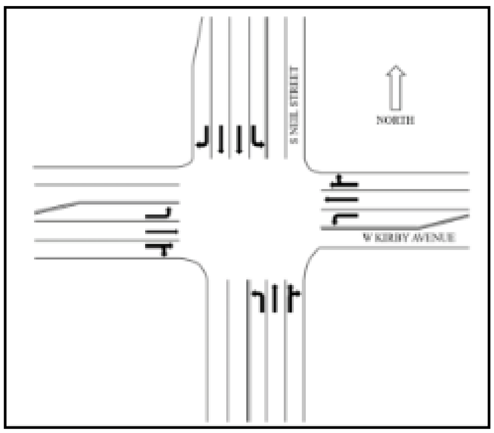

Figure 4. Geometry of the intersection of Neil Street and Kirby Avenue.

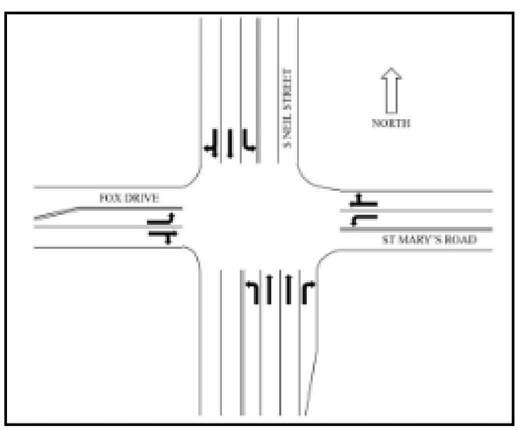

Figure 5. Geometry of the intersection of Neil Street and St. Mary's Road.

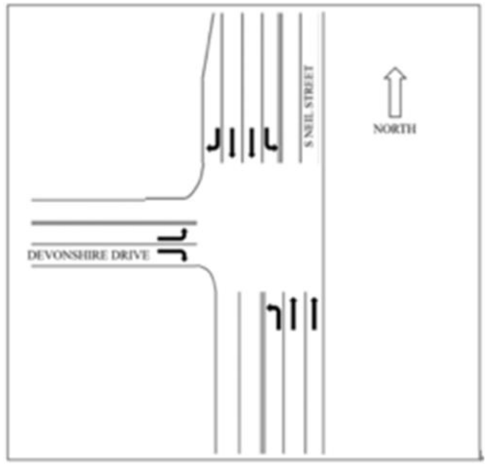

Figure 6. Geometry of the intersection of Neil Street and Devonshire Drive (since 2015).

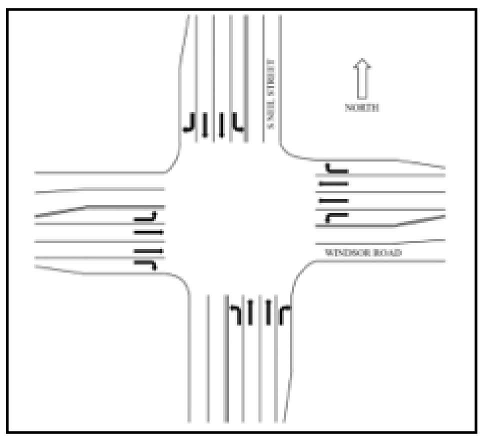

Figure 7. Geometry of the intersection of Neil Street and Windsor Drive.

2.2 FIELD DATA COLLECTION METHODOLOGY

During data-collection dates for the TBC 2017 and ASCT 2017 conditions, traffic operation was normal; and there were no roadway-construction activities. For both conditions, data collection was conducted by recording the online streaming traffic videos provided by the ASCT cameras at the five intersections. Two video sets of data were recorded for each condition under TBC 2017 and ASCT 2017, during morning peak (7:30–8:30 a.m.), noon peak (12:10–1:10 p.m.), and afternoon peak (4:40–5:40 p.m.) hours in a day. Tables 1-4 show the dates of data collection at each intersection and data reduction.

Table 1. TBC 2017 Data Collection Dates (Video Sets 1 and 2)

Intersection	AM Peak	Off Peak	Noon Peak	PM Peak
Stadium	Feb 15, 2017	Feb 15, 2017	Feb 15, 2017	Feb 15, 2017
Kirby	Feb 15, 2017	Feb 15, 2017	Feb 15, 2017	Feb 15, 2017
St. Mary's	Feb 16, 2017	Feb 16, 2017	Feb 16, 2017	Feb 16, 2017; Feb 22, 2017
Devonshire	Feb 16, 2017	Feb 16, 2017	Feb 16, 2017	Feb 16, 2017; Feb 22, 2017
Knollwood	Feb 28, 2017	Feb 28, 2017	Feb 28, 2017	Feb 28, 2017
Windsor	Feb 28, 2017	Feb 28, 2017	Feb 28, 2017	Feb 28, 2017

Intersection	AM Peak	Off Peak	Noon Peak	PM Peak
Stadium	March 1, 2017	March 1, 2017	March 1, 2017	March 1, 2017
Kirby	March 1, 2017	March 1, 2017	March 1, 2017	March 1, 2017
St. Mary's	March 2, 2017	March 2, 2017	March 2, 2017	March 2, 2017
Devonshire	March 2, 2017	March 2, 2017	March 2, 2017	March 2, 2017
Knollwood	March 7, 2017	March 7, 2017	March 7, 2017	March 7, 2017
Windsor	March 7, 2017	March 7, 2017	March 7, 2017	March 7, 2017

Table 2. ASCT 2017 Data Collection Dates (Video Sets 1 and 2)

Intersection	AM Peak	Off Peak	Noon Peak	PM Peak
Stadium	April 11, 2017	April 11, 2017	April 11, 2017	April 11 2017
Kirby	April 12, 2017	April 12, 2017	April 12, 2017	April 12 2017
St. Mary's	April 13, 2017	April 13, 2017	April 13, 2017	April 13 2017
Devonshire	April 13, 2017	April 13, 2017	April 13, 2017	April 13 2017
Knollwood	April 14, 2017	NA	April 14, 2017	April 14 2017
Windsor	April 12, 2017	April 12, 2017	April 12, 2017	April 12 2017

Intersection	AM Peak	Off Peak	Noon Peak	PM Peak
Stadium	April 25, 2017	April 25, 2017	April 25, 2017	April 25, 2017
Kirby	April 18, 2017	April 18, 2017	April 18, 2017	April 18, 2017
St. Mary's	April 25, 2017	April 25, 2017	April 25, 2017	April 25, 2017
Devonshire	April 19, 2017	April 19, 2017	April 19, 2017	April 19, 2017
Knollwood	April 19, 2017	April 19, 2017	April 19, 2017	April 19, 2017
Windsor	April 18, 2017	April 18, 2017	April 18, 2017	April 18, 2017

Table 3. TBC 2017 Data Reduction Dates

Intersection	AM Peak	Noon Peak	PM Peak
Stadium	Feb 15, 2017	Feb 15, 2017	Feb 15, 2017
Kirby	March 1, 2017; Feb 15 2017	Feb 15, 2017	March 1, 2017 (NB, EB, WB); Feb 15, 2017 (SB)
St. Mary's	March 2, 2017	March 2, 2017	March 2, 2017
Devonshire	March 2, 2017	March 2, 2017	March 2, 2017
Knollwood	March 7, 2017	March 7, 2017	March 7, 2017
Windsor	March 7, 2017	March 7, 2017	Feb 28, 2017

Table 4. April 2017 Data Reduction Dates

Intersection	AM Peak	Noon Peak	PM Peak
Stadium	April 11, 2017	April 11, 2017	April 11, 2017
Kirby	April 12, 2017	April 12, 2017	April 12, 2017
St. Mary's	April 13, 2017	April 13, 2017	April 13, 2017
Devonshire	April 13, 2017	April 13, 2017	April 13, 2017
Knollwood	April 19, 2017	April 19, 2017	April 19, 2017
Windsor	April 12, 2017	April 12, 2017	April 12, 2017

CHAPTER 3: DATA REDUCTION

This chapter describes the methodology used for reducing the data elements from the traffic videos. Several types of characteristics data were extracted from the traffic videos: hourly volume, signal timing, proportion of vehicles stopping, arrival type, field delay, and queue length. Data reduction was performed for the three time periods (AM peak, noon peak, and PM peak). In the following sections, a detailed description of the data reduction, along with the outcomes for each item, is presented.

3.1 VOLUME

The through volumes during the three time periods were determined for all approaches of the five intersections. Averaged hourly volumes were used in the delay and capacity analysis, which are discussed later in the report.

The through movement volumes for one hour were manually counted using the recorded traffic videos. The volume counts were obtained at 20 second intervals for the entire time period. Traffic volume for each approach in every cycle was counted manually. The average volumes per cycle are presented in Chapter 4, Table 5. NBT, SBT, EBT, and WBT are abbreviations for northbound through, southbound through, eastbound through, and westbound through, respectively. The same abbreviations are used in the following tables and figures. AM, NP, and PM indicate the morning peak, noon peak, and afternoon peak, respectively; and the same indicators are used in the following tables and figures.

3.2 SIGNAL TIMING

Signal timing data were reduced to obtain the green time ratio data. Signal timing data are obtained from the SynchroGreen reports. In the reports, the cycle length, phases used, and split times in each cycle for the intersections are listed. The corresponding movements for these green splits are determined by checking the traffic videos. The green time ratio for each through movement per cycle can be computed, and thus the green time ratio for each through movement is obtained. In Chapter 4, Table 27 shows the green-time ratio for each through movement for the five intersections under the TBC 2017 and ASCT 2017 conditions.

3.3 FIELD DELAY

The control delay and stopped delay in the field were calculated from the video data for TBC 2017 and ASCT 2017. The field measurement technique for intersection control delay, as described in Chapter 31 of *HCM 2010 (8)*, was adopted to calculate stopped delay and control delay using the field videos. The measurements were carried out on a lane-group basis for each approach of the five intersections. The procedure was performed for all three time periods.

The procedure requires identifying the approach speed. The speed limit of each approach was assumed to be its approach speed. The duration of the survey period was about one hour for each time period. The count interval of 20 seconds was selected for this study because it is an integral divisor of the duration of the survey period (1 hour), as required by the *HCM*. The stopped delay obtained for each lane group in the study (using the *HCM* field-measurement methodology) is presented in Table 5.

3.4 QUEUE LENGTH

The queue lengths in the field were determined using the video images of the approaches. They are compared to their estimations (discussed in the next chapter).

The queue length of a through lane group in each cycle was determined by manually counting the number of stopped vehicles at the beginning of the green light for that direction. This counting also included vehicles that joined the queue after the end of the red light and came to a complete stop. The average queue lengths for the TBC 2017 condition are compared to those under the ASCT 2017 condition. The average queue length data are shown in Table 5 for TBC 2017 and ASCT 2017.

CHAPTER 4: DATA ANALYSIS

This chapter explains three steps of data analysis: average volumes comparison of TBC 2017 and ASCT 2017 conditions, field stopped delays comparison of TBC 2017 and ASCT 2017, and field queue lengths comparison of TBC 2017 and ASCT 2017. It also includes the discussions about the findings of these comparisons. First, the methodology for the analyses is explained. Then, the comparisons for all approaches combined (corridor level) are discussed. Finally, the results at the intersection level are analyzed.

4.1 METHODOLOGY

Statistical comparisons were performed using two-sided t-tests (unpaired) at 0.03-significance levels (97% confidence level). The null hypothesis of the test is that the field measurements under the TBC 2017 and ASCT 2017 conditions are not significantly different. The t values were computed using the means and variances of the data:

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_p} \tag{1}$$

where

$$s_p = \begin{cases} \sqrt{\dfrac{(n_1 - 1)s_1{}^2 + (n_2 - 1)s_2{}^2}{n_1 + n_2 - 2}} & \text{if } \dfrac{s_1}{s_2} < 2 \text{ or pooled variance} \\ \\ \sqrt{\dfrac{s_1{}^2}{n_1} + \dfrac{s_2{}^2}{n_2}} & \text{if } \dfrac{s_1}{s_2} \geq 2 \text{ or unpooled variance} \end{cases}$$

in Equation (1):

for the volume comparisons, $\bar{\mathbf{x}}_1$ and $\bar{\mathbf{x}}_2$ are the average volumes of the subject lane group for the TBC 2017 and ASCT 2017 conditions, respectively; $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$ are the number of observations; and $\boldsymbol{s_1}^2$ and $\boldsymbol{s_2}^2$ are the variances.

for the field stopped comparisons, $\bar{\mathbf{x}}_1$ and $\bar{\mathbf{x}}_2$ are the average stopped delays of the subject lane group for the TBC 2017 and ASCT 2017 conditions, respectively; $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$ are the number of observations; and $\boldsymbol{s_1}^2$ and $\boldsymbol{s_2}^2$ are the variances.

for the queue-length comparisons, $\bar{\mathbf{x}}_1$ and $\bar{\mathbf{x}}_2$ are the average queue lengths of the subject lane group for the TBC 2017 and ASCT 2017 conditions, respectively; $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$ are the numbers of observations; and $\boldsymbol{s_1}^2$ and $\boldsymbol{s_2}^2$ are the variances.

4.1.1 For Volume Comparison

From field data, traffic volume for each lane group in each cycle was determined. Each lane group had about 30 data points (30 cycles and about 60 minutes total). The average and variance of those 30 volumes were computed. Consequently, as mentioned before, in Equation (1), $\overline{X_1}$ and $\overline{X_2}$ are the average traffic volumes of the subject lane group for the TBC 2017 and ASCT 2017 conditions, respectively; n_1 and n_2 are their numbers of observations; and ${s_1}^2$ and ${s_2}^2$ are their variances. Thus, using this methodology, the differences are tested to determine whether they are statistically significant. The data analysis and tests were performed for a total of 57 cases (three time periods * [four * four-legged intersections] + [one * three-legged intersection]). The summary of the results is presented in section 4.2, and the detailed results are available in Appendix A.1.

4.1.2 For Field Stopped Delay Comparison

The delay comparison was made between the field stopped delay measured for the TBC 2017 and ASCT 2017 conditions on a lane-group basis. The data analysis procedure of this report is the same one used in report Volumes 1 *(6)* and 2 *(7)* of this research project. Comparisons are only for through lane groups, except at Neil Street and Devonshire (a T-intersection), where the comparisons are for the eastbound left-turn lane. Changes in traffic volume (increase or decrease) may affect the magnitude of stopped delay, so volumes under the TBC 2017 and ASCT 2017 conditions were taken into account.

The field variance of stopped delay of a lane group was obtained by measuring average stopped delays per cycle. Therefore, each lane group ideally had around 30 stopped delays during every hour (60 minutes); and the variance of those 30 observations is equal to the variance s^2. The observation time was deliberately chosen in a way to capture traffic data of complete cycles (110 or 120 seconds) during each time interval.

Thus, using this methodology, the differences are tested to determine whether they are statistically significant. The data analysis and tests were performed for a total of 57 cases, the summary of results is presented in section 4.2, and detailed results are available in Appendix A.1.

4.1.3 For Field Queue Length Comparison

Similar to the delay comparison, the queue length comparison in this study was made between the average field queue length measured for the TBC 2017 and ASCT 2017 conditions, based on lane groups. Changes in the traffic volume under TBC 2017 and ASCT 2017 conditions were also considered in queue length comparisons.

Thus, using this methodology, the differences are tested to determine whether they are statistically significant. The data analysis and tests were performed for a total of 57 cases, the summary of the results is presented in section 4.2, and detailed results are available in Appendix A.1.

4.2 COMPARISONS OF VOLUME, DELAY, AND QUEUE LENGTH (TBC 2017 VS. ASCT 2017 AT APPROACH LEVEL)

4.2.1 Single Variable Analysis

For each of the 57 cases, any statistically significant change that may have occurred when comparing the TBC 2017 and ASCT 2017 conditions—such as changes in volume, delay, and queue length—was taken into consideration. The results are given in Table 5. In the table, NBT means northbound through and SBT southbound through; etc.. The p-values resulting from the tests are also given. Based on the required confidence level and by the use of the p-values, from now on any significant increase is indicated by “Inc” and any significant decrease by “Dec.” The unchanged ones are labeled “Unch,” and nonapplicable ones are labeled “NA” (in addition to shading).

Table 5. Volume, Delay, and Queue Length of TBC 2017 and ASCT 2017 Data Comparison Results

Intersection	Time Period	Approach	March Volume	April Volume	t-test P value	March Delay	April Delay	t-test P value	March Queue	April Queue	t-test P value
Stadium	AM	NBT	8.659	7.776	0.39412557	1.827	6.776	0.00674307	1.138	1.948	0.01904614
		SBT	6.584	5.776	0.22256143	3.605	7.620	0.00360772	1.707	2.379	0.1037344
		EBT	5.060	3.621	0.00569158	7.485	13.753	0.00086216	1.397	2.328	0.0037214
		WBT	0.953	0.500	0.00586304	4.707	3.103	0.32490696	0.086	0.276	0.02230378
	NP	NBT	6.476	6.400	0.8999122	1.922	6.831	6.1818E-07	0.683	2.446	7.4664E-08
		SBT	6.095	5.738	0.51085754	4.060	6.826	0.04413999	1.730	2.338	0.10955738
		EBT	1.635	1.000	0.00516742	4.776	7.569	0.11485334	0.381	0.708	0.02731159
		WBT	1.365	0.908	0.0250772	4.881	5.631	0.64008449	0.444	0.600	0.26299364
	PM	NBT	7.271	7.831	0.4468989	5.012	5.851	0.48627725	1.458	2.169	0.01614335
		SBT	8.153	8.339	0.79117967	2.799	7.664	0.00032562	1.695	3.305	0.00122081
		EBT	2.068	1.000	0.00016712	3.549	7.958	0.01640074	0.450	0.525	0.5671527
		WBT	3.678	3.966	0.55504388	6.497	14.408	3.206E-06	1.119	2.576	5.2445E-06
Kirby	AM	NBT	15.562	16.571	0.39882862	10.000	14.854	0.01197897	5.214	8.893	6.6612E-05
		SBT	11.857	9.357	0.02347278	12.675	14.278	0.37003018	4.464	4.929	0.50675509
		EBT	12.859	13.107	0.79197951	15.282	31.335	8.1749E-07	3.714	8.357	1.2262E-08
		WBT	9.325	5.214	2.0722E-05	23.189	21.865	0.77149312	2.920	2.821	0.87642959
	NP	NBT	11.097	11.258	0.85699282	19.592	13.745	0.01762097	7.323	6.806	0.40982477
		SBT	10.129	9.161	0.23133219	17.139	22.607	0.11714126	5.516	4.935	0.36328357
		EBT	5.968	7.000	0.16557692	24.504	61.769	3.77E-08	4.258	5.032	0.21878243
		WBT	7.677	6.258	0.03243753	14.890	32.116	5.3461E-05	3.290	3.032	0.65822167
	PM	NBT	12.379	13.583	0.19832115	29.155	21.192	0.00705806	7.655	8.792	0.05293245
		SBT	16.759	14.862	0.09661101	19.605	26.536	0.01216578	7.345	10.345	0.00104622
		EBT	7.276	7.161	0.87562077	20.916	20.726	0.95992685	3.207	3.552	0.52496557
		WBT	15.897	11.241	0.00013951	25.566	30.400	0.22500748	7.310	6.966	0.48251019
St. Mary's	AM	NBT	19.219	17.483	0.2498226	4.291	6.522	0.07640859	3.034	3.828	0.18918118
		SBT	8.514	7.897	0.47477662	7.563	7.861	0.84999212	3.034	3.103	0.8813062
		EBT	5.166	4.759	0.52917522	32.860	31.101	0.73616585	2.759	3.517	0.17062407
		WBT	3.059	1.172	0.00024889	20.356	16.034	0.3689176	1.103	0.931	0.62260657
	NP	NBT	14.313	16.469	0.02782481	6.600	8.339	0.10258036	3.375	5.531	0.00028385
		SBT	11.500	13.719	0.01310986	2.682	5.939	0.000195	1.500	4.313	1.9245E-09
		EBT	4.156	3.219	0.09627411	22.133	31.508	0.04570057	2.094	2.438	0.42856488
		WBT	3.969	1.531	1.0526E-07	19.207	17.484	0.73951973	1.688	1.000	0.08682897
	PM	NBT	14.621	15.241	0.5270375	7.555	5.460	0.07381417	4.103	3.034	0.08694377
		SBT	19.276	18.931	0.77964758	6.146	4.619	0.07360804	3.207	4.310	0.03467799
		EBT	3.931	2.552	0.03935207	15.378	23.208	0.06779658	1.207	1.724	0.19547741
		WBT	10.761	5.483	5.4669E-09	17.138	25.961	0.01991103	2.759	3.966	0.06986392
Devonshire	AM	NBT	21.577	19.350	0.19577121	1.071	2.036	0.02419261	1.643	3.607	0.00017299
		SBT	7.835	7.500	0.69511998	0.864	1.120	0.63744139	0.464	0.670	0.32972053
		EBL	3.639	3.320	0.56302541	43.153	45.640	0.6508074	2.536	3.070	0.21123639
	NP	NBT	13.120	15.375	0.01653586	1.550	2.140	0.21853083	1.590	2.650	0.01690812
		SBT	12.340	13.310	0.21092099	1.750	6.170	0.00057684	1.281	3.250	0.00097145
		EBL	4.125	5.280	0.04759346	41.070	35.720	0.12093307	3.650	4.400	0.145627
	PM	NBT	12.890	12.821	0.94099443	0.910	1.595	0.15386009	0.780	1.643	0.02582909
		SBT	21.070	21.714	0.64291091	1.355	3.766	0.00016296	2.250	4.429	0.00073814
		EBL	2.780	4.286	0.00224166	53.880	46.860	0.24743924	2.570	3.714	0.02150805
Windsor	AM	NBT	19.056	17.000	0.19265764	10.395	19.722	0.00303326	5.704	10.037	0.00011839
		SBT	4.965	3.444	0.00784716	5.732	9.244	0.1898932	0.926	1.519	0.10505367
		EBT	13.017	11.741	0.21773395	22.547	38.711	0.00077755	7.778	9.444	0.07610339
		WBT	7.113	5.852	0.14458357	30.797	33.963	0.54547496	4.111	4.852	0.3237321
	NP	NBT	10.100	10.645	0.58473734	12.483	23.199	0.00213803	5.333	5.806	0.57323471
		SBT	7.600	7.581	0.97793252	7.086	10.231	0.07476182	2.033	2.839	0.15810721
		EBT	5.700	6.452	0.30273642	30.080	35.701	0.22337379	4.000	5.290	0.05973661
		WBT	4.300	4.290	0.98628787	27.726	37.434	0.04649338	2.900	3.867	0.06326605
	PM	NBT	8.867	8.067	0.28259059	19.419	25.270	0.0853706	5.333	5.000	0.57541411
		SBT	15.400	13.767	0.20752316	12.906	19.450	0.00785558	5.300	7.233	0.04461025
		EBT	6.867	6.167	0.22354658	20.165	29.487	0.00616664	5.433	4.933	0.31445129
		WBT	11.267	10.333	0.33097932	21.540	39.104	6.8352E-06	7.400	8.000	0.47623979

Based on the statistical tests, the results of volume, delay, and queue length comparisons are presented in Table 5. They can be grouped into three categories: (a) lane groups with no significant changes in delay or volume (Unch); (2) lane groups with significant increases in delay or volume (Inc); and (3) lane groups with significant decreases in delay or volume (Dec). Table 6 shows the number and percent of lane groups in each group. The column with heading "%" gives the ratio of the number of lane groups divided by the total number of lane groups, which is 57.

Table 6. Summary of t-test Results at 90% and 97% Confidence Levels

Categories	No. of lane groups (90% CL*)	%	No. of lane groups (97% CL)	%
VOLUME				
Total	57		57	
Unchanged (Unch)	36	63%	41	72%
Significantly increased (Inc)	5	9%	4	7%
Significantly decreased (Dec)	16	28%	12	21%
DELAY				
Total	57		57	
Unchanged (Unch)	23	40%	32	56%
Significantly increased (Inc)	30	53%	23	40%
Significantly decreased (Dec)	4	7%	2	4%
QUEUE LENGTH				
Total	57		57	
Unchanged (Unch)	28	49%	37	65%
Significantly increased (Inc)	27	47%	20	35%
Significantly decreased (Dec)	2	4%	0	0%

*CL: Confidence level.

To maintain a 91% confidence level for the combined analyses (volume, delay, and queue all together) that is discussed in the next sections, a confidence level of 97% for the single variable comparisons (volume to volume, delay to delay, etc.) is used. In general, for comparison of individual variables (volume, delay, or queue length alone), confidence levels of 90% or 95% is used.

With a 97% confidence level:

- Out of the 57 lane-group-volume comparisons, 41 lane groups (72%) showed no significant change in volume; however, 4 (7%) had a significant increase, and 12 (21%) had a significant decrease.
- Out of the 57 lane-group-delay comparisons, 32 lane groups (56%) had no significant change in delay; however, 23 (40%) showed a significant increase, and 2 (4%) showed significant decrease.
- Out of the 57 lane-group-queue-length comparisons, 37 (65%) had no significant change in queue length; however, 20 (35%) showed a significant increase, and none had a significant decrease.
- Volume significantly increased in 7% of the lane groups, delay significantly increased in 40%, and queue significantly increased in 35%. Similarly, volume decreased significantly in 21% of the lane groups, but delay significantly decreased in 4% of the lane groups and there was no queue length decrease. These findings are indications that the ASCT was not improving traffic operation conditions for the cases where volume was significantly increased.

4.2.2 Delay and Volume Combination Analysis

Looking at the changes in delay without paying attention to the changes in traffic volume may not reveal the impact of ASCT on traffic operation. Delay may increase due to the volume increase, and ASCT may also show an increase in delay; but this pattern is not an indication that ACST is not working properly. To consider the influence of volume changes on the delay changes, a combined-analysis approach is used, where the delay-volume, D_V, performance measure is analyzed. As Table 7 shows,

- In the 41 lane groups for which volume remained unchanged, delay significantly increased in 19, remained unchanged in 20, and decreased in 2.
- In the 4 lane groups for which volume significantly increased, delay significantly increased in only 1, and remained unchanged in 3.
- In the 12 lane groups for which volume significantly decreased, delay remained unchanged in 9 and significantly increased in 3.

Table 7. Summary of Volume and Delay Combination Analysis at 94% Confidence Level (0.97*0.97 Individual Confidence Levels)

Number of lane groups					
Categories	Delay increased	Delay unchanged	Delay decreased	**Total**	**%**
Volume increased	1	3	0	**4**	**7%**
Volume unchanged	19	20	2	**41**	**72%**
Volume decreased	3	9	0	**12**	**21%**
Total				**57**	

- The final decision as to whether these changes should be considered improvement or deterioration will be made when all three variables (volume, delay, and queue length) are considered. Based on the volume and delay combination (only two variables), the results can be grouped into three groups, e.g., categories (this is not a complete picture): (1) in 20 lane groups, both delay and volume were unchanged (white cell in Table 7); (2) in 3 lane groups, delay remained unchanged while volume increased; and there was no lane group with delay decrease and volume increase; but in 1 case, delay decreased while volume remained unchanged (green cells in Table 7); (3) in 19 lane groups, delay increased while volume remained unchanged; in 9, delay remained unchanged while volume significantly decreased; and in 3, delay significantly increased and volume decreased significantly (blue cells in Table 7). For the lane groups where both delay and volume significantly increased/decreased (yellow cells), *HCS 2010 (9)* was used to estimate the expected delay increase/decrease due to the volume change. More detailed information on these special cases, as well as intersection-level delay and volume combination analysis, is given in Appendix A.2

4.2.3 Queue Length and Volume Combination Analysis

To consider the influence of volume changes on queue length changes, similar to the delay and volume combined analysis, a combined analysis approach is used in which the queue length-volume, Q_V, performance measure is analyzed. Table 8, shows the summary of the volume and queue length conditions for all cases in the study.

- In the 41 lane groups for which volume remained unchanged, queue length significantly increased in 13, remained unchanged in 28, and decreased in none.
- In the 4 lane groups for which volume significantly increased, queue length significantly increased in all 4.
- In the 12 lane groups for which volume significantly decreased, queue length remained unchanged in 8, significantly decreased in 1, and significantly increased in 4.

Table 8. Summary of Volume and Queue-Length Combination Analysis, 0.94 Confidence Levels

Number of lane groups					
	Queue increased	Queue unchanged	Queue decreased	**Total**	**%**
Volume increased	4	0	0	**4**	**7%**
Volume unchanged	13	28	0	**41**	**72%**
Volume decreased	3	9	0	**12**	**21%**
Total				**57**	

- As mentioned before, the final decision as to whether these changes should be considered improvement or deterioration will be made when all three variables (volume, delay, and queue length) are considered. Based on the volume and queue length combination (only two variables), the results can be grouped into three categories (even though this analysis does not give a complete picture): (1) in 28 lane groups, both queue length and volume remained unchanged (white cell in Table 8); (2) in no lane group did queue length remain unchanged while volume increased, and in no case did queue length decrease while volume remained unchanged or significantly increased (green cells in Table 8); (3) in 13 lane groups, queue length increased while volume remained unchanged; in 2, queue length significantly increased while volume significantly decreased; and in 9, queue length remained unchanged while volume decreased significantly (blue cells in Table 8). For the lane groups in which both queue length and volume significantly increased/decreased (yellow cells), *HCS 2010* was used to estimate the expected queue length increases/decreases due to the volume changes. More detailed information on these special cases, as well as intersection level queue length and volume combination analysis, is given in Appendix A.2.

4.3 ANALYSIS OF THE ASCT PERFORMANCE

Considering the volume, delay, and queue length changes combined, an overall performance indicator (PI) was determined for each lane group, for each intersection, and for each time period. Almost all of the lane groups could easily be assigned to one of three PI categories (classes): Imp (Improved), Unch (Unchanged), or Det (Deteriorated). For example, the class for which volume increased significantly while delay and queue length significantly decreased: that approach was placed in Imp category. The Unch category is assigned to an approach when volume, delay, and queue length remained unchanged. Finally, the Det category is assigned to an approach for which volume did not change significantly; but delay and queue length significantly increased. However, for a very small number of lane groups, careful consideration is needed to determine their category. On the rare occasion that the lane group could not be assigned into one of the three categories, it was labeled as "Mixed" results. The results of such determinations are summarized in Table 9.

4.3.1 Number of Cases Involved in Performance Analysis

According to Table 5, further investigation was done for the cases with average volumes of more than 2 cars. According to the frequency at which the signal was called for a green-time allocation to a specific phase, for a specific case, if in 50% or more of the cycles during the analysis period, the corresponding phase called the signal, we took that case into consideration; but if the signal was called less frequently (less than 50%), we did not take that case into account any more. As a result, one case was removed from the list of cases for further analysis: Neil and Stadium, WB, during the AM peak, with an average volume of 0.7 car under TBC 2017 and 0.5 car under ASCT 2017. Thus, the number of cases analyzed is 56 in the following sections.

Table 9. PI for Three Volume Groups, Considering Delay and Queue, at 91% Confidence Level

(a) when VOLUME INCREASED SIGNIFICANTLY (on 4 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	Det* (1)	Imp* (1), Det* (2)	-
Unchanged	-	-	-
Decreased	-	-	-

(b) when VOLUME DECREASED SIGNIFICANTLY (on 11 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	Det *(1)	Det (1)	-
Unchanged	Det (2)	Det (7)	-
Decreased	-	-	-

(c) when VOLUME DID NOT CHANGE SIGNIFICANTLY (on 41 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	Det (11)	Det (2)	-
Unchanged	Det (8)	Unch (18)	Imp (2)
Decreased	-	-	-

Note: The Imp* and Det* indicate that some of the PIs are a result of the *HCS* runs mentioned in previous sections.

Now that the PI for each lane group is determined, Table 10 summarizes the outcome of the analyses for each lane group during the three time periods (AM peak, off peak, and PM peak). The *NA* entry indicates that the Stadium intersection on WB, AM, is removed from the analysis due to the low volume, leaving 56 cases.

Table 10. Performance Indicator (PI) for Each Lane Group at 91% Confidence Level

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

Table 11 gives the ratio of the number of lane groups in a category to the total number of lane groups analyzed at that intersection. In the last row of Table 11, the ratios for the corridor level are given.

Table 11. Performance Indicator (PI) at Intersection and Corridor Levels at 91% Confidence Level

Performance / Intersections	Improved	Deteriorated	Unchanged
Stadium	0/11	10/11	1/11
Kirby	2/12	8/12	2/12
St. Mary's	0/12	5/12	7/12
Devonshire	1/9	5/9	3/9
Windsor	0/12	7/12	5/12
Total at corridor level (%)	3/56 (5%)	35/56 (63%)	18/56 (32%)

Out of the 56 lane groups, PI improved in 3 lane groups (5%), remained unchanged in 18 (32%), and deteriorated in 35 (63%)—as shown in Table 11.

Overall, PI either improved or remained unchanged in 37% of the lane groups. However, in 63%, PI deteriorated. Out of the 35 deteriorated cases (the 63%), volume significantly increased in 3, did not change significantly in 21, and significantly decreased in 11. The deterioration in the 3 cases can be attributed to the volume increase, which indicates the system's inability to respond adequately to the volume increase. However, in the 21 lane groups for which volume did not change significantly, the deterioration in PI is not expected.

Schematically, Figure 8 reflects the improvements and deteriorations at each intersection.

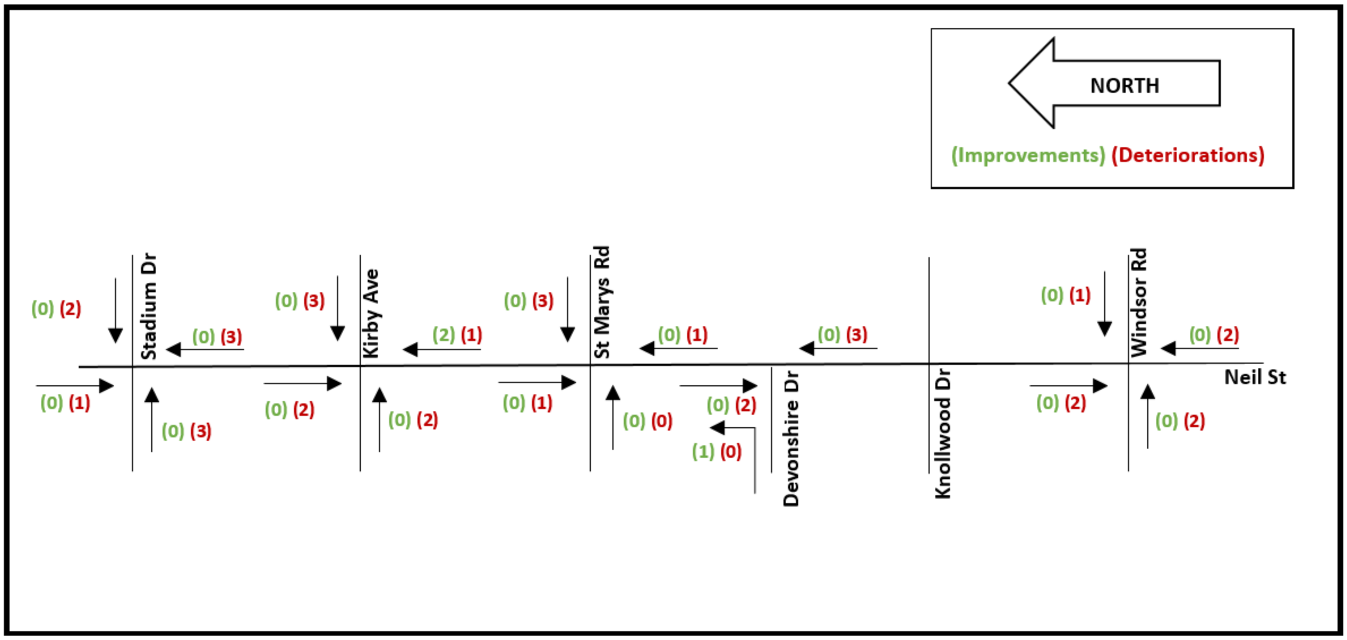

Figure 8. Number of improvements and deteriorations at intersections on Neil Street.

In the next section, the changes of PI at each intersection is discussed.

4.4 DETAILED ANALYSIS OF PI AT INTERSECTION LEVEL

In the following section, the ASCT performance at each intersection for each time period is further analyzed, considering volume, delay, and queue length combined. Thus, we will use the words “improved,” “deteriorated,” “unchanged,” and “mixed results” as the performance indicator (PI) for each approach of each intersection.

4.4.1 Neil Street and Stadium Drive

AM peak (AM): Generally, there was deterioration on all approaches analyzed.

Major street: During this period, even though the through volumes on two approaches (NB, SB) remained unchanged, queue and delay significantly increased. Thus, performance deteriorated on the NB and SB approaches.

Minor street: Volume on EB approach significantly decreased; delay and queue length significantly increased. Thus, ASCT performance deteriorated on EB. WB is removed from further analysis due to low volume.

Noon peak (NP): Generally, there was deterioration on all approaches except for SB, which had unchanged performance.

Major street: Although volume on NB remained unchanged, delay and queue length increased significantly. Volume, delay, and queue length remained unchanged on SB. Thus, performance deteriorated on NB and remained unchanged on SB.

Minor street: Although volume decreased significantly on EB and WB approaches, delay remained unchanged on both. Queue length increased significantly on EB and remained unchanged on WB. Thus, the intersection performance deteriorated on EB and WB approaches.

PM peak (PM): Generally, there was deterioration on all approaches.

Major street: On NB and SB, volume did not changed significantly; delay remained unchanged on NB and increased significantly on SB. Queue length significantly increased on both NB and SB approaches. Thus, performance deteriorated on NB and SB approaches.

Minor street: Volume decreased significantly on EB and remained unchanged on WB. Delay increased significantly on both EB and WB approaches. Queue length remained unchanged on EB and increased significantly on WB. Thus, performance deteriorated on EB and WB approaches.

Summary: At the intersection of Neil and Stadium, for all 11 analyzed approaches during all three time periods, system performance did not improve on any approach, remained unchanged on one, and deteriorated on 10.

4.4.2 Neil Street and Kirby Avenue

AM peak (AM): Generally, ASCT performance deteriorated on all approaches.

Major street: Volume remained unchanged, and both delay and queue length increased significantly on NB; therefore, performance deteriorated on NB. On SB, volume decreased significantly; delay and queue length remained unchanged; therefore, performance deteriorated on SB.

Minor street: Volume remained unchanged, and both delay and queue length increased significantly on EB; therefore, performance deteriorated on EB. On WB, although volume decreased significantly, delay and queue length remained unchanged.

Noon peak (NP): Generally, performance improved on NB, remained unchanged on SB, and deteriorated on EB and WB.

Major street: Volume and queue length remained unchanged on NB and SB. Delay decreased significantly on NB and remained unchanged on SB.

Minor street: Although volume and queue length remained unchanged on EB, delay increased significantly. On WB, volume decreased significantly; delay increased significantly; and queue length remained unchanged.

PM peak (PM): Generally, performance improved on NB, deteriorated on SB, remained unchanged on EB, and deteriorated on WB.

Major street: On NB, although volume and queue length remained unchanged, delay decreased significantly; therefore, performance improved on NB. On SB, volume decreased significantly, but delay and queue length increased significantly; therefore, performance deteriorated on SB.

Minor street: On EB, volume, delay, and queue length did not change significantly. On WB, volume decreased significantly; but delay and queue length remained unchanged. Thus, system performance remained unchanged on EB and deteriorated on WB.

Summary: At the intersection of Neil and Kirby, for all 12 approaches during all three time periods, system performance improved on 2 approaches, remained unchanged on 2, and deteriorated on 8.

4.4.3. Neil Street and St. Mary's Road

AM peak (AM): Generally, performance remained unchanged on NB, SB, and EB, and deteriorated on WB.

Volume, delay, and queue length remained unchanged on NB, SB, and EB approaches. On WB, although volume decreased significantly, delay and queue length remained unchanged. Thus, performance deteriorated on WB.

Noon peak (NP): Generally, performance deteriorated on NB, SB, and WB, and remained unchanged on EB.

Major street: On NB, volume and queue length increased significantly; and delay remained unchanged. The queue length increase was more than expected due to the volume increase (based on the *HCS* runs, see A.2). Thus, performance deteriorated on NB. On SB, volume, delay, and queue length increased significantly. The increase in both delay and queue length was more than expected due to the volume increase (based on the *HCS* runs, see A.2). Thus, the performance deteriorated on SB.

Minor street: On EB, volume, delay, and queue length remained unchanged. On WB, although volume decreased significantly, delay and queue length remained unchanged. Thus, performance remained unchanged on EB and deteriorated on WB.

PM peak (PM): Generally, performance remained unchanged on NB, SB, and EB. Performance deteriorated on WB.

Volume, delay, and queue length remained unchanged on NB, SB, and EB. On WB, although volume decreased significantly, delay increased significantly; and queue length remained unchanged. Thus, performance deteriorated on WB.

Summary: At the intersection of Neil and St. Mary's, for all 12 approaches during all three time periods, system performance improved on no approaches, remained unchanged on 7, and deteriorated on 5.

4.4.4. Neil Street and Devonshire Drive

Note that the minor-street analysis at this intersection is for EBL (eastbound left) approach only.

AM peak (AM): Generally, performance deteriorated on NB and remained unchanged on SB and EBL.

Volume remained unchanged on all three approaches. On NB, delay and queue length increased significantly. On SB and EBL, delay and queue length did not change significantly.

Noon peak (NP): Generally, during this period, performance deteriorated on NB and SB, and remained unchanged on EBL.

On NB, volume and queue length increased significantly; and delay remained unchanged. The queue-length increase was more than expected due to the volume increase (based on the *HCS* runs, see A.2). Thus, the performance deteriorated on NB.

On SB, volume did not change significantly although delay and queue length increased significantly.

On EBL, volume, queue length, and delay did not change significantly. Thus, the performance remained unchanged on EBL.

PM peak (PM): Generally, performance deteriorated on NB and SB, and improved on EBL.

On NB, volume and delay remained unchanged although queue length increased significantly.

On SB, volume did not change significantly; but both delay and queue increased significantly.

On EBL, volume and queue length increased significantly; but delay did not change significantly. The queue-length increase was less than expected due to the volume increase (based on the *HCS* runs, see A.2). Thus, the performance improved on EBL.

Summary: At the intersection of Neil and Devonshire, for the 9 approaches during three time periods, system performance improved on 1 approach, remained unchanged on 3, and deteriorated on 5.

4.4.5. Neil Street and Windsor Road

AM peak (AM): Generally, performance deteriorated on NB, SB, and EB and remained unchanged on WB.

Volume decreased significantly on SB and remained unchanged on all other approaches. On NB, SB, and EB, queue length increased significantly; and it remained unchanged on WB. Delay increased significantly on NB and EB, and remained unchanged on SB and WB.

Noon peak (NP): Generally, performance deteriorated on NB and remained unchanged on SB, EB, and WB.

Volume and queue length remained unchanged on NB, and delay increased significantly. Thus, performance deteriorated on NB. On all other approaches, volume, delay, and queue length remained unchanged; therefore, performance remained unchanged on SB, EB, and WB.

PM peak (PM): Generally, performance remained unchanged on NB and deteriorated on SB, EB, and WB.

Volume, delay, and queue length remained unchanged on NB.

On SB, EB, and WB, volume and queue length remained unchanged; delay significantly increased. Thus, performance deteriorated on SB, EB, and WB.

Summary: At the intersection of Neil and Windsor, for the 12 approaches during three time periods, system performance did not improve on any approach, remained unchanged on 5, and deteriorated on 7.

4.5 DETERIORATION ANALYSIS

The results showed a 63% deterioration (35 cases) in performance at the intersections along Neil Street. Further analysis was performed to investigate possible causes for the deterioration.

4.5.1. Deterioration due to Arrival Type Changes under ASCT 2017

Quality of progression at signalized intersections along a coordinated corridor is decided based on the arrival type (AT) (*10*). The AT parameter is based upon the percentage of vehicles arriving during the green indication, when they arrive during the green interval, and the density of the arriving platoon.

Currently, two common methods are available to determine arrival types at a signalized intersection, on a cycle-by-cycle basis: the *HCM* method and a visual method. In the visual method, the procedure involves matching the observed traffic conditions (through videos) to one of the detailed definitions of quality of progression and arrival types. These definitions are based on platoon arrival time during the cycle. Depending on a platoon arrival time, the observer assigns an arrival type of 1 to 5 for each approach during a signal cycle. No arrival type 6 was observed. During data reduction, it was observed that a platoon arrives during a span of time that practically can be considered a “point.” For example, a platoon with very favorable progression (arrival type 5) can arrive around the beginning of green but does not need to be exactly at the beginning of green. A reasonable range was established for data-reduction purposes. These ranges are shown in Table 12 and schematically shown in Figure 9.

Table 12. Relationship between Arrival Type and Platoon-Arrival Time

Arrival type	Arrival time of the platoon	Progression quality
1	95% of the green elapsed—25% of the red elapsed	Very poor
2	25% of the red elapsed—95% of the red elapsed	Poor
3	Random arrivals did not platoon anytime during a cycle.	No platooning
4	25% of the green elapsed—75% of the green elapsed	Good
	75% of the green elapsed—95% of the green elapsed	Not good
5	95% of the red elapsed—25% of the green elapsed	Very good

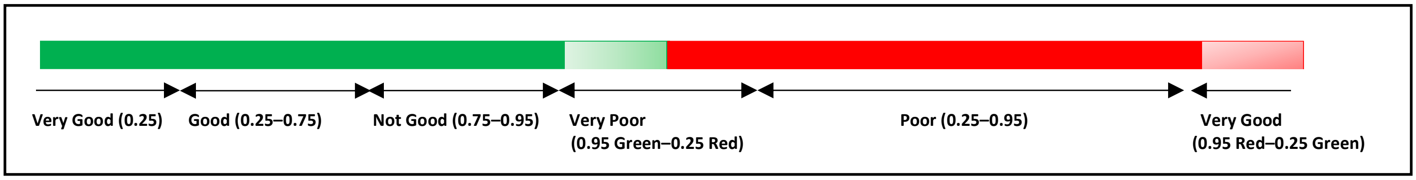

Figure 9. Relationship between the relative platoon-arrival time and progression quality.

We have determined cycle-by-cycle arrival types for the deteriorated cases, using March and April 2017 videos. This way, we compared the arrival types in March and those in April for the cases with deteriorated performances.

In the cases for which arrival types where mostly very good or good in March and very poor or poor in April, we can conclude that unfavorable arrival types in April could be the reason for the deterioration. Cases with the condition mentioned are highlighted in Table 13. In 10 cases, the arrival type worsened. In all 10 cases, the PI also deteriorated.

Table 13. Cases with Deteriorated Performance under ASCT 2017 and with More Frequent Unfavorable Arrival Types, as Compared to TBC 2017

Intersections	Approach	AM Peak	Noon Peak	PM Peak
Stadium	NBT	Det[1]	Det	Det
	SBT	Det	Unch	Det[2]
	EBT	Det	Det	Det
	WBT	*NA*	Det	Det
Kirby	NBT	Det	Imp	Imp
	SBT	Det	Unch	Det
	EBT	Det	Det	Unch
	WBT	Det	Det	Det
St. Mary's	NBT	Unch	Det	Unch
	SBT	Unch	Det	Unch
	EBT	Unch	Unch	Unch
	WBT	Det	Det	Det
Devonshire	NBT	Det[3]	Det	Det[4]
	SBT	Unch	Det	Det[5]
	EBL	Unch	Unch	Imp
Windsor	NBT	Det[6]	Det	Unch
	SBT	Det[7]	Unch	Det[8]
	EBT	Det	Unch	Det
	WBT	Unch	Unch	Det

Based on the highlighted and numbered cases above, an analysis of the detailed cycle-by-cycle arrival-type conditions is presented in the following:

1. Stadium, AM, NB:

Table 14. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Stadium, AM, NB	TBC 2017	ASCT 2017
Cycles	58	58
Very good or good	53%	34%
Poor or very poor	2%	19%
Not good	0%	12%
No platooning	45%	34%

Based on Table 14, during the AM peak at Stadium NB under TBC 2017, 53% of the cycles had very good or good ATs; and only 2% had poor or very poor. Under ASCT 2017, 34% of the cycles had very good or good ATs; and 19% had poor or very poor. Also, the ATs in the not-good category were more frequent during ASCT 2017. These findings show that the ATs were relatively worsened under ASCT 2017; and Stadium, AM, NB was in a better condition during TBC 2017, in terms of AT.

2. Stadium, PM, SB:

Table 15. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Stadium, PM, SB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	77%	25%
Poor or very poor	3%	31%
Not good	3%	5%
No platooning	17%	39%

Based on Table 15, during the PM peak at Stadium SB under TBC 2017 conditions, 77% of the cycles had very good or good ATs; and 3% had poor or very poor. Under ASCT 2017, 25% of the cycles had very good or good ATs; and 31% had poor and very poor. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to TBC 2017. These findings show that ATs were relatively worsened under ASCT 2017; and Stadium, PM, SB was in a better condition during TBC 2017, in terms of AT.

3. Devonshire, AM, NB:

Table 16. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Devonshire, AM, NB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	82%	29%
Poor or very poor	11%	57%
Not good	0%	0%
No platooning	32%	11%

Based on Table 16, during the AM peak at Devonshire NB under TBC 2017 conditions, 82% of the cycles had very good or good ATs; and 11% had poor or very poor. Under ASCT 2017, 29% of the cycles had very good or good ATs; and 57% had poor or very poor. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to TBC 2017. These findings show that the ATs were relatively worsened under ASCT 2017; and Devonshire, AM, NB was in a better condition during TBC 2017, in terms of AT.

4. Devonshire, PM, NB:

Table 17. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Devonshire, PM, NB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	63%	50%
Poor or very poor	3%	23%
Not good	0%	0%
No platooning	30%	27%

Based on Table 17, during the PM peak at Devonshire NB under TBC 2017 conditions, 63% of the cycles had very good or good ATs; and 3% had poor or very poor. Under ASCT 2017, 50% of the cycles had very good or good ATs; and 23% had poor or very poor. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to TBC 2017. These findings show that the ATs were relatively worsened under ASCT 2017; and Devonshire, PM, NB was in a better condition during TBC 2017, in terms of AT.

5. Devonshire, PM, SB:

Table 18. Distribution of the Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Devonshire, PM, SB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	89%	33%
Poor or very poor	0%	37%
Not good	0%	0%
No platooning	32%	10%

Based on Table 18, during the PM peak at Devonshire SB under TBC 2017 conditions, 89% of the cycles had very good or good ATs; and none had poor or very poor. Under ASCT 2017, 33% of the cycles had very good or good ATs; and 37% had poor or very poor. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to the TBC 2017 conditions. These findings show that the ATs are relatively worsened under ASCT 2017; and Devonshire, PM, SB was in a better condition under TBC 2017, in terms of AT.

6. Windsor, AM, NB:

Table 19. Distribution of the Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Windsor, AM, NB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	61%	18%
Poor or very poor	14%	54%
Not good	4%	11%
No platooning	21%	18%

Based on Table 19, during the AM peak at Windsor NB under TBC 2017 conditions, 61% of the cycles had very good or good ATs; and 14% had poor or very poor. Under ASCT 2017, 18% of the cycles had very good or good ATs; and 54% had poor or very poor. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to TBC 2017 conditions. These findings show that ATs were relatively worsened under ASCT 2017; and Windsor, AM, NB was in a better condition during TBC 2017, in terms of AT.

7. Windsor, AM, SB:

Table 20. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Windsor, AM, SB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	43%	33%
Poor or very poor	7%	15%
Not good	0%	0%
No platooning	50%	52%

Based on Table 20, during the AM peak at Windsor SB under TBC 2017 conditions, 43% of the cycles had very good or good ATs; and 7% had poor or very poor. Under ASCT 2017, 33% of the cycles had very good or good ATs; and 15% had poor or very poor. These findings show that the ATs were relatively worsened under ASCT 2017; and Windsor, AM, SB was in a better condition during TBC 2017, in terms of AT.

8. Windsor, PM, SB:

Table 21. Distribution of Arrival Types for TBC 2017 vs. ASCT 2017 Conditions

Windsor, PM, SB	TBC 2017	ASCT 2017
Cycles	28	28
Very good or good	90%	43%
Poor or very poor	7%	40%

Not good	0%	13%
No platooning	3%	3%

Based on Table 21, during the PM peak at Windsor SB under TBC 2017 conditions, 90% of the cycles had very good or good ATs; and 7% had poor or very poor. Under ASCT 2017, 43% of the cycles had very good or good ATs; but 40% had poor or very poor. Also, the percent for the "not good" arrival-type category was 13% for ASCT 2017, as compared to 0% for TBC 2017. These findings show that good progression conditions were less frequent during ASCT 2017 and poor progression conditions more frequent, as compared to TBC 2017. These findings show that ATs were relatively worsened under ASCT 2017; and Windsor, PM, SB was in a better condition during TBC 2017, in terms of AT.

4.5.2 Deterioration due to Insufficient System Response to Volume Increase

Among the 56 cases, 3 had significant volume increase. In all 3 cases, volume increase resulted in deterioration in system performance, showing the system response was insufficient for the volume increase. Based on the volume increase, some adjustments to the signal timing is to be expected, such as increase in the green time or cycle length for the subject lane group. The system's failure to adapt the signal timing to the volume changes could be the cause of the deterioration. These cases are highlighted in Table 22: NB and SB at St. Mary's during the noon peak and NB at Devonshire during the noon peak.

Table 22. Cases in Which the System Response Is Insufficient to the Volume Increase

Intersections	Approach	AM Peak	Noon Peak	PM Peak
Stadium	NBT	Det	Det	Det
	SBT	Det	Unch	Det
	EBT	Det	Det	Det
	WBT	*NA*	Det	Det
Kirby	NBT	Det	Imp	Imp
	SBT	Det	Unch	Det
	EBT	Det	Det	Unch
	WBT	Det	Det	Det
St. Mary's	NBT	Unch	Det[1]	Unch
	SBT	Unch	Det[2]	Unch
	EBT	Unch	Unch	Unch
	WBT	Det	Det	Det
Devonshire	NBT	Det	Det[3]	Det
	SBT	Unch	Det	Det
	EBL	Unch	Unch	Imp
Windsor	NBT	Det	Det	Unch
	SBT	Det	Unch	Det
	EBT	Det	Unch	Det
	WBT	Unch	Unch	Det

4.5.3 Deterioration due to Signal Timing Changes

We examined the cycle length changes, the "Average Effective Green Time" change, and "the g/C Ratio" changes between TBC 2017 and ASCT 2017 to find potential factors contributing to the deterioration. The details are given in Appendix A.3 and a brief summary in the following sections.

To investigate the changes in the signal timing between TBC 2017 and ASCT 2017, t-tests were conducted to compare the average effective greens, average g/C ratios, and average cycle lengths. Specific test results are presented in Table 23.

Table 23. Signal Timing Change Comparisons between TBC 2017 and ASCT 2017

			Previous results			Signal timing changes											
						Average cycle length changes				Average effective green time changes				Average g/C changes			
Intersection	Time period	Approach	Delay change (Apr–Mar)	Queue length change (Apr–Mar)	PI	April cycle length average	March cycle length average	p-value	Cycle length change (Apr–Mar)	April effective green time average	March effective green time average	p-value	Effective green time change (Apr–Mar)	April average g/C	March average g/C	p-value	g/C change (Apr-Mar)
Stadium	AM	NBT	Inc	Inc	Det	60.862	54.985	1.367E-18	Inc	32.06	28.32	1.08E-08	Inc	0.53	0.52	0.2718	Unch
		SBT	Inc	Unch	Det					32.06	28.32	1.08E-08	Inc	0.53	0.52	0.2718	Unch
		EBT	Inc	Inc	Det					17.01	14.85	0.0007	Inc	0.28	0.27	0.3372	Unch
		WBT	Unch	Inc	-					17.01	14.85	0.0007	Inc	0.28	0.27	0.3372	Unch
	NP	NBT	Inc	Inc	Det	55.092	56.698	0.0049	Dec	28.55	31.60	6.05E-06	Dec	0.52	0.56	0.0003	Dec
		SBT	Unch	Unch	Unch					28.55	31.60	6.05E-06	Dec	0.52	0.56	0.0003	Dec
		EBT	Unch	Inc	Det					14.75	13.30	0.0301	Unch	0.27	0.23	0.0023	Inc
		WBT	Unch	Unch	Det					14.75	13.30	0.0301	Unch	0.27	0.23	0.0023	Inc
	PM	NBT	Unch	Inc	Det	60.339	60	0.4669	Unch	31.07	31.19	0.7791	Unch	0.51	0.52	0.5500	Unch
		SBT	Inc	Inc	Det					31.07	31.19	0.7791	Unch	0.51	0.52	0.5500	Unch
		EBT	Inc	Unch	Det					17.47	17.01	0.5221	Unch	0.29	0.28	0.6170	Unch
		WBT	Inc	Inc	Det					17.47	17.01	0.5221	Unch	0.29	0.28	0.6170	Unch
Kirby	AM	NBT	Inc	Inc	Det	121.5	110	2.398E-15	Inc	42.74	37.87	0.0002	Inc	0.35	0.34	0.4424	Unch
		SBT	Unch	Unch	Det					53.37	46.50	0.0032	Inc	0.44	0.42	0.3693	Unch
		EBT	Inc	Inc	Det					34.73	37.63	3.22E-03	Dec	0.29	0.34	6.35E-08	Dec
		WBT	Unch	Unch	Det					38.62	38.21	0.7877	Unch	0.32	0.35	0.0386	Unch
	NP	NBT	Dec	Unch	Imp	110.032	110	0.9785	Unch	45.03	41.35	0.0346	Unch	0.41	0.38	0.0350	Unch
		SBT	Unch	Unch	Unch					43.90	41.10	0.1110	Unch	0.40	0.37	0.1053	Unch
		EBT	Inc	Unch	Det					22.62	34.00	4.82E-08	Dec	0.20	0.31	2.39E-09	Dec
		WBT	Inc	Unch	Det					27.42	36.52	4.46E-08	Dec	0.25	0.33	6.19E-09	Dec
	PM	NBT	Dec	Unch	Imp	118.231	120	0.1926	Unch	48.69	49.27	0.7474	Unch	0.41	0.41	0.8764	Unch
		SBT	Inc	Inc	Det					44.24	44.66	0.7450	Unch	0.37	0.37	0.5220	Unch
		EBT	Unch	Unch	Unch					30.27	31.27	0.2995	Unch	0.25	0.26	0.1499	Unch
		WBT	Unch	Unch	Det					35.17	36.96	0.2181	Unch	0.29	0.31	0.1351	Unch

Note: Highlighted cells are explained in the text.

Table 23. Signal Timing Change Comparisons between TBC 2017 and ASCT 2017 (Cont.)

			Previous results			Signal timing changes											
						Average cycle length changes				Average effective green time changes				Average g/C changes			
Intersection	Time period	Approach	Delay change (Apr-Mar)	Queue length change (Apr-Mar)	PI	April cycle length average	March cycle length average	p-value	Cycle length change (Apr-Mar)	April effective green time average	March effective green time average	p-value	Effective green time change (Apr-Mar)	April average g/C	March average g/C	p-value	g/C change (Apr-Mar)
St. Mary's	AM	NBT	Unch	Unch	Unch	120.414	110	6.263E-16	Inc	65.42	61.59	0.0779	Unch	0.54	0.56	0.3193	Unch
		SBT	Unch	Unch	Unch					78.00	74.15	0.0649	Unch	0.65	0.67	0.0971	Unch
		EBT	Unch	Unch	Unch					22.11	18.14	0.0109	Inc	0.18	0.16	0.1547	Unch
		WBT	Unch	Unch	Det					24.01	18.17	1.13E-05	Inc	0.20	0.17	0.0032	Inc
	NP	NBT	Unch	Inc	Det	110.375	110	0.1099	Unch	55.12	61.21	0.0024	Dec	0.50	0.56	0.0016	Dec
		SBT	Inc	Inc	Det					63.40	67.37	0.0385	Unch	0.57	0.61	0.0265	Dec
		EBT	Unch	Unch	Unch					20.58	19.45	0.4482	Unch	0.19	0.18	0.4661	Unch
		WBT	Unch	Unch	Det					23.23	21.92	0.2329	Unch	0.21	0.20	0.2617	Unch
	PM	NBT	Unch	Unch	Unch	119.414	120	0.6254	Unch	69.38	60.87	0.0005	Inc	0.58	0.51	0.0001	Inc
		SBT	Unch	Unch	Unch					69.11	62.69	0.0086	Inc	0.58	0.52	0.0022	Inc
		EBT	Unch	Unch	Unch					15.67	22.46	1.93E-09	Dec	0.13	0.19	2.34E-08	Dec
		WBT	Inc	Unch	Det					29.04	35.60	7.88E-06	Dec	0.24	0.30	2.12E-05	Dec
Devonshire	AM	NBT	Inc	Inc	Det	120.464	110.031	2.658E-15	Inc	96.49	86.92	8.34E-11	Inc	0.80	0.79	0.2573	Unch
		SBT	Unch	Unch	Unch					91.35	83.37	0.0022	Inc	0.76	0.76	0.9619	Unch
		EBL	Unch	Unch	Unch					12.87	12.01	0.4434	Unch	0.11	0.11	0.8036	Unch
	NP	NBT	Unch	Inc	Det	110.4	110	0.11	Unch	82.46	84.38	0.2018	Unch	0.75	0.77	0.1365	Unch
		SBT	Inc	Inc	Det					73.99	78.35	0.0889	Unch	0.67	0.71	0.0669	Unch
		EBL	Unch	Unch	Unch					17.17	14.52	0.0424	Unch	0.16	0.13	0.0468	Unch
	PM	NBT	Unch	Inc	Det	119.333	120	0.5666	Unch	94.10	96.92	0.0951	Unch	0.79	0.81	0.0264	Dec
		SBT	Inc	Inc	Det					90.42	91.28	0.7440	Unch	0.76	0.76	0.8028	Unch
		EBL	Unch	Inc	Imp					14.41	11.98	0.0321	Unch	0.12	0.10	0.0275	Inc

Note: Highlighted cells are explained in the text.

Table 23. Signal Timing Change Comparisons between TBC 2017 and ASCT 2017 (Cont.)

			Previous results			Signal timing changes											
						Average cycle length changes				Average effective green time changes				Average g/C changes			
Intersection	Time period	Approach	Delay change (Apr-Mar)	Queue length change (Apr-Mar)	PI	April cycle length average	March cycle length average	p-value	Cycle length change (Apr-Mar)	April effective green time average	March effective green time average	p-value	Effective green time change (Apr-Mar)	April average g/C	March average g/C	p-value	g/C change (Apr-Mar)
Windsor	AM	NBT	Inc	Inc	Det	119.714	110	4.74E-08	Inc	50.71	49.23	0.6167	Unch	0.42	0.45	0.2646	Unch
		SBT	Unch	Unch	Det					52.89	52.93	0.9862	Unch	0.44	0.48	0.0644	Unch
		EBT	Inc	Unch	Det					31.58	30.47	0.5865	Unch	0.26	0.28	0.4769	Unch
		WBT	Unch	Unch	Unch					26.19	20.47	2.09E-05	Inc	0.22	0.19	0.0046	Inc
	NP	NBT	Inc	Unch	Det	109.258	113.516	0.0106	Dec	45.21	49.40	0.0617	Unch	0.41	0.43	0.2544	Unch
		SBT	Unch	Unch	Unch					49.79	54.77	0.0507	Unch	0.46	0.48	0.2250	Unch
		EBT	Unch	Unch	Unch					20.71	27.67	2.75E-07	Dec	0.19	0.24	6.49E-06	Dec
		WBT	Unch	Unch	Unch					23.19	28.03	0.0078	Dec	0.21	0.25	0.0318	Unch
	PM	NBT	Unch	Unch	Unch	118.367	120	0.2738	Unch	38.03	40.17	0.2428	Unch	0.32	0.33	0.3970	Unch
		SBT	Inc	Unch	Det					42.23	50.07	0.0003	Dec	0.36	0.42	0.0004	Dec
		EBT	Inc	Unch	Det					29.97	30.27	0.7794	Unch	0.25	0.25	0.8542	Unch
		WBT	Inc	Unch	Det					30.87	32.63	0.1616	Unch	0.26	0.27	0.1684	Unch

Note: Highlighted cells are explained in the text.

When cycle lengths were not significantly changed, any decrease in the average effective green time caused their red time increase, which then contributed to delay and/or queue length increases. The increased queue lengths or delays finally resulted in deterioration of the ASCT system performance during ASCT 2017. Under this circumstance, 6 deteriorated cases highlighted in Table 23 were explained. In contrast, any decrease in the g/C may not explain the deteriorations, because g and C can change simultaneously or both unchanged g and C can result in g/C decrease.

A summary of the cases explained is presented in Table 24; in which 6 cases explained by the decrease of average effective green time are highlighted. These explained cases accounted for 17% of the total of 35 deteriorated cases.

Table 24. Summary of Cases Explained by Signal Timing Change

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

Note: Highlighted cells indicate cases are explained in the text.

4.5.4 Deterioration due to Pedestrian Effects at Stadium Drive

At Stadium Drive, all lane groups except one showed deterioration. Also, 15 cycle lengths under TBC 2017 conditions had high values. We suspected pedestrian activities to be the cause of the deterioration. As shown in Table 25, 52 out of 183 cycles under ASCT and 54 out of 187 under TBC showed the pedestrian signal was on, with pedestrians crossing the major street. In contrast, 7 out of 183 cycles under ASCT 2017 and 4 out of 187 cycles under TBC 2017 showed the pedestrian signal was on, with pedestrians crossing the minor street. Hence, pedestrians crossing the major street were more prevalent than pedestrians crossing the minor street.

Table 25. Pedestrian Activities at Stadium Drive under ASCT 2017 and TBC 2017

		Pedestrian crossed major street	Pedestrian crossed minor street	No pedestrian cycles	Total
ASCT	AM	16	1	41	58
	NP	16	3	46	65
	PM	20	3	37	60*
Total cases for ASCT		**52**	**7**	**124**	**183**
TBC	AM	17	3	45	65*
	NP	15	0	48	63
	PM	22	1	36	59
Total cases for TBC		**54**	**4**	**129**	**187**

*For ASCT PM and TBC AM, one cycle in each showed pedestrian crossing of both major and minor streets.

4.5.4.1 Pedestrian Effects on Cycle Length and Green Time at Stadium Drive

Figure 10 shows the minor street's green time for each cycle and the cycle length under ASCT 2017 and TBC 2017 conditions at Stadium Drive during NP. The cycles marked "P" are those with pedestrian(s) present. In general, cycle lengths were higher when pedestrians were present, as compared to cycle lengths without pedestrians.

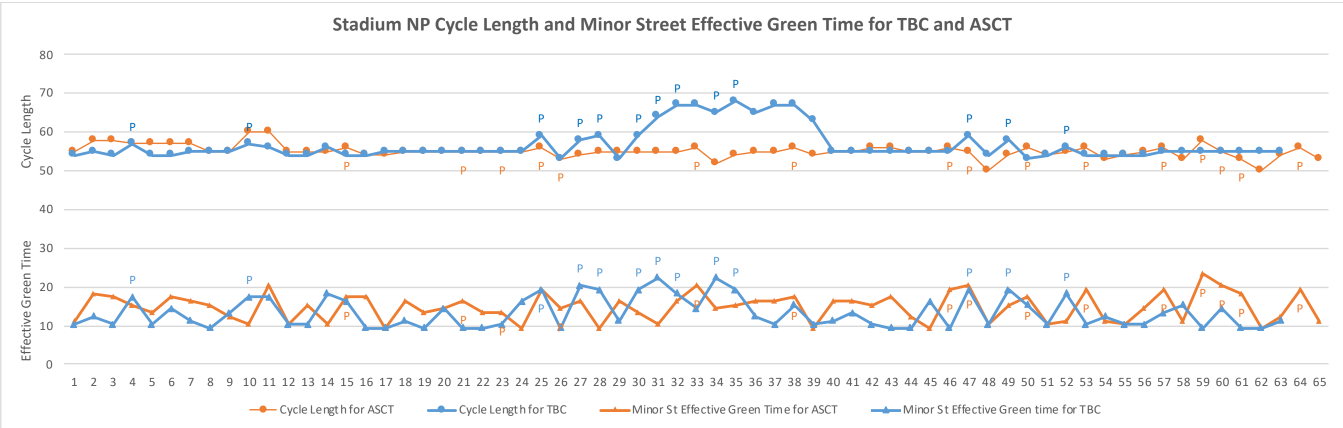

Figure 10. Cycle length and minor street's green time for TBC and ASCT conditions.

Comparisons were made between TBC and ASCT conditions with and without pedestrian presence on the minor street's average green time, major street's average green time, and cycle length, presented in Table 26.

Table 26. Green Time and Cycle Length with and without Pedestrians Present

Time periods	Green time/Cycle length (secs)		No pedestrians		Pedestrians present		Numerical difference	p value	Results with 97% confidence level	Results with 90% confidence level
			Average	Variance	Average	Variance				
AM	ASCT	Minor st green	16.6	15.2	18.4	18.4	1.8	0.0179	yes	yes
		Major st green	32.5	15.8	30.8	8.8	-1.7	0.0895	no	yes
		Cycle length	61	13	61	13	0	0.8732	no	no
	TBC	Minor st green	13.7	9.2	17.5	6.2	3.8	2.64E-05	yes	yes
		Major st green	28.9	9.0	27.0	1.5	-1.8	1.09E-03	yes	yes
		Cycle length	54	1	56	3	2	4.70E-04	yes	yes
NP	ASCT	Minor st green	13.6	9.1	18.4	6.0	4.8	3.66E-07	yes	yes
		Major st green	29.6	7.7	25.3	4.0	-4.3	8.59E-08	yes	yes
		Cycle length	55	4.0	56	1.0	1	0.2121	no	no
	TBC	Minor st green	11.8	6.6	18.2	12.4	6.4	1.64E-10	yes	yes
		Major st green	32.2	16.3	29.6	12.8	-2.6	0.0303	no	yes
		Cycle length	56	13.0	60	19.0	4	0.001	yes	yes
PM	ASCT	Minor st green	16.6	14.5	19.1	3.5	2.5	1.70E-03	yes	yes
		Major st green	32.3	18.1	28.8	6.2	-3.5	2.47E-04	yes	yes
		Cycle length	61	15	60	9	-1	0.3084	no	no
	TBC	Minor st green	15.83	20.60	19.3	5.05	3.47	2.87E-04	yes	yes
		Major st green	32.37	20.60	28.9	5.05	-3.47	0.0003	yes	yes
		Cycle length	60	0	60	0	0	—	—	—

In all three time periods, when pedestrians were present, the average green times for the minor streets were increased under both ASCT 2017 and TBC 2017 conditions, while the average green times for the major streets were reduced (with 90% confidence). Hence, at Stadium Drive, the pedestrians significantly (at 90% confidence level) reduced the major street's green time and increased the minor street's green time.

4.5.5 Deterioration due to Volume Miscounting

This section mainly discusses the volume-count comparisons between ASCT and field data. Table 27 shows the volume counts obtained from the ASCT system and those obtained by manually counting the vehicles in the videos taken at the sites (the field data). Comparisons between field and system hourly volume counts were made for March and April data. The March system volume was obtained from records the ASCT system had stored on the server. These volumes were not used in operating the signal during March 2017. The reason for using them here is to have matching data for the field data collected in March 2017.

Table 27. Comparisons of System Volume Count with Field Volume Count in 2017

Intersection	Time period	Approach	April system volume	April field volume	April volume change (system–field)	April percent of volume change (field base)	March system volume	March field volume	March volume change (system–field)	March percent of volume change (field base)
Stadium	AM	NBT	401	460	-59	-13%	351	462	-111	-24%
		SBT	248	342	-94	-27%	228	352	-124	-35%
		EBT	120	214	-94	-44%	132	270	-138	-51%
		WBT	48	30	18	60%	136	51	85	167%
	NP	NBT	336	419	-83	-20%	376	411	-35	-9%
		SBT	371	376	-5	-1%	363	387	-24	-6%
		EBT	67	65	2	3%	47	104	-57	-55%
		WBT	67	59	8	14%	53	87	-34	-39%
	PM	NBT	362	470	-108	-23%	317	436	-119	-27%
		SBT	449	500	-51	-10%	413	489	-76	-16%
		EBT	54	60	-6	-10%	48	124	-76	-61%
		WBT	200	238	-38	-16%	284	221	63	29%
Kirby	AM	NBT	294	491	-197	-40%	244	417	-173	-41%
		SBT	241	277	-36	-13%	194	318	-124	-39%
		EBT	294	388	-94	-24%	273	345	-72	-21%
		WBT	119	154	-35	-23%	369	223	146	65%
	NP	NBT	269	368	-99	-27%	306	363	-57	-16%
		SBT	319	300	19	6%	245	331	-86	-26%
		EBT	141	229	-88	-38%	141	195	-54	-28%
		WBT	187	205	-18	-9%	203	251	-48	-19%
	PM	NBT	255	337	-82	-24%	305	371	-66	-18%
		SBT	377	446	-69	-15%	287	503	-216	-43%
		EBT	173	217	-44	-20%	158	218	-60	-28%
		WBT	289	337	-48	-14%	322	477	-155	-32%

Table 27. Comparisons of System Volume Count with Field Volume Count in 2017 (Cont.)

Intersection	Time period	Approach	April system volume	April field volume	April volume change (system-field)	April percentage of volume change (field base)	March system volume	March field volume	March volume change (system-field)	March percentage of volume change (field base)
St. Mary's	AM	NBT	368	523	-155	-30%	383	525	-142	-27%
		SBT	333	236	97	41%	308	232	76	33%
		EBT	54	142	-88	-62%	88	141	-53	-38%
		WBT	47	35	12	34%	56	84	-28	-33%
	NP	NBT	285	539	-254	-47%	299	468	-169	-36%
		SBT	479	449	30	7%	483	376	107	28%
		EBT	67	105	-38	-36%	212	136	76	56%
		WBT	113	50	63	126%	96	130	-34	-26%
	PM	NBT	249	461	-212	-46%	331	442	-111	-25%
		SBT	530	573	-43	-8%	509	583	-74	-13%
		EBT	89	77	12	16%	93	119	-26	-22%
		WBT	185	166	19	11%	214	280	-66	-24%
Devonshire	AM	NBT	431	578	-147	-25%	458	589	-131	-22%
		SBT	266	224	42	19%	227	214	13	6%
		EBL	43	99	-56	-57%	45	99	-54	-55%
	NP	NBT	350	503	-153	-30%	325	430	-105	-24%
		SBT	370	436	-66	-15%	319	404	-85	-21%
		EBL	74	173	-99	-57%	46	135	-89	-66%
	PM	NBT	263	385	-122	-32%	277	387	-110	-28%
		SBT	538	651	-113	-17%	516	632	-116	-18%
		EBL	68	129	-61	-47%	39	84	-45	-54%
Windsor	AM	NBT	240	518	-278	-54%	241	516	-275	-53%
		SBT	188	106	82	77%	229	135	94	70%
		EBT	278	355	-77	-22%	235	353	-118	-33%
		WBT	124	184	-60	-33%	149	193	-44	-23%
	NP	NBT	188	351	-163	-46%	156	320	-164	-51%
		SBT	344	250	94	38%	394	241	153	63%
		EBT	163	213	-50	-23%	112	181	-69	-38%
		WBT	140	141	-1	-1%	101	136	-35	-26%
	PM	NBT	116	245	-129	-53%	180	270	-90	-33%
		SBT	314	419	-105	-25%	364	468	-104	-22%
		EBT	120	188	-68	-36%	173	209	-36	-17%
		WBT	289	314	-25	-8%	297	343	-46	-13%

Highlights: Red cell, overcounted; blue cell, undercounted; white cell, unchanged.

For March data, the system overcounted in 9 cases and undercounted in 48. Similarly, for April, the system overcounted in 12 cases and undercounted in 42. The average undercount for March and April was 31% and 29%, respectively. The average overcount for March and April was 57% and 37%, respectively. If we consider undercounts or overcounts of up to 5% as "similar," Figure 11 shows the frequency of under- or overcounting on major and minor streets.

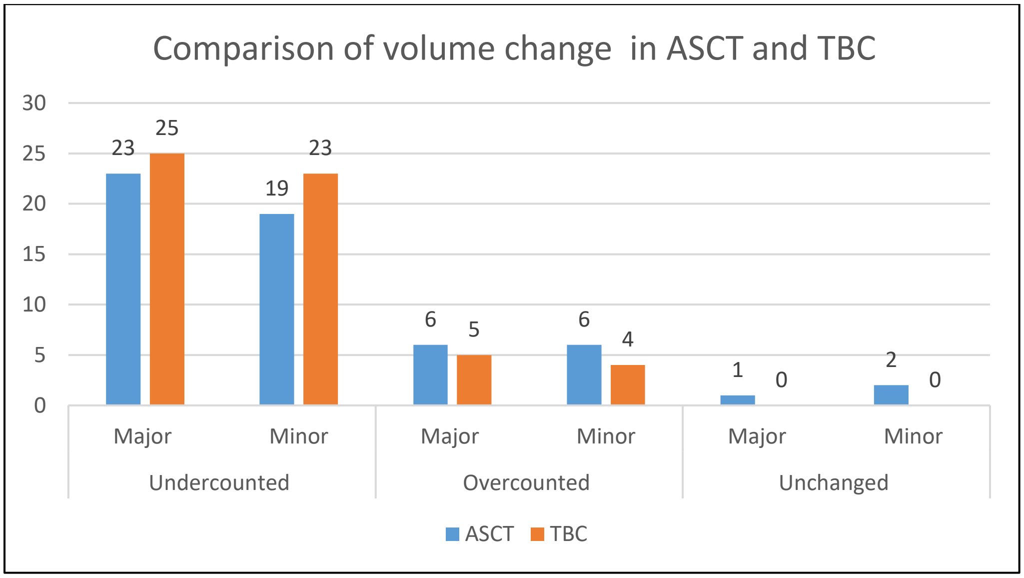

Figure 11. Comparison of the volume count under ASCT 2017 and TBC 2017.

One reason we observed for the system's overcounting could be that vehicles on the major street activated the minor street's detectors. Thus, it resulted in overcounting vehicles on the minor street. A specific example at Stadium Drive and Neil Street AM, with screen snapshots and video recorded times is provided in Appendix A.6. This kind of event can explain the overcounted volume on WBT at Stadium during the AM peak.

In summary, the undercounting of volume by the ASCT system indicates that the system received volume counts that were less than the actual demand and therefore was not providing optimal operation. Thus, the green time could not process the real traffic demand, which could be a contributing factor to the deterioration in ASCT performance in 2017.

4.5.6 Deterioration due to Proportion of Vehicles Stopped (P_S)

In this section, we compare the proportion of stopped vehicles under ASCT and TBC conditions. The average stopped proportion was calculated by

$$\overline{P_S} = \frac{\sum_{i=1}^{n} \frac{V_{Stopped,i}}{V_{total,i}} \times 100\%}{n} \quad (2)$$

where n is number of cycles;

$V_{Stopped,i}$ is the number of stopped vehicles in cycle i;

$V_{total,i}$ is the number of total vehicles in cycle i, which is the sum of stopped and through vehicles;

$\overline{P_S}$ is the average proportion of stopped vehicles.

It should be noticed that in some cycles no vehicles stopped or passed through. For these cycles, $\overline{P_S}$ are invalid and not used in calculations and comparisons.

In Tables 28 and 31, a statistical test (97% confidence level) showed the stopped-proportion change between ASCT and TBC.

Table 28. Comparison of Proportion of Vehicles Stopped under TBC 2017 and ASCT 2017 Conditions

Intersection	Time periods	Approaches	April average stopped proportion	March average stopped proportion	Change in stopped proportion (Apr–Mar)	p-value	Stopped proportion (Apr–Mar)	Delay change (Apr–Mar)	PI
Stadium	AM	NBT	33.2%	30.8%	2.4%	0.8538	Unch	Inc	Det
		SBT	46.0%	37.4%	8.6%	0.1547	Unch	Inc	Det
		EBT	62.3%	42.8%	19.5%	0.0075	Inc	Inc	Det
		WBT	47.7%	48.0%	-0.3%	0.6560	Unch	Unch	-
	NP	NBT	42.6%	20.2%	22.4%	8.26E-06	Inc	Inc	Det
		SBT	41.1%	32.3%	8.8%	0.1092	Unch	Unch	Unch
		EBT	64.1%	40.3%	23.8%	0.0112	Inc	Unch	Det
		WBT	58.1%	50.1%	8.0%	0.4028	Unch	Unch	Det
	PM	NBT	28.6%	31.2%	-2.6%	0.5308	Unch	Unch	Det
		SBT	36.9%	39.6%	-2.7%	0.6457	Unch	Inc	Det
		EBT	51.6%	44.0%	7.6%	0.4142	Unch	Inc	Det
		WBT	65.5%	55.2%	10.3%	0.0698	Unch	Inc	Det
Kirby	AM	NBT	44.8%	39.2%	5.6%	0.2959	Unch	Inc	Det
		SBT	50.2%	47.0%	3.2%	0.7737	Unch	Unch	Det
		EBT	58.8%	32.8%	26.0%	3.61E-07	Inc	Inc	Det
		WBT	63.3%	55.0%	8.3%	0.2563	Unch	Unch	Det
	NP	NBT	53.5%	64.5%	-11.0%	0.0447	Unch	Dec	Imp
		SBT	51.4%	52.8%	-1.4%	0.8013	Unch	Unch	Unch
		EBT	74.2%	73.0%	1.2%	0.8292	Unch	Inc	Det
		WBT	71.5%	56.9%	14.6%	0.0527	Inc	Inc	Det
	PM	NBT	54.7%	68.1%	-13.4%	0.0145	Dec	Dec	Imp
		SBT	58.1%	46.5%	11.6%	0.0157	Inc	Inc	Det
		EBT	45.2%	43.9%	1.3%	0.8502	Unch	Unch	Unch
		WBT	61.2%	47.1%	14.1%	0.0113	Inc	Unch	Det

Table 28. Comparison of Proportion of Vehicles Stopped in TBC 2017 and ASCT 2017 Conditions (Cont.)

Intersection	Time periods	Approaches	April average stopped proportion	March average stopped proportion	Change in stopped proportion (Apr-Mar)	p-value	Stopped proportion (Apr-Mar)	Delay change (Apr-Mar)	PI
St. Mary's	AM	NBT	22.2%	20.3%	1.9%	0.9522	Unch	Unch	Unch
		SBT	40.0%	45.1%	-5.1%	0.3911	Unch	Unch	Unch
		EBT	73.2%	83.4%	-10.2%	0.1111	Unch	Unch	Unch
		WBT	69.1%	76.1%	-7.0%	0.4586	Unch	Unch	Det
	NP	NBT	32.2%	27.6%	4.6%	0.2161	Unch	Unch	Det
		SBT	30.4%	15.8%	14.6%	0.0001	Inc	Inc	Det
		EBT	84.8%	86.2%	-1.4%	0.8169	Unch	Unch	Unch
		WBT	61.5%	27.6%	33.9%	0.0037	Inc	Unch	Det
	PM	NBT	19.7%	27.8%	-8.1%	0.0155	Dec	Unch	Unch
		SBT	23.6%	17.7%	5.9%	0.0588	Unch	Unch	Unch
		EBT	85.6%	64.4%	21.2%	0.0276	Inc	Unch	Unch
		WBT	71.6%	54.8%	16.8%	0.0118	Inc	Inc	Det
Devonshire	AM	NBT	18.6%	8.6%	10.0%	0.0007	Inc	Inc	Det
		SBT	8.0%	7.1%	0.9%	0.5180	Unch	Unch	Unch
		EBL	89.0%	92.4%	-3.4%	0.4844	Unch	Unch	Unch
	NP	NBT	17.6%	11.7%	5.9%	0.0442	Unch	Unch	Det
		SBT	22.1%	10.5%	11.6%	0.0014	Inc	Inc	Det
		EBL	81.6%	88.4%	-6.8%	0.1957	Unch	Unch	Unch
	PM	NBT	12.0%	8.0%	4.0%	0.2048	Unch	Unch	Det
		SBT	19.7%	11.1%	8.6%	0.0016	Inc	Inc	Det
		EBL	89.6%	90.7%	-1.1%	0.8162	Unch	Unch	Imp
Windsor	AM	NBT	51.8%	38.0%	13.8%	0.0153	Inc	Inc	Det
		SBT	47.0%	27.5%	19.5%	0.0187	Inc	Unch	Det
		EBT	76.1%	72.2%	3.9%	0.7098	Unch	Inc	Det
		WBT	82.3%	82.8%	-0.5%	0.5175	Unch	Unch	Unch
	NP	NBT	48.9%	53.8%	-4.9%	0.4157	Unch	Inc	Det
		SBT	35.5%	22.9%	12.6%	0.0014	Inc	Unch	Unch
		EBT	83.0%	72.2%	10.8%	0.1172	Unch	Unch	Unch
		WBT	85.8%	76.2%	9.6%	0.1459	Unch	Unch	Unch
	PM	NBT	64.2%	60.0%	4.2%	0.4738	Unch	Unch	Unch
		SBT	50.7%	34.9%	15.8%	0.0053	Inc	Inc	Det
		EBT	84.5%	75.6%	8.9%	0.0722	Unch	Inc	Det
		WBT	76.4%	55.1%	21.3%	0.0001	Inc	Inc	Det

In 19 cases, the proportion of stopped vehicles increased. In 13 of them, the delay also increased. In the remaining 6 cases, the proportion of stopped vehicles increased; but delay remained unchanged.

In all 13 cases, 8 on major streets and 5 on minor, the proportion of vehicles stopped and the delay increased; performance deteriorated. The average increase in the proportion stopped at major streets was 13.6% and at minor streets, 19.6%

Table 29 shows the cases with deteriorated performances that could be explained by the proportion of vehicles stopped.

Table 29. Summary of Cases Explained by Proportion of Vehicles Stopped

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

Note: Highlighted cells indicate cases explained by proportion of stopped vehicles.

4.5.7 Deterioration-Analysis Summary

In section 4.5, we have presented the deterioration analysis by looking at arrival-type changes, average effective green changes, and g/C ratio changes; additionally, in a few cases, there were other contributors: inadequate response to volume increase, pedestrian effects, volume miscounting, and proportion of vehicles stopped. The effects of phase plan on deterioration are presented in Appendix A.5 even though they did not yield a clear message. These analyses enabled us to provide some explanation for some of the deteriorated cases. The cases highlighted in Table 30 are the deteriorated cases for which we could provide some explanations.

Table 30. All of the Deteriorated Cases that Were Explained

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

Legend:

- **Green:** Cases explained by deterioration of arrival types under ASCT 2017, as compared to TBC 2017
- **Blue:** Cases explained by signal-timing changes (comparing ASCT 2017 to TBC 2017)
- **Orange:** Cases explained by insufficient response to volume increase under ASCT 2017, as compared to TBC 2017
- **Star (*):** Cases with higher proportion of stopped vehicles under ASCT 2017, as compared to TBC 2017
- **Orange and blue/Green and blue/Green and star (*)/Blue and star (*)/Orange and star (*)/Green and blue and star (*):** Cases explained by more than one reason

CHAPTER 5: CONCLUSIONS

The volume, delay, and queue length data from the field for TBC 2017 were measured and compared that for ASCT 2017, at the 97% confidence level. Field volumes were compared for 57 lane groups (approaches). Traffic volume for 7% of the lane groups increased significantly, did not change significantly on 72%, and decreased significantly on 21%. Field delays were compared for 57 lane groups, of which 56% showed significant increase, 40% showed no significant change, and 4% showed significant decrease. Queue length was compared for 57 lane groups. Of these 57 lane groups, 48% showed significant increase in queue length, 48% showed no significant change, and 4% 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). As we considered the 97% confidence interval for individual comparisons of volume, delay, and queue length, so the PI presents 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; of the 56 lane groups analyzed, the PI showed improvement in 5%, remained unchanged in 32%, but showed deterioration in 63%. In summary, for 37% of the lane groups, performance under ASCT either improved or was unchanged; however, on 63% of the lane groups, performance deteriorated. Out of the 35 deteriorated cases (the 63%), volume significantly increased in 3, did not change significantly in 21, and decreased significantly in 11. The deterioration in the 3 cases can be attributed to the increase in volume and the system's inability to respond adequately to the increase. However, for the 25 lane groups in which volume did not change significantly, the deterioration in PI was not expected.

Further investigations were performed to find factors contributing to the ASCT performance deterioration. Out of 35 cases, deterioration in 20 cases could be explained by 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 PI deterioration when ASCT was operating.

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APPENDIX A: STATISTICAL COMPARISON AT CORRIDOR LEVEL

A.1 STATISTICAL DELAY COMPARISON

Using the methodology for comparison in Chapter 4, t-tests were performed for the three time periods and for all through-lane groups in the study area, except for the eastbound approach of the intersection of Neil Street and Devonshire Drive, where the tests were performed for the protected left-turn lane rather than the through lane.

The details of the t-tests performed are presented in Tables 31 to 33. For each table, the column heading "n" stands for the number of cycle-by-cycle observations obtained from the field for the subject lane group. The other columns show the field measurements, t-statistics, and p-values. EBL stands for the eastbound left-lane group.

A total of 56 tests was performed over the three time periods for volume, stopped delay, and queue length. We have pointed out the significant comparison with two confidence levels; an observed error in a comparison is considered as significant if the p-value of its t-test was less than 10% or 3%. Based on each confidence level (the last two columns), the tests in which volume or stopped delay for ASCT 2017 conditions is significantly larger than that for TBC 2017 conditions are highlighted with pink, while those in which ASCT 2017 conditions are significantly lower than TBC 2017 conditions are highlighted with blue.

Table 31. Statistical Comparison Between TBC2017 and ASCT2017 Conditions for Stopped Delay

			April				Feb										
Delay			Mean	Variance	Std	n	Mean	Variance	Std	n	Pooled?	Sp	df	T-statistic	P-value	(Alpha = 0.1) Significant?	(Alpha = 0.03) significant?
stadium	AM	NBT	6.77641198	170.386966	13.053	58	1.827	16.138	4.017	58	0	1.793	114	2.75968337	0.00674307	YES	YES
		SBT	7.62046574	82.910	9.105	58	3.605	22.969	4.793	58	1	7.276	114	2.97219974	0.00360772	YES	YES
		EBL	13.7531796	124.959	11.179	58	7.485	69.567	8.341	58	1	9.862	114	3.42262678	0.00086216	YES	YES
		WBL	3.10344828	61.2522686	7.826	58	4.707	91.299	9.555	58	1	8.734	114	-0.9886935	0.32490696	NO	NO
	NP	NBT	6.83117882	42.475	6.517	65	1.922	12.950	3.599	63	1	5.286	126	5.25299797	6.1818E-07	YES	YES
		SBT	6.8261039	78.450	8.857	65	4.060	40.546	6.368	63	0	1.360	126	2.03313074	0.04413999	YES	NO
		EBL	7.56923077	119.561538	10.934	65	4.776	77.835	8.822	63	1	9.951	126	1.58773168	0.11485334	NO	NO
		WBL	5.63076923	93.799	9.685	65	4.881	69.562	8.340	63	1	9.048	126	0.46871331	0.64008449	NO	NO
	PM	NBT	5.85095518	40.323	6.350	59	5.012	44.811	6.694	59	1	6.524	116	0.6984764	0.48627725	NO	NO
		SBT	7.66358472	81.061	9.003	59	2.79873367	20.674	4.547	59	1	7.132	116	3.70477375	0.00032562	YES	YES
		EBL	7.95762712	149.916	12.244	59	3.549	43.421	6.589	59	1	9.832	116	2.43532402	0.01640074	YES	YES
		WBL	14.4083535	90.736	9.526	59	6.497	63.379	7.961	59	1	8.778	116	4.89494946	3.206E-06	YES	YES
Kirby	AM	NBT	14.8541825	36.6031008	6.050	28	10.000	60.940	7.806	28	1	6.984	54	2.60063875	0.01197897	YES	YES
		SBT	14.2783565	52.903	7.273	28	12.675	35.130	5.927	28	1	6.635	54	0.90396306	0.37003018	NO	NO
		EBL	31.3354541	113.008	10.631	28	15.282	119.344	10.924	28	1	10.779	54	5.57280916	8.1749E-07	YES	YES
		WBL	21.8650974	375.817544	19.386	28	23.189	199.806	14.135	28	1	16.965	54	-0.2918848	0.77149312	NO	NO
	NP	NBT	13.7445861	58.117	7.623	31	19.592	119.795	10.945	31	1	9.432	60	-2.4408543	0.01762097	YES	YES
		SBT	22.6067299	284.138	16.856	31	17.139	82.535	9.085	31	0	3.439	60	1.58977571	0.11714126	NO	NO
		EBL	61.7690941	936.096929	30.596	31	24.504	146.548	12.106	31	1	23.266	60	6.30573306	3.77E-08	YES	YES
		WBL	32.115752	324.564	18.016	31	14.890	161.316	12.701	31	1	15.587	60	4.3511137	5.3461E-05	YES	YES
	PM	NBT	21.1920718	167.000	12.923	29	29.155	68.039	8.249	29	1	10.841	56	-2.7969296	0.00705806	YES	YES
		SBT	26.5363819	145.920	12.080	29	19.6045915	61.576	7.847	29	1	10.186	56	2.59142795	0.01216578	YES	YES
		EBL	20.7257484	273.268	16.531	29	20.916	139.334	11.804	29	1	14.363	56	-0.0504708	0.95992685	NO	NO
		WBL	30.4004622	266.962	16.339	29	25.566	183.336	13.540	29	1	15.005	56	1.22686248	0.22500748	NO	NO
St Marys	AM	NBT	6.5224352	31.3661445	5.601	29	4.291	12.949	3.598	29	1	4.707	56	1.80527363	0.07640859	YES	NO
		SBT	7.86086672	33.528	5.790	29	7.563	37.662	6.137	29	1	5.966	56	0.19000521	0.84999212	NO	NO
		EBL	31.1009852	390.615	19.764	29	32.860	391.605	19.789	29	1	19.777	56	-0.3386154	0.73616585	NO	NO
		WBL	16.0344828	427.67734	20.680	29	20.356	232.301	15.241	29	1	18.166	56	-0.9058095	0.3689176	NO	NO
	NP	NBT	8.33931274	15.298	3.911	32	6.600	19.980	4.470	32	1	4.200	62	1.65695844	0.10258036	NO	NO
		SBT	5.93860063	15.734	3.967	32	2.682	5.889	2.427	32	0	0.822	62	3.96140784	0.000195	YES	YES
		EBL	31.5082949	398.924133	19.973	32	22.133	277.414	16.656	32	1	18.389	62	2.03917981	0.04570057	YES	NO
		WBL	17.484375	497.266	22.299	32	19.207	353.736	18.808	32	1	20.628	62	-0.3339826	0.73951973	NO	NO
	PM	NBT	5.46004377	16.300	4.037	29	7.555	22.052	4.696	29	1	4.379	56	-1.8218866	0.07381417	YES	NO
		SBT	4.61922284	6.661	2.581	29	6.14584079	13.671	3.697	29	1	3.188	56	-1.8232274	0.07360804	YES	NO
		EBL	23.2078818	324.119	18.003	29	15.378	188.407	13.726	29	1	16.008	56	1.8623955	0.06779658	YES	NO
		WBL	25.9606807	269.153	16.406	29	17.138	123.868	11.130	29	1	14.018	56	2.39660793	0.01991103	YES	YES
Devonshire	AM	NBT	2.03576048	2.96204825	1.721	28	1.071	1.878	1.371	28	1	1.556	54	2.31926627	0.02419261	YES	YES
		SBT	1.12	5.079	2.254	28	0.864	3.095	1.759	28	1	2.022	54	0.47395698	0.63744139	NO	NO
		EBL	45.64	470.478	21.691	28	43.153	365.202	19.110	28	1	20.441	54	0.45517614	0.6508074	NO	NO
	NP	NBT	2.14	4.013	2.003	32	1.550	3.196	1.788	32	1	1.899	62	1.24304709	0.21853083	NO	NO
		SBT	6.17	43.409	6.589	32	1.750	4.054	2.013	32	0	1.218	62	3.62927387	0.00057684	YES	YES
		EBL	35.72	208.449	14.438	32	41.070	161.974	12.727	32	1	13.609	62	-1.5724624	0.12093307	NO	NO
	PM	NBT	1.59494665	3.508	1.873	28	0.910	2.771	1.665	28	1	1.772	54	1.44634536	0.15386009	NO	NO
		SBT	3.76620318	8.493	2.914	28	1.355	1.414	1.189	28	0	0.595	54	4.05357914	0.00016296	YES	YES
		EBL	46.8596939	312.914	17.689	28	53.880	696.471	26.391	28	1	22.465	54	-1.1692478	0.24743924	NO	NO
Windsor	AM	NBT	19.7215602	189.09524	13.751	27	10.395	53.721	7.329	27	1	11.019	52	3.110087	0.00303326	YES	YES
		SBT	9.24444444	106.685	10.329	27	5.732	82.092	9.060	27	1	9.715	52	1.32825845	0.1898932	NO	NO
		EBL	38.7110421	392.466	19.811	27	22.547	160.912	12.685	27	1	16.634	52	3.57038213	0.00077755	YES	YES
		WBL	33.9626984	338.04413	18.386	27	30.797	392.718	19.817	27	1	19.115	52	0.60854552	0.54547496	NO	NO
	NP	NBT	23.1994771	266.948	16.339	31	12.483	69.169	8.317	30	1	13.028	59	3.2116827	0.00213803	YES	YES
		SBT	10.2305404	43.672	6.608	31	7.086	47.889	6.920	30	0	1.734	59	1.81401125	0.07476182	YES	NO
		EBL	35.7013825	312.91758	17.689	31	30.080	323.512	17.986	30	1	17.836	59	1.23055261	0.22337379	NO	NO
		WBL	37.4344575	430.291	20.743	31	27.726	261.783	16.180	30	1	18.640	59	2.03363672	0.04649338	YES	NO
	PM	NBT	25.2701598	248.027	15.749	30	19.419	87.272	9.342	30	1	12.948	58	1.75020959	0.0853706	YES	NO
		SBT	19.4495301	123.275	11.103	30	12.906067	46.118	6.791	30	1	9.203	58	2.75372142	0.00785558	YES	YES
		EBL	29.4873443	187.766	13.703	30	20.165	134.908	11.615	30	1	12.702	58	2.84266131	0.00616664	YES	YES
		WBL	39.1036011	271.757	16.485	30	21.540	106.572	10.323	30	1	13.754	58	4.94575578	6.8352E-06	YES	YES

Table 32. Statistical Comparison Between TBC2017 and ASCT2017 Conditions for Volume

			April				Feb										
Volume			Mean	Variance	Std	n	Mean	Variance	Std	n	Pooled?	Sp	df	T-statistic	P-value	(Alpha = 0.1) Significant?	(Alpha = 0.03) significant?
stadium	AM	NBT	7.77586207	27.1944949	5.215	58	8.6593557	34.678	5.889	58	1	5.562	114	-0.8553971	0.39412557	NO	NO
		SBT	5.77586207	11.791	3.434	58	6.584	13.423	3.664	58	1	3.551	114	-1.226437	0.22256143	NO	NO
		EBL	3.62068966	6.976	2.641	58	5.060	8.152	2.855	58	1	2.750	114	-2.8184014	0.00569158	YES	YES
		WBL	0.5	0.500	0.707	58	0.953	1.008	1.004	58	1	0.868	114	-2.8081839	0.00586304	YES	YES
	NP	NBT	6.4	9.119	3.020	65	6.476	14.350	3.788	63	1	3.419	126	-0.126026	0.8999122	NO	NO
		SBT	5.73846154	9.321	3.053	65	6.095	9.410	3.068	63	0	0.541	126	-0.6593762	0.51085754	NO	NO
		EBL	1	1.063	1.031	65	1.635	2.139	1.462	63	1	1.262	126	-2.84615	0.00516742	YES	YES
		WBL	0.90769231	1.116	1.057	65	1.365	1.494	1.222	63	1	1.141	126	-2.2672734	0.0250772	YES	YES
	PM	NBT	7.83050847	15.212	3.900	59	7.271	16.477	4.059	59	1	3.981	116	0.7631909	0.4468989	NO	NO
		SBT	8.33898305	13.262	3.642	59	8.153	15.856	3.982	59	1	3.816	116	0.26539056	0.79117967	NO	NO
		EBL	1	1.034	1.017	59	2.068	3.409	1.846	59	1	1.491	116	-3.890873	0.00016712	YES	YES
		WBL	3.96610169	6.378	2.525	59	3.678	7.601	2.757	59	1	2.644	116	0.59193826	0.55504388	NO	NO
Kirby	AM	NBT	16.5714286	12.9206349	3.595	28	15.5616648	26.552	5.153	28	1	4.443	54	0.85045288	0.39882862	NO	NO
		SBT	9.35714286	13.868	3.724	28	11.857	18.302	4.278	28	1	4.011	54	-2.3317748	0.02347278	YES	YES
		EBL	13.1071429	8.914	2.986	28	12.859	15.612	3.951	28	1	3.502	54	0.26505078	0.79197951	NO	NO
		WBL	5.21428571	8.471	2.910	28	9.325	13.268	3.643	28	1	3.297	54	-4.665039	2.0722E-05	YES	YES
	NP	NBT	11.2580645	9.731	3.119	31	11.097	14.890	3.859	31	1	3.509	60	0.18098053	0.85699282	NO	NO
		SBT	9.16129032	9.273	3.045	31	10.129	10.583	3.253	31	0	0.800	60	-1.2091926	0.23133219	NO	NO
		EBL	7	8.933	2.989	31	5.968	7.83225806	2.799	31	1	2.895	60	1.40365279	0.16557692	NO	NO
		WBL	6.25806452	8.265	2.875	31	7.677	4.759	2.182	31	1	2.552	60	-2.1898046	0.03243753	YES	NO
	PM	NBT	13.5833333	9.993	3.161	29	12.379	14.815	3.849	29	1	3.522	56	1.30178027	0.19832115	NO	NO
		SBT	14.862069	17.623	4.198	29	16.759	18.904	4.348	29	1	4.274	56	-1.689881	0.09661101	YES	NO
		EBL	7.16129032	10.118	3.181	29	7.276	5.278	2.297	29	1	2.775	56	-0.1572406	0.87562077	NO	NO
		WBL	11.2413793	25.475	5.047	29	15.897	12.096	3.478	29	1	4.334	56	-4.0898362	0.00013951	YES	YES
St Marys	AM	NBT	17.4827586	30.044335	5.481	29	19.2193611	34.633	5.885	29	1	5.687	56	-1.162848	0.2498226	NO	NO
		SBT	7.89655172	8.310	2.883	29	8.514	13.068	3.615	29	1	3.269	56	-0.7195791	0.47477662	NO	NO
		EBL	4.75862069	7.404	2.721	29	5.166	4.629	2.151	29	1	2.453	56	-0.6332083	0.52917522	NO	NO
		WBL	1.17241379	1.648	1.284	29	3.059	5.089	2.256	29	1	1.835	56	-3.9134623	0.00024889	YES	YES
	NP	NBT	16.46875	12.773	3.574	32	14.313	16.544	4.067	32	1	3.829	62	2.25273619	0.02782481	YES	YES
		SBT	13.71875	15.434	3.929	32	11.500	8.710	2.951	32	0	0.869	62	2.55433215	0.01310986	YES	YES
		EBL	3.21875	3.467	1.862	32	4.156	6.394	2.529	32	1	2.220	62	-1.6888391	0.09627411	YES	NO
		WBL	1.53125	2.064	1.436	32	3.969	3.193	1.787	32	1	1.621	62	-6.0143671	1.0526E-07	YES	YES
	PM	NBT	15.2413793	12.547	3.542	29	14.621	15.030	3.877	29	1	3.713	56	0.63650978	0.5270375	NO	NO
		SBT	18.9310345	15.924	3.990	29	19.276	27.707	5.264	29	1	4.671	56	-0.281129	0.77964758	NO	NO
		EBL	2.55172414	5.470	2.339	29	3.931	6.924	2.631	29	1	2.489	56	-2.1098603	0.03935207	YES	NO
		WBL	5.48275862	6.330	2.516	29	10.761	10.740	3.277	29	1	2.921	56	-6.8797843	5.4669E-09	YES	YES
Devonshire	AM	NBT	19.35	48.1640212	6.940	28	21.577	32.784	5.726	28	1	6.362	54	-1.3099112	0.19577121	NO	NO
		SBT	7.5	9.815	3.133	28	7.835	10.376	3.221	28	1	3.177	54	-0.3940173	0.69511998	NO	NO
		EBL	3.32	3.041	1.744	28	3.639	5.373	2.318	28	1	2.051	54	-0.5819451	0.56302541	NO	NO
	NP	NBT	15.375	13.468	3.670	32	13.120	13.339	3.652	32	1	3.661	62	2.46377969	0.01653586	YES	YES
		SBT	13.31	12.286	3.505	32	12.340	6.555	2.560	32	0	0.767	62	1.26411414	0.21092099	NO	NO
		EBL	5.28	6.467	2.543	32	4.125	3.984	1.996	32	1	2.286	62	2.02109282	0.04759346	YES	NO
	PM	NBT	12.8214286	13.263	3.642	28	12.890	10.544	3.247	28	1	3.450	54	-0.0743654	0.94099443	NO	NO
		SBT	21.7142857	23.693	4.868	28	21.070	29.772	5.456	28	1	5.170	54	0.46625152	0.64291091	NO	NO
		EBL	4.28571429	3.101	1.761	28	2.780	3.063	1.750	28	1	1.756	54	3.20914637	0.00224166	YES	YES
Windsor	AM	NBT	17	24	4.899	28	19.0564158	43.128	6.567	27	1	5.778	53	-1.3195488	0.19265764	NO	NO
		SBT	3.44444444	2.410	1.553	28	4.965	5.985	2.446	27	1	2.041	53	-2.7634603	0.00784716	YES	YES
		EBL	11.7407407	11.046	3.323	28	13.017	17.879	4.228	27	1	3.794	53	-1.2474021	0.21773395	NO	NO
		WBL	5.85185185	8.285	2.878	28	7.113	11.708	3.422	27	1	3.157	53	-1.480789	0.14458357	NO	NO
	NP	NBT	10.6451613	18.770	4.332	31	10.100	11.748	3.428	31	1	3.906	60	0.54944804	0.58473734	NO	NO
		SBT	7.58064516	6.252	2.500	31	7.600	8.800	2.966	31	0	0.697	60	-0.0277766	0.97793252	NO	NO
		EBL	6.4516129	7.989	2.827	31	5.700	8.217	2.867	31	1	2.847	60	1.03951464	0.30273642	NO	NO
		WBL	4.29032258	4.013	2.003	31	4.300	5.734	2.395	31	1	2.208	60	-0.0172582	0.98628787	NO	NO
	PM	NBT	8.06666667	8.271	2.876	30	8.867	8.051	2.837	30	1	2.857	58	-1.0845912	0.28259059	NO	NO
		SBT	13.7666667	28.530	5.341	30	15.400	20.731	4.553	30	1	4.963	58	-1.2746302	0.20752316	NO	NO
		EBL	6.16666667	4.282	2.069	30	6.867	5.430	2.330	30	1	2.204	58	-1.2303131	0.22354658	NO	NO
		WBL	10.3333333	11.954	3.457	30	11.267	15.237	3.903	30	1	3.687	58	-0.9803618	0.33097932	NO	NO

A.2 STATISTICAL QUEUE-LENGTH COMPARISON

Using the methodology for comparison described in Chapter 4, t-tests were performed for all lane groups for both TBC 2017 and ASCT 2017 conditions. The tests include all through movements at the intersections of Neil Street with Stadium Drive, Kirby Avenue, St. Mary's Road, and Windsor Road; and for NBT, SBT, and EBL of Neil Street and Devonshire Drive.

The details of the t-tests performed are presented in Table 33. In this table, the column heading "n" stands for the number of cycle-by-cycle observations obtained from the field for the subject lane group. A total of 56 tests was performed for the average queue-length comparisons. We have pointed out the significant comparison with two confidence levels; an observed error in a comparison is considered as significant if the p-value of its t-test was less than 10% or 3%. Based on each confidence level (the last two columns), the queue-length values under ASCT 2017 conditions that are significantly larger than for TBC 2017 conditions are highlighted with pink, while those in which ASCT 2017 conditions are significantly lower than TBC 2017 conditions are highlighted with blue.

Table 33. Statistical Comparison Between TBC2017 and ASCT2017 Conditions for Average Queue Length

			April				Feb										
Queue Length			Mean	Variance	Std	n	Mean	Variance	Std	n	Pooled?	Sp	df	T-statistic	P-value	(Alpha = 0.1) Significant?	(Alpha = 0.03) significant?
stadium	AM	NBT	1.94827586	5.41833031	2.328	58	1.138	1.314	1.146	58	0	0.341	114	2.37849352	0.01904614	YES	YES
		SBT	2.37931034	5.433	2.331	58	1.707	4.316	2.078	58	1	2.208	114	1.64013131	0.1037344	NO	NO
		EBL	2.32758621	3.803	1.950	58	1.397	1.928	1.388	58	1	1.693	114	2.96191384	0.0037214	YES	YES
		WBL	0.27586207	0.309	0.555	58	0.086	0.080	0.283	58	1	0.441	114	2.31674668	0.02230378	YES	YES
	NP	NBT	2.44615385	4.751	2.180	65	0.683	1.285	1.133	63	1	1.745	126	5.7162069	7.4664E-08	YES	YES
		SBT	2.33846154	6.259	2.502	65	1.730	2.910	1.706	63	0	0.377	126	1.61157155	0.10955738	NO	NO
		EBL	0.70769231	0.96009615	0.980	65	0.381	0.401	0.633	63	1	0.828	126	2.23303616	0.02731159	YES	YES
		WBL	0.6	0.713	0.844	65	0.444	0.509	0.713	63	1	0.783	126	1.12436978	0.26299364	NO	NO
	PM	NBT	2.16949153	3.109	1.763	59	1.458	1.908	1.381	59	1	1.584	116	2.44134262	0.01614335	YES	YES
		SBT	3.30508475	10.629	3.260	59	1.695	3.285	1.812	59	1	2.638	116	3.31566212	0.00122081	YES	YES
		EBL	0.52542373	0.564	0.751	59	0.45	0.45508475	0.675	59	1	0.714	116	0.57389092	0.5671527	NO	NO
		WBL	2.57627119	3.662	1.914	59	1.119	1.831	1.353	59	1	1.657	116	4.77726937	5.2445E-06	YES	YES
Kirby	AM	NBT	8.89285714	7.87698413	2.807	28	5.214	12.397	3.521	28	1	3.184	54	4.32305268	6.6612E-05	YES	YES
		SBT	4.92857143	7.550	2.748	28	4.464	5.962	2.442	28	1	2.599	54	0.66835323	0.50675509	NO	NO
		EBL	8.35714286	3.275	1.810	28	3.714	10.138	3.184	28	1	2.590	54	6.70820393	1.2262E-08	YES	YES
		WBL	2.82142857	5.485	2.342	28	2.920	5.660	2.379	28	1	2.361	54	-0.1562361	0.87642959	NO	NO
	NP	NBT	6.80645161	8.161	2.857	31	7.323	3.826	1.956	31	1	2.448	60	-0.8300077	0.40982477	NO	NO
		SBT	4.93548387	7.129	2.670	31	5.516	5.325	2.308	31	0	0.634	60	-0.9160968	0.36328357	NO	NO
		EBL	5.03225806	7.23225806	2.689	31	4.258	4.798	2.190	31	1	2.453	60	1.24278396	0.21878243	NO	NO
		WBL	3.03225806	5.099	2.258	31	3.290	5.346	2.312	31	1	2.285	60	-0.4445817	0.65822167	NO	NO
	PM	NBT	8.79166667	8.346	2.889	29	7.655	1.234	1.111	29	0	0.575	56	1.97734925	0.05293245	YES	NO
		SBT	10.3448276	17.663	4.203	29	7.345	4.163	2.040	29	0	0.868	56	3.45813467	0.00104622	YES	YES
		EBL	3.55172414	4.685	2.164	29	3.207	3.741	1.934	29	1	2.053	56	0.63971639	0.52496557	NO	NO
		WBL	6.96551724	3.106	1.762	29	7.310	3.793	1.948	29	1	1.857	56	-0.7069805	0.48251019	NO	NO
St Marys	AM	NBT	3.82758621	6.93349754	2.633	29	3.034	3.392	1.842	29	1	2.272	56	1.3291721	0.18918118	NO	NO
		SBT	3.10344828	3.382	1.839	29	3.034	2.749	1.658	29	1	1.751	56	0.14999665	0.8813062	NO	NO
		EBL	3.51724138	5.616	2.370	29	2.759	3.047	1.746	29	1	2.081	56	1.38803531	0.17062407	NO	NO
		WBL	0.93103448	1.281	1.132	29	1.103	2.239	1.496	29	1	1.327	56	-0.4949005	0.62260657	NO	NO
	NP	NBT	5.53125	6.386	2.527	32	3.375	3.661	1.913	32	1	2.241	62	3.84811204	0.00028385	YES	YES
		SBT	4.3125	3.383	1.839	32	1.500	1.742	1.320	32	0	0.400	62	7.02781928	1.9245E-09	YES	YES
		EBL	2.4375	2.64112903	1.625	32	2.094	3.314	1.820	32	1	1.725	62	0.79687471	0.42856488	NO	NO
		WBL	1	1.935	1.391	32	1.688	3.060	1.749	32	1	1.581	62	-1.7399544	0.08682897	YES	NO
	PM	NBT	3.03448276	3.749	1.936	29	4.103	7.167	2.677	29	1	2.336	56	-1.7423116	0.08694377	YES	NO
		SBT	4.31034483	5.293	2.301	29	3.207	2.241	1.497	29	1	1.941	56	2.16483229	0.03467799	YES	NO
		EBL	1.72413793	2.850	1.688	29	1.207	1.670	1.292	29	1	1.503	56	1.31019894	0.19547741	NO	NO
		WBL	3.96551724	5.677	2.383	29	2.759	6.690	2.586	29	1	2.487	56	1.84814887	0.06986392	YES	NO
Devonshire	AM	NBT	3.607	4.83994709	2.200	28	1.643	1.794	1.339	28	1	1.821	54	4.0353157	0.00017299	YES	YES
		SBT	0.67	0.671	0.819	28	0.464	0.554	0.744	28	1	0.783	54	0.9835555	0.32972053	NO	NO
		EBL	3.07	2.513	1.585	28	2.536	2.480	1.575	28	1	1.580	54	1.26518781	0.21123639	NO	NO
	NP	NBT	2.65	3.330	1.825	32	1.590	2.636	1.624	32	1	1.727	62	2.45498708	0.01690812	YES	YES
		SBT	3.25	9.226	3.037	32	1.281	1.112	1.054	32	0	0.568	62	3.46380603	0.00097145	YES	YES
		EBL	4.4	4.830	2.198	32	3.650	3.459	1.860	32	1	2.036	62	1.47368055	0.145627	NO	NO
	PM	NBT	1.64285714	2.979	1.726	28	0.780	0.989	0.995	28	1	1.409	54	2.29201885	0.02582909	YES	YES
		SBT	4.42857143	7.661	2.768	28	2.250	2.713	1.647	28	1	2.278	54	3.57907344	0.00073814	YES	YES
		EBL	3.71428571	3.323	1.823	28	2.570	3.217	1.794	28	1	1.808	54	2.36774626	0.02150805	YES	YES
Windsor	AM	NBT	10.037037	15.4985755	3.937	27	5.704	13.755	3.709	27	1	3.824	52	4.16307857	0.00011839	YES	YES
		SBT	1.51851852	2.413	1.553	27	0.926	1.071	1.035	27	1	1.320	52	1.64959917	0.10505367	NO	NO
		EBL	9.44444444	13.103	3.620	27	7.778	9.795	3.130	27	1	3.384	52	1.8098276	0.07610339	YES	NO
		WBL	4.85185185	7.285	2.699	27	4.111	7.641	2.764	27	1	2.732	52	0.99627096	0.3237321	NO	NO
	NP	NBT	5.80645161	10.228	3.198	31	5.333	11.057	3.325	30	1	3.261	59	0.56645259	0.57323471	NO	NO
		SBT	2.83870968	4.673	2.162	31	2.033	4.999	2.236	30	0	0.563	59	1.42959535	0.15810721	NO	NO
		EBL	5.29032258	8.07956989	2.842	31	4.000	5.655	2.378	30	1	2.624	59	1.91968913	0.05973661	YES	NO
		WBL	3.86666667	4.395	2.097	31	2.900	3.541	1.882	30	1	1.994	59	1.89299913	0.06326605	YES	NO
	PM	NBT	5	2.897	1.702	30	5.333	7.609	2.758	30	1	2.292	58	-0.563282	0.57541411	NO	NO
		SBT	7.23333333	19.564	4.423	30	5.300	7.045	2.654	30	1	3.648	58	2.05282295	0.04461025	YES	NO
		EBL	4.93333333	3.237	1.799	30	5.433	4.047	2.012	30	1	1.908	58	-1.0147251	0.31445129	NO	NO
		WBL	8	7.379	2.716	30	7.400	13.628	3.692	30	1	3.241	58	0.71701944	0.47623979	NO	NO

APPENDIX B: COMBINATION ANALYSIS (DELAY VS. VOLUME, QUEUE LENGTH VS. VOLUME)

B.1 DELAY AND VOLUME COMBINATION ANALYSIS

Table 34 shows the combined-analysis results for delay and volume. In the table, “D” is the abbreviation for delay and “V” for volume. The upward arrow “↑” stands for increase, downward arrow “↓”for decrease, and dash “—”for unchanged. For instance, the column heading “D ↑ & V ↓” stands for the category with increased delay and decreased volume. And the cells with entries “yes” signify that these lane groups (row heads) fall into the corresponding categories (column heads).

Table 34. Combined Analysis for Delay and Volume

			Improved			Unchanged	Deteriorated			To be determined	
			D↓& V ↑	D↓& V -	D - & V ↑	D - & V -	D - & V↓	D↑& V -	D↑& V↓	D↑& V↑	D↓& V ↓
Stadium	AM	NBT						yes			
		SBT						yes			
		EBT							yes		
		WBT									
	NP	NBT						yes			
		SBT				yes					
		EBT					yes				
		WBT					yes				
	PM	NBT				yes					
		SBT						yes			
		EBT							yes		
		WBT						yes			
Kirby	AM	NBT						yes			
		SBT					yes				
		EBT						yes			
		WBT					yes				
	NP	NBT		yes							
		SBT				yes					
		EBT						yes			
		WBT						yes			
	PM	NBT		yes							
		SBT						yes			
		EBT				yes					
		WBT					yes				
St. Marys	AM	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT					yes				
	NP	NBT			yes						
		SBT								yes (deteriorated)	
		EBT				yes					
		WBT					yes				
	PM	NBT		yes							
		SBT		yes							
		EBT							yes		
		WBT							yes		

Table 34. Combined Analysis for Delay and Volume (Continued)

			Improved			Unchanged	Deteriorated			To be determined	
			D↓ & V ↑	D↓ & V -	D - & V ↑	D - & V -	D - & V↓	D↑ & V -	D↑ & V↓	D↑ & V↑	D↓ & V ↓
Devon shire	AM	NBT						yes			
		SBT				yes					
		EBL				yes					
	NP	NBT			yes						
		SBT						yes			
		EBL				yes					
	PM	NBT				yes					
		SBT						yes			
		EBL			yes						
Windsor	AM	NBT						yes			
		SBT				yes					
		EBT				yes					
		WBT				yes					
	NP	NBT						yes			
		SBT				yes					
		EBT				yes					
		WBT				yes					
	PM	NBT				yes					
		SBT						yes			
		EBT						yes			
		WBT						yes			
Subtotal			0	4	3	19	7	18	4	1 (deteriorated)	
Total			7 (D_V improved)			12 (D_V unchanged)	34 (D_V deteriorated)			1 (D_V deteriorated)	

B.2 APPLICATION OF HCS IN DETERMINING CONDITION OF CASES WITH BOTH INCREASED OR DECREASED DELAY AND VOLUME

For the cases of "To be Determined," the lane groups for which both delay and volume significantly increased (or decreased), *HCS 2010* was used to estimate the expected delay increases (or decreases) due to volume changes. In the *HCS* estimations, all the inputs except for volume were the same for both TBC 2017 and ASCT 2017 runs. Thus by entering the volumes for TBC 2017 and ASCT 2017 conditions for the subject lane group, the estimated changes in delay solely due to the volume changes can be obtained, which are then compared to the field stopped-delay discrepancies. As a result, if the field stopped-delay increases after ASCT implementation and the measured discrepancy are larger than the estimated increase due to volume, it indicates that ASCT implementation leads to a longer delay, and thus traffic performance for the subject lane group potentially deteriorates. If the field discrepancy equals the estimated values, the delay change for the subject lane group is solely due to volume change. Otherwise, the ASCT implementation shortens the field delay for the subject lane group and improves its traffic performance.

In the study, three lane groups were found for which both delay and volume significantly increased, including the eastbound through traffic at Neil Street and Stadium Drive during PM peak, and the northbound and southbound through traffic at Neil Street and Knollwood Drive during the noon peak (NP). Table 35 shows the delay discrepancy comparison results. The field delay discrepancy is larger than the *HCS* estimates, both numerically and by percent on St. Mary's, NP, SB. This finding means the field delay increases on this lane group after ASCT implementation is due not only to volume increase but also to the system's inappropriate performance. Therefore, this lane group was also considered as a lane group with potentially deteriorated D_V.

Table 35. Delay Discrepancy Comparison, *HCS* vs. Field

Lane groups	Volume difference in *HCS* runs	*HCS* discrepancy		Field discrepancy		Results
		Numerical	%	Numerical	%	
St. Mary's NP SB	68	0.153	2%	3.257	121%	deteriorated D_V

B.3 QUEUE LENGTH AND VOLUME COMBINATION ANALYSIS

Table 36 shows the combined analysis results for queue and volume. In the table, "Q" is the abbreviation for queue and "V" for volume. The upward arrow "↑" stands for increase, downward arrow "↓"for decrease, and dash "—"for unchanged. For instance, the column heading "Q ↑ & V ↓" stands for the category with increased queue length and decreased volume. The cells with entries "1" signify that these lane groups (row heads) fall into the corresponding categories (column heads).

Table 36. Combined Analysis for Queue and Volume

			Improved			Unchanged	Deteriorated			To be determined	
			Q ↓ & V↑	Q ↓ & V -	Q - & V ↑	Q - & V -	Q ↑ & V ↓	Q ↑ & V -	Q - & V ↓	Q↑ & V↑	Q↓ & V ↓
Stadium	AM	NBT						yes			
		SBT				yes					
		EBT					yes				
		WBT									
	NP	NBT						yes			
		SBT				yes					
		EBT					yes				
		WBT							yes		
	PM	NBT						yes			
		SBT						yes			
		EBT							yes		
		WBT						yes			
Kirby	AM	NBT						yes			
		SBT							yes		
		EBT						yes			
		WBT							yes		
	NP	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT				yes					
	PM	NBT				yes					
		SBT						yes			
		EBT				yes					
		WBT							yes		
St. Mary's	AM	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT							yes		
	NP	NBT								yes (deteriorated)	
		SBT								yes (deteriorated)	
		EBT				yes					
		WBT							yes		
	PM	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT							yes		

Table 36. Combined Analysis for Queue and Volume (Cont.)

			Improved			Unchanged	Deteriorated			To be determined	
			Q↓ & V↑	Q↓ & V -	Q - & V ↑	Q - & V -	Q↑ & V ↓	Q↑ & V -	Q - & V ↓	Q↑& V ↑	Q↓ & V ↓
Devonshire	AM	NBT						yes			
		SBT				yes					
		EBL				yes					
	NP	NBT								yes (deteriorated)	
		SBT						yes			
		EBL			yes						
	PM	NBT						yes			
		SBT						yes			
		EBL								yes (improved)	
Windsor	AM	NBT						yes			
		SBT							yes		
		EBT				yes					
		WBT				yes					
	NP	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT				yes					
	PM	NBT				yes					
		SBT				yes					
		EBT				yes					
		WBT				yes					
Subtotal			0	0	1	27	2	13	9	3 (deteriorated) 1 (improved)	0
Total			1 (Q_V improved)			27 (Q_V unchanged)	24(Q_V deteriorated)			3 (Q_V deteriorated) 1 (Q_V improved)	

B.4 APPLICATION OF HCS IN DETERMINING CONDITION OF CASES WITH BOTH INCREASED OR DECREASED QUEUE LENGTH AND VOLUME

For the cases “To be determined,” the lane groups where both delay and volume significantly increased (or decreased), the same method in delay comparison was used to estimate the expected queue changes due to the volume changes. For the lane groups for which both queue and volume significantly increased, the performance potentially deteriorated if the field-measured queue increased more than the expected value due to volume increase. For the lane groups with significantly decreased queue and volume, deteriorated Q_V was defined as when the field-measured queue decreased less than the expected value due to volume decrease, while improvement happened when the field-queue decrease was more than expected. Improved Q_V was defined as when the field queue increase was less than the expected value. Comparison results of the field-measured and expected queue changes are shown in Table 37.

Table 37. Queue-Discrepancy Comparison, *HCS* vs. Field

Lane groups	Volume difference in *HCS* runs	*HCS* discrepancy		Field discrepancy		Results
		Numerical	%	Numerical	%	
St. Mary's NP NB	67	1.1	17%	2.151	64%	Q_V deteriorated
St. Mary's NP SB	68	0.8	22%	2.813	188%	Q_V deteriorated
Devonshire NP NB	72	0	0%	1.06	67%	Q_V deteriorated
Devonshire PM EBL	41	3.1	62%	1.09	42%	Q_V improved

APPENDIX C: DETAILED SIGNAL TIMING CHANGE CALCULATIONS

C.1. ENTIRE TIME LENGTH AND ENTIRE GREEN TIME

It should be noted that the entire studied time length (i.e. $\sum_{i=1}^{n} C_i$) must be kept the same in both TBC 2017 and ASCT 2017 for studying the average effective green-time changes and average g/C ratio changes; that is:

$$\sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_April}} \approx \sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_March}} \tag{3}$$

where

$\sum_{i=1}^{n} \boldsymbol{C_i}$: the entire studied time length during the whole analysis period;

$\boldsymbol{C_i}$: cycle length of the i_{th} Cycle;

$\boldsymbol{n}$: number of cycles during the whole analysis period.

Specific entire time-length-calculation results are shown in Table 38. In this table, the differences of entire studied time length and entire effective green-time length between ASCT 2017 and TBC 2017 were calculated, respectively:

$$\boldsymbol{Diff\_C} = \sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_April}} - \sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_March}} \tag{4}$$

$$\boldsymbol{Diff\_G} = \sum_{i=1}^{n} \boldsymbol{G}_{\boldsymbol{i\_April}} - \sum_{i=1}^{n} \boldsymbol{G}_{\boldsymbol{i\_March}} \tag{5}$$

It should be also noted that the entire green time must be the same for studying the average effective green-time changes and average g/C ratio changes, that is:

$$\sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_April\_GT}} = \sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_April\_gc}} \tag{6}$$

$$\sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_March\_GT}} = \sum_{i=1}^{n} \boldsymbol{C}_{\boldsymbol{i\_March\_gc}} \tag{7}$$

where

$\sum_{i=1}^{n} C_{i\_March\_GT}$ is the entire studied time under TBC 2017 for average effective green-time changes;

$\sum_{i=1}^{n} C_{i\_March\_gc}$ is the entire studied time under TBC 2017 for average g/C ratios changes;

$\sum_{i=1}^{n} C_{i\_April\_GT}$ is the entire studied time under ASCT 2017 for average effective green-time changes;

$\sum_{i=1}^{n} C_{i\_April\_gc}$ is the entire studied time under ASCT 2017 for average g/C ratios changes;

Table 38. Entire Studied Time Length and Effective Green Time Comparison for Each Intersection under ASCT 2017 and TBC 2017

			April			March			Comparisons	
Intersection	Time period	Approach	n	$\sum_{i=1}^{n} C_i$	$\sum_{i=1}^{n} G_i$	n	$\sum_{i=1}^{n} C_i$	$\sum_{i=1}^{n} G_i$	$\sum_{i=1}^{n} C_{i\_April} - \sum_{i=1}^{n} C_{i\_March}$	$\sum_{i=1}^{n} G_{i\_April} - \sum_{i=1}^{n} G_{i\_March}$
Stadium	AM	NBT	58	3530	1859	64	3518	1813	12	46
		SBT			1859			1813		46
		EBT			986			950		36
		WBT			986			950		36
	NP	NBT	65	3581	1856	63	3572	1991	9	-135
		SBT			1856			1991		-135
		EBT			958			838		120
		WBT			958			838		120
	PM	NBT	59	3560	1833	59	3540	1840	20	-7
		SBT			1833			1840		-7
		EBT			1031			1004		27
		WBT			1031			1004		27
Kirby	AM	NBT	27	3282	1154	30	3300	1136	-18	18
		SBT			1441			1395		46
		EBT			938			1129		-191
		WBT			1043			1032		11
	NP	NBT	31	3411	1396	31	3410	1282	1	114
		SBT			1361			1274		87
		EBT			701			1054		-353
		WBT			850			1132		-282
	PM	NBT	29	3494	1266	29	3480	1281	14	-15
		SBT			1283			1295		-12
		EBT			878			907		-29
		WBT			1020			1072		-52
St. Mary's	AM	NBT	29	3492	1897	32	3520	1971	-28	-74
		SBT			2262			2373		-111
		EBT			641			580		61
		WBT			696			581		115
	NP	NBT	32	3532	1764	32	3520	1959	12	-195
		SBT			2029			2156		-127
		EBT			658			622		36
		WBT			743			701		42
	PM	NBT	29	3463	2012	29	3480	1765	-17	247
		SBT			2004			1818		186
		EBT			454			651		-197
		WBT			842			1032		-190
Devonshire	AM	NBT	28	3373	2702	31	3411	2695	-38	7
		SBT			2558			2585		-27
		EBL			360			372		-12
	NP	NBT	32	3532	2639	32	3520	2700	12	-61
		SBT			2368			2507		-139
		EBL			549			465		84
	PM	NBT	28	3463	2635	28	3480	2714	-17	-79
		SBT			2532			2556		-24
		EBL			403			335		68
Windsor	AM	NBT	28	3352	1420	30	3300	1477	52	-57
		SBT			1481			1588		-107
		EBT			884			914		-30
		WBT			733			614		119
	NP	NBT	31	3387	1402	30	3409	1482	-22	-80
		SBT			1544			1643		-99
		EBT			642			830		-188
		WBT			719			841		-122
	PM	NBT	30	3551	1141	30	3600	1205	-49	-64
		SBT			1267			1502		-235
		EBT			899			908		-9
		WBT			926			979		-53

- The $\boldsymbol{Diff\_C}$ varied from 1 to 52 seconds. Considering the largest $\boldsymbol{Diff\_C}$: 52 seconds, the difference means the entire studied time between TBC 2017 and ASCT 2017 varied less than half of one cycle length (55–60 seconds). If the time difference was evenly distributed to each cycle, for example, 52/30=1.73 seconds difference for each cycle; and this small amount can be ignored. Hence, the entire studied time lengths in ASCT 2017 and TBC 2017 were considered similar, that is to say, $\sum_{i=1}^{n} \boldsymbol{C_{i\_April}} \approx \sum_{i=1}^{n} \boldsymbol{C_{i\_March}}$ was acceptable.

C.2 DETAILED CYCLE-LENGTH-CALCULATION RESULTS

Table 39. Comparison of Average Cycle Length under ASCT 2017 and TBC 2017

		April			March			Test results	
Intersection	**Time period**	**Cycle-length average**	**Cycle-length variance**	**Cycle-length range**	**Cycle-length average**	**Cycle-length variance**	**Cycle-length range**	**p-value**	**Cycle-length change**
Stadium	AM	60.862	12.612	58–70	54.969	2.348	53–59	1.203E-18	**Inc**
	NP	55.092	2.991	50–60	56.698	16.569	53–68	0.0049	**Dec**
	PM	60.339	12.642	54–68	60.000	0.000	60–60	0.4669	**Unch**
Kirby	AM	121.556	14.949	119–134	110.000	0.069	109–111	1.023E-14	**Inc**
	NP	110.032	43.699	98–118	110.000	0.000	110–110	0.9785	**Unch**
	PM	120.483	48.544	110–133	120.000	0.000	120–120	0.7119	**Unch**
St. Mary's	AM	120.414	11.608	119–137	110.000	0.000	110–110	6.263E-16	**Inc**
	NP	110.375	1.661	110–116	110.000	0.000	110–110	0.1099	**Unch**
	PM	119.414	40.894	110–132	120.000	0.000	120–120	0.6254	**Unch**
Devonshire	AM	120.464	11.962	119–137	110.032	0.032	110–111	2.654E-15	**Inc**
	NP	110.400	1.766	110–116	110.000	0.000	110–110	0.11	**Unch**
	PM	119.607	40.544	110-132	120.000	0.000	120–120	0.7466	**Unch**
Windsor	AM	119.714	47.175	88-132	110.000	0.000	110–110	4.740E-08	**Inc**
	NP	109.258	6.865	100-114	113.633	72.447	110–135	0.0108	**Dec**
	PM	118.367	64.309	107-133	120.000	0.000	120–120	0.2738	**Unch**

From Table 39, of the 15 cases, 5 significantly increased, 2 significantly decreased, and the other 8 cases were unchanged. The 5 increased cases all happened at AM time periods. There were also two cases showing cycle lengths significantly decreased at Stadium NP and Windsor NP, with both caused by pedestrian activities; detailed analyses were discussed in section 4.5.4.

C.3 DETAILED AVERAGE EFFECTIVE GREEN-TIME-COMPARISON RESULTS

Table 40. Statistical Comparison Between TBC2017 and ASCT2017 Conditions, Average Effective Green Time

Intersection	Time periods	Approaches	April average effective green time	April effective green time variance	March average effective green time	March effective green time variance	p–value	Effective green time change (Apr–Mar)	Volume change (Apr–Mar)	Delay change (Apr–Mar)	Queue length change (Apr–Mar)	PI
Stadium	AM	NBT	32.06	14.239	28.32	7.327	1.08E-08	Inc	Unch	Inc	Inc	Det
		SBT	32.06	14.239	28.32	7.327	1.08E-08	Inc	Unch	Inc	Unch	Det
		EBT	17.01	12.597	14.85	11.109	0.0007	Inc	Dec	Inc	Inc	Det
		WBT	17.01	12.597	14.85	11.109	0.0007	Inc	Dec	Unch	Inc	-
	NP	NBT	28.55	9.982	31.60	16.440	6.05E-06	Dec	Unch	Inc	Inc	Det
		SBT	28.55	9.982	31.60	16.440	6.05E-06	Dec	Unch	Unch	Unch	Unch
		EBT	14.75	12.532	13.30	15.323	0.0301	Unch	Dec	Unch	Inc	Det
		WBT	14.75	12.532	13.30	15.323	0.0301	Unch	Dec	Unch	Unch	Det
	PM	NBT	31.07	16.040	31.19	18.140	0.7791	Unch	Unch	Unch	Inc	Det
		SBT	31.07	16.040	31.19	18.140	0.7791	Unch	Unch	Inc	Inc	Det
		EBT	17.47	11.833	17.01	18.140	0.5221	Unch	Dec	Inc	Unch	Det
		WBT	17.47	11.833	17.01	18.140	0.5221	Unch	Unch	Inc	Inc	Det
Kirby	AM	NBT	42.74	32.276	37.87	7.154	0.0002	Inc	Unch	Inc	Inc	Det
		SBT	53.37	98.473	46.50	35.017	0.0032	Inc	Dec	Unch	Unch	Det
		EBT	34.73	3.2422	37.63	21.982	3.22E-03	Dec	Unch	Inc	Inc	Det
		WBT	38.62	34.7977	38.21	26.333	0.7877	Unch	Dec	Unch	Unch	Det
	NP	NBT	45.03	57.766	41.35	31.570	0.0346	Unch	Unch	Dec	Unch	Imp
		SBT	43.90	57.357	41.10	35.957	0.1110	Unch	Unch	Unch	Unch	Unch
		EBT	22.62	67.058	34.00	36.090	4.82E-08	Dec	Unch	Inc	Unch	Det
		WBT	27.42	52.359	36.52	13.052	4.46E-08	Dec	Unch	Inc	Unch	Det
	PM	NBT	48.69	50.542	49.27	31.965	0.7474	Unch	Unch	Dec	Unch	Imp
		SBT	44.24	35.975	44.66	10.377	0.7450	Unch	Unch	Inc	Inc	Det
		EBT	30.27	21.791	31.27	4.4335	0.2995	Unch	Unch	Unch	Unch	Unch
		WBT	35.17	38.638	36.96	21.337	0.2181	Unch	Dec	Unch	Unch	Det
St. Mary's	AM	NBT	65.42	95.116	61.59	39.512	0.0779	Unch	Unch	Unch	Unch	Unch
		SBT	78.00	83.453	74.15	41.226	0.0649	Unch	Unch	Unch	Unch	Unch
		EBT	22.11	44.966	18.14	25.673	0.0109	Inc	Unch	Unch	Unch	Unch
		WBT	24.01	21.079	18.17	23.870	1.13E-05	Inc	Dec	Unch	Unch	Det
	NP	NBT	55.12	66.757	61.21	51.577	0.0024	Dec	Inc	Unch	Inc	Det
		SBT	63.40	69.871	67.37	42.902	0.0385	Unch	Inc	Inc	Inc	Det
		EBT	20.58	45.145	19.45	24.387	0.4482	Unch	Unch	Unch	Unch	Unch
		WBT	23.23	16.064	21.92	21.918	0.2329	Unch	Dec	Unch	Unch	Det
	PM	NBT	69.38	92.259	60.87	59.106	0.0005	Inc	Unch	Unch	Unch	Unch
		SBT	69.11	109.670	62.69	49.599	0.0086	Inc	Unch	Unch	Unch	Unch
		EBT	15.67	12.034	22.46	14.118	1.93E-09	Dec	Unch	Unch	Unch	Unch
		WBT	29.04	38.663	35.60	8.667	7.88E-06	Dec	Dec	Inc	Unch	Det
Devonshire	AM	NBT	96.49	23.581	86.92	19.292	8.34E-11	Inc	Unch	Inc	Inc	Det
		SBT	91.35	111.528	83.37	73.047	0.0022	Inc	Unch	Unch	Unch	Unch
		EBL	12.87	17.735	12.01	18.880	0.4434	Unch	Unch	Unch	Unch	Unch
	NP	NBT	82.46	52.519	84.38	18.370	0.2018	Unch	Inc	Unch	Inc	Det
		SBT	73.99	136.973	78.35	66.065	0.0889	Unch	Unch	Inc	Inc	Det
		EBL	17.17	33.668	14.52	18.370	0.0424	Unch	Unch	Unch	Unch	Unch
	PM	NBT	94.10	63.222	96.92	12.819	0.0951	Unch	Unch	Unch	Inc	Det
		SBT	90.42	129.115	91.28	129.115	0.7440	Unch	Unch	Inc	Inc	Det
		EBL	14.41	21.284	11.98	12.819	0.0321	Unch	Inc	Unch	Inc	Imp
Windsor	AM	NBT	50.71	185.433	49.23	57.482	0.6167	Unch	Unch	Inc	Inc	Det
		SBT	52.89	163.101	52.93	51.264	0.9862	Unch	Dec	Unch	Unch	Det
		EBT	31.58	90.745	30.47	26.185	0.5865	Unch	Unch	Inc	Unch	Det
		WBT	26.19	29.915	20.47	11.220	2.09E-05	Inc	Unch	Unch	Unch	Unch
	NP	NBT	45.21	41.778	49.40	103.407	0.0617	Unch	Unch	Inc	Unch	Det
		SBT	49.79	88.295	54.77	101.523	0.0507	Unch	Unch	Unch	Unch	Unch
		EBT	20.71	9.561	27.67	30.668	2.75E-07	Dec	Unch	Unch	Unch	Unch
		WBT	23.19	59.058	28.03	34.602	0.0078	Dec	Unch	Unch	Unch	Unch
	PM	NBT	38.03	65.909	40.17	31.909	0.2428	Unch	Unch	Unch	Unch	Unch
		SBT	42.23	64.585	50.07	59.844	0.0003	Dec	Unch	Inc	Unch	Det
		EBT	29.97	25.582	30.27	8.447	0.7794	Unch	Unch	Inc	Unch	Det
		WBT	30.87	30.999	32.63	15.444	0.1616	Unch	Unch	Inc	Unch	Det

C.4 DETAILED AVERAGE G/C-COMPARISON RESULTS

Table 41. Statistical Comparison Between TBC2017 and ASCT2017 Conditions, Average g/C

APPENDIX D: DETAILED COMPARISON OF SYSTEM VOLUME COUNTS AND FIELD VOLUME COUNTS

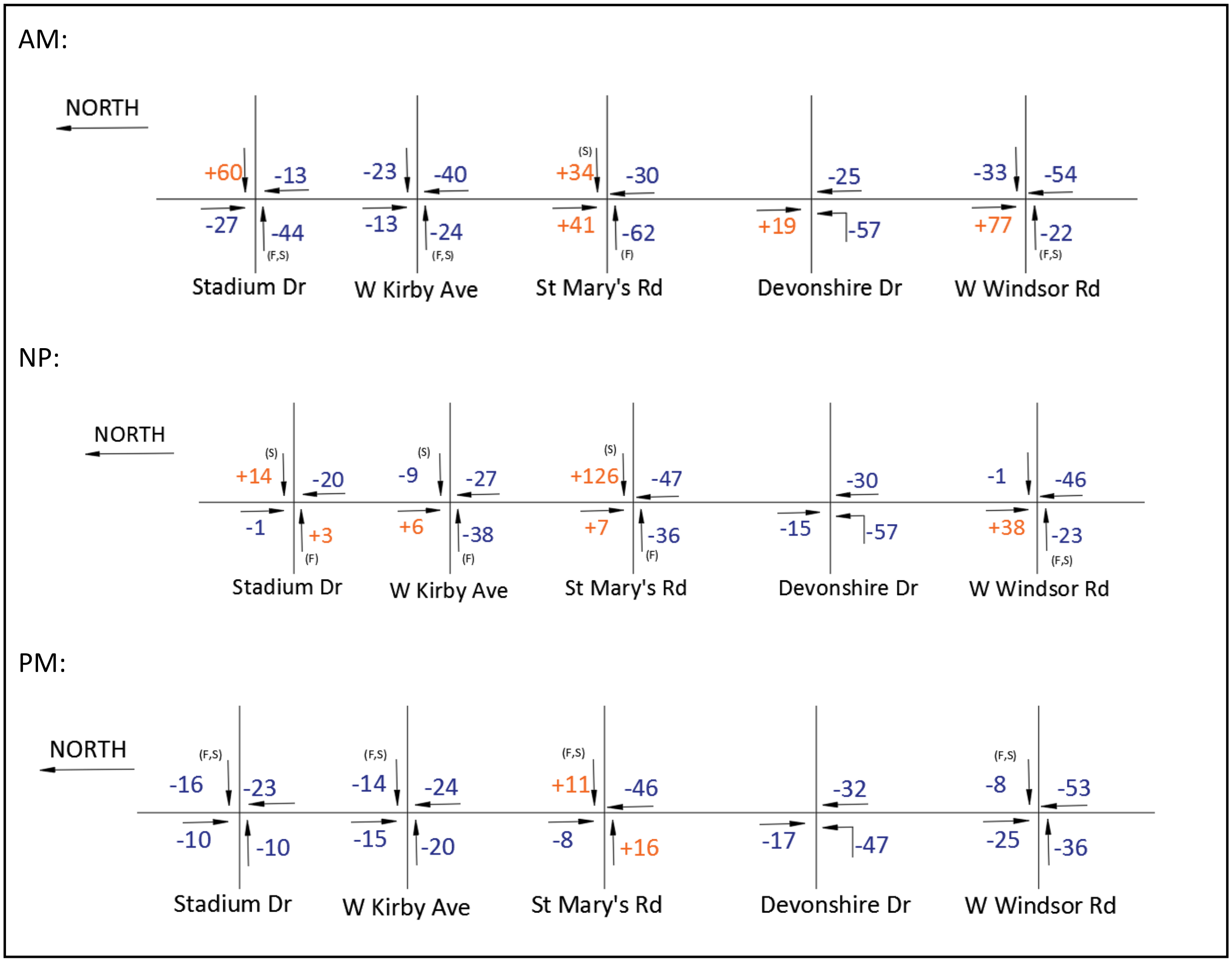

Figure 12. Comparison of system volume counts and field volume counts (%) in April 2017.

Notes:

1. +: System overcounted, -: system undercounted.
2. (F) indicates the highest-volume approach, based on field data.
3. (S) indicates the highest-volume approach, based on system data.
4. The number represents the percentage (%) increased or decreased.
5. The comparison base is the field data.

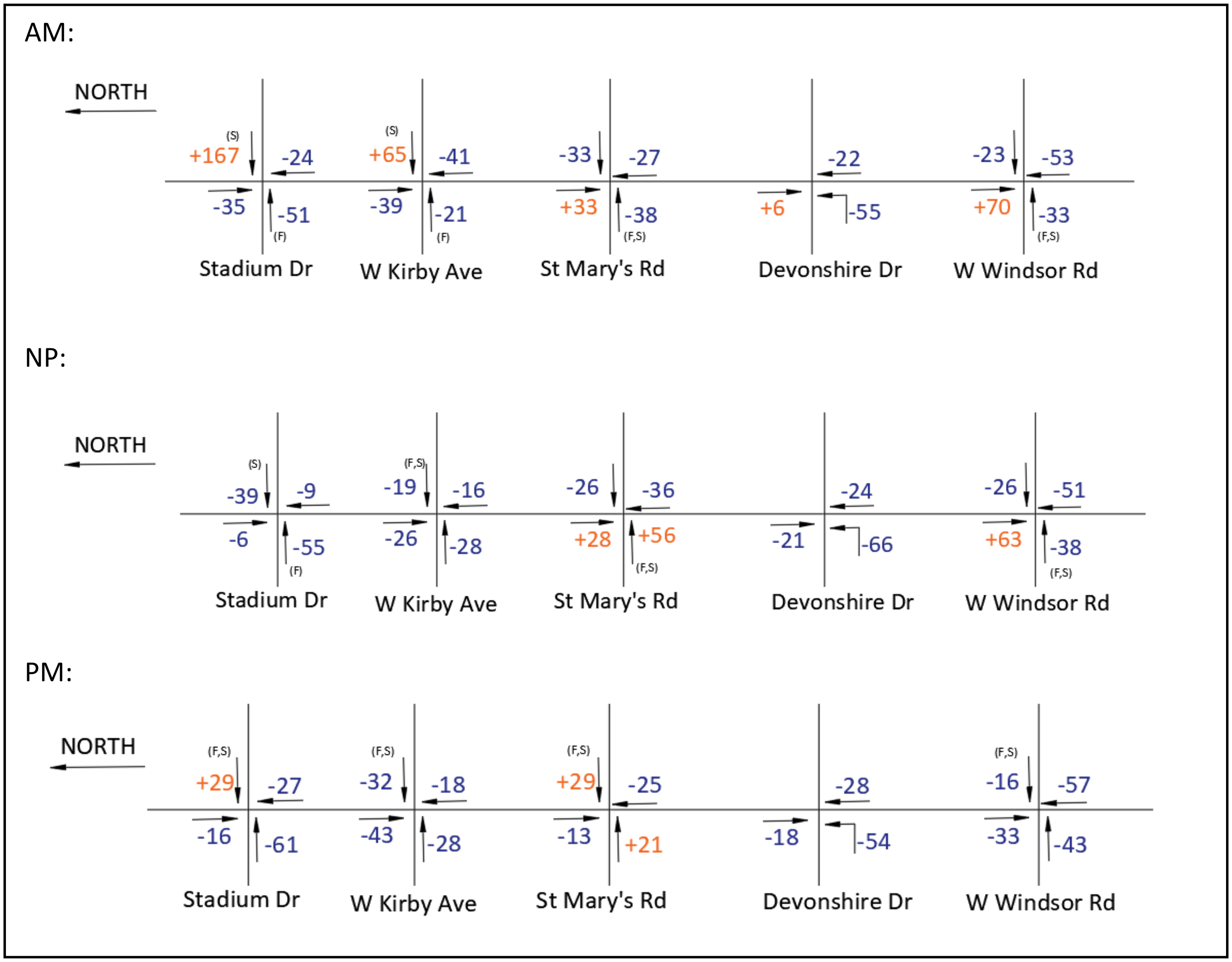

Figure 13. Comparison of system volume counts and field volume counts (%) in March 2017.

Notes:
1. +: System overcounted, -: system undercounted.
2. (F) indicates the highest-volume approach, based on field data.
3. (S) indicates the highest-volume approach, based on system data.
4. The number represents the percentage (%) increased or decreased.
5. The comparison base is the field data.

APPENDIX E: PHASE PLANS

Based on signal-timing information, there were six types of phase plans at either minor or major streets. The detailed phase plans are shown in Figures 14 and 15.

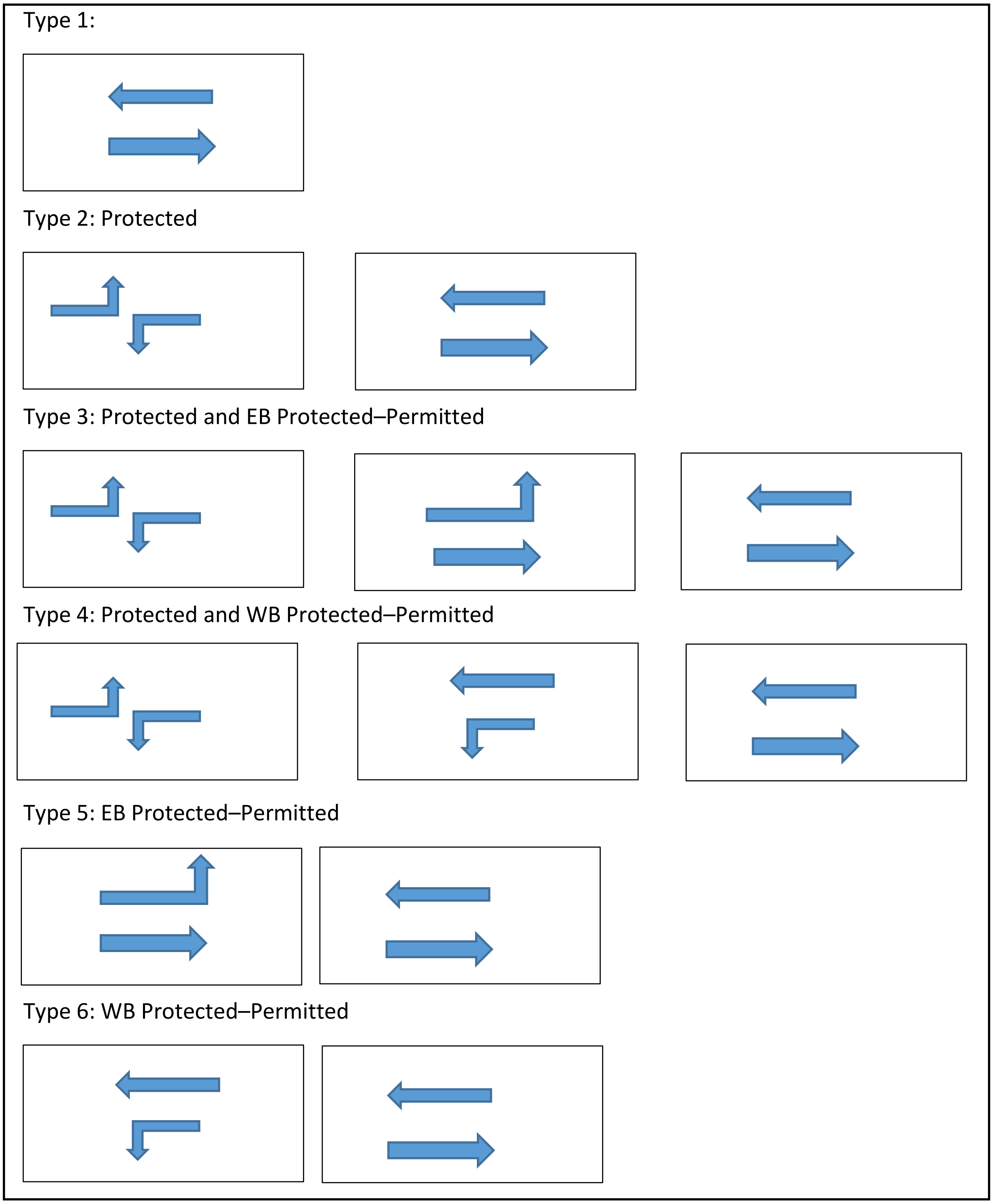

Figure 14. Minor streets' possible phase plan.

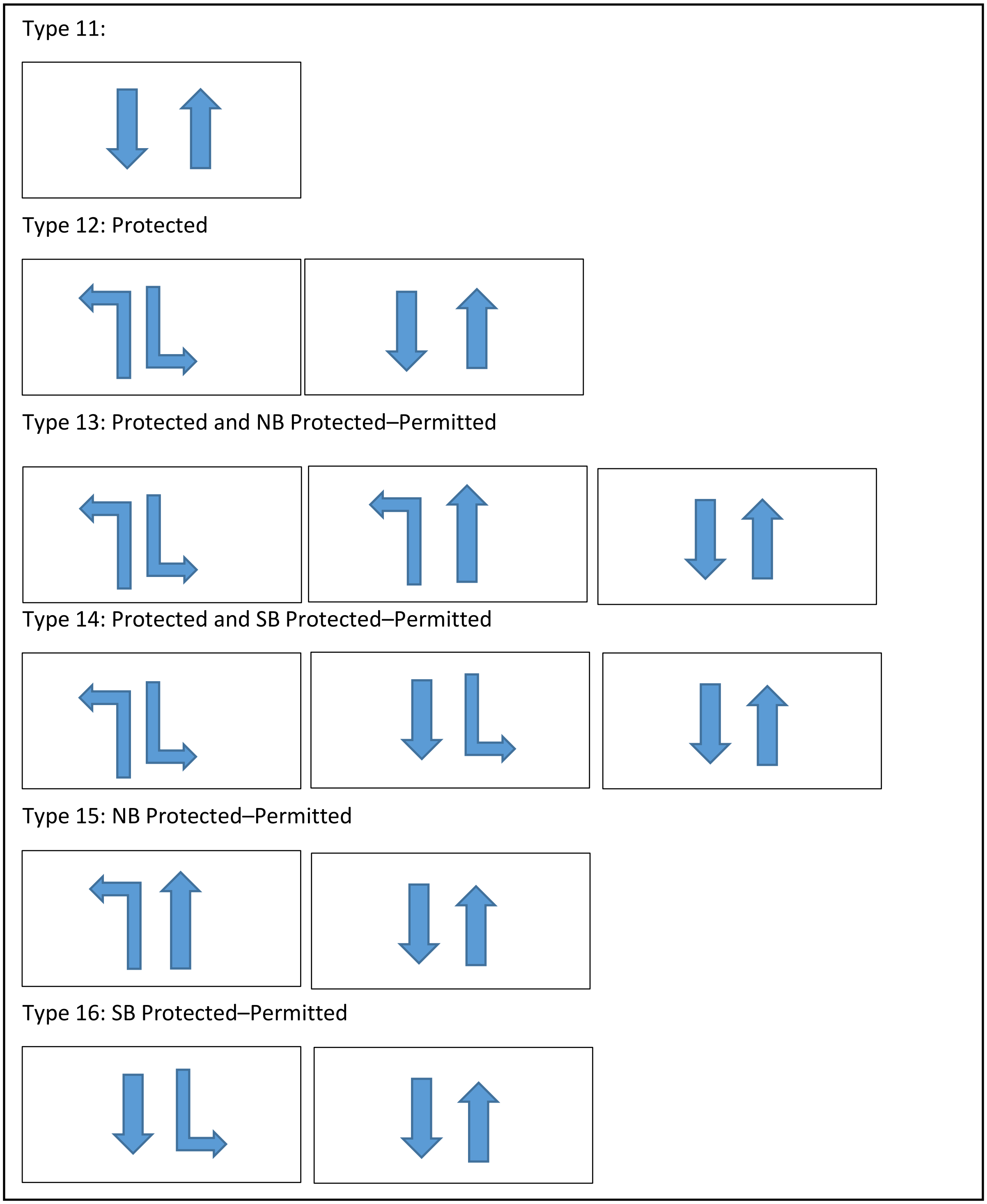

Figure 15. Major streets' possible phase plans.

E.1. PHASE EFFECTS

We defined overlapped phase plans as shown by Types 3, 4, 13, or 14 in Figures 14 and 15. Protected phase plans were shown by Types 2 or 12. The overlapped phases were expected to happen more frequently under ASCT and less frequently under TBC. However, in some cases, it did not meet our expectation.

Table 42. Overlapped Phases and Protected Phases, Numbers in ASCT 2017 and TBC 2017

Intersection	Time	Phase type	Major		Minor	
			ASCT	TBC	ASCT	TBC
Kirby	AM	Overlapped	10/28	2/30	13/28	0/30
		Protected	4/28	9/30	8/28	16/30
	NP	Overlapped	7/31	0/32	15/31	15/32
		Protected	16/31	21/32	11/31	7/32
	PM	Overlapped	8/31	4/29	14/31	20/29
		Protected	14/31	15/29	11/31	5/29
St. Mary's	AM	Overlapped	4/29	3/32	2/29	0/32
		Protected	1/29	1/32	4/29	6/32
	NP	Overlapped	5/32	3/32	9/32	0/32
		Protected	2/32	1/32	8/32	13/32
	PM	Overlapped	3/29	0/30	10/29	16/30
		Protected	1/29	2/30	2/29	1/30
Windsor	AM	Overlapped	1/28	0/32	5/28	21/32
		Protected	9/28	6/32	15/28	5/32
	NP	Overlapped	3/31	0/31	1/31	0/31
		Protected	15/31	13/31	24/31	26/31
	PM	Overlapped	8/30	11/30	7/30	5/30
		Protected	14/30	6/30	21/30	23/30

From Table 42, there are three cases in minor streets and one case in major streets that showed the overlapped phases occur more under TBC and less under ASCT. That indicated the phase allocation in these four cases did not meet our expectations because we expected the adaptive signal could develop more overlapped phases.

APPENDIX F: SYSTEM TECHNICAL ERRORS OBSERVED IN THE FIELD

Through observations and data reductions, we discovered some issues existing in the system. The issues, or errors, were categorized as combining cycles or splitting cycles spontaneously, wrongly allocating green time at minor streets, and wrongly counting the traffic volume.

F.1 COMBINING CYCLES

System combined two consecutive cycles spontaneously, leading to cycle lengths twice as long as the normal cycles, as shown in Table 43.

Table 43. System Issue of Combining Cycles

	Approaches	Timestamps in our recorded video	Observed cycle length (sec)	System-recorded time	System-recorded cycle length (sec)
Winsor, April 12 NP	All	0:51:16–0:54:44	100 106	13:05:52 PM	206
Kirby, April 12 NP	All	0:24:09–0:27:43	98 116	12:40:05 PM	214
Kirby, April 12 NP	All	0:48:01–0:51:39	100 118	13:03:58 PM	218
Kirby, April 12 NP	All	1:02:23–1:05:58	113 107	13:18:19 PM	220
Kirby, April 12 PM	All	0:34:58–0:38:50	112 120	17:08:02 PM	232

F.2 SPLITTING CYCLES

Table 44 shows a case that the system split one long cycle into two separate cycles. This happened at Devonshire Road during April NP.

Table 44. System Issue of Splitting Cycle

	Approaches	Timestamps in our recorded video	Observed cycle length(sec)	System-recorded time	System-recorded cycle length (sec)
Devonshire, April 13 NP	All	0:20:36–0:24:20	224	12:27:34PM 12:29:28PM	114 110

F.3 GREEN TIME WRONGLY ALLOCATED TO MINOR STREETS

The system did not allocate WBT green time at Windsor NP on one cycle although a queue existed, as shown in Table 45.

Table 45. Green Time Wrongly Allocated to Minor Streets

	Approaches	Timestamps in our recorded video	Observed cycle length(sec)	System-recorded time	System-recorded cycle length (sec)
Winsor, April 12 NP	WBT	0:16:11–0:18:00	224	12:30:58PM	110

F.4 VOLUME MISCOUNTED BY SYSTEM

Table 46 shows a specific example detected at Stadium, AM.

Table 46. Example of Volume Miscount by System

	Approaches	Timestamps in our recorded video	Description
Stadium, April 11 AM	WBT	0:15:44–0:15:58	A series of cars (grey, black, grey van, red truck) on NB activated the specified area in counting of WBT

Figure 16. Snapshot of the mismatching case at minor street.

In the snapshot, the grey car activated the detection zone for counting of the minor streets, and the following black car also activated that area; but the vehicles on minor streets should be activating these detection zones; hence, the miscounting occurred. .