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EVALUATION OF ADAPTIVE SIGNAL CONTROL TECHNOLOGY—VOLUME 2: COMPARISON OF BASE CONDITIONS TO FIRST YEAR AFTER IMPLEMENTATION

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A report of the findings of
ICT PROJECT R27-127
Safety and Efficiency Benefits of Implementing Adaptive Signal Control Technology in Illinois

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16. Abstract

Field evaluation of adaptive signal control technologies (ASCT) is very important in understanding the system's contribution to safety and operational efficiency. Data were collected at six intersections along the Neil Street corridor in Champaign, Illinois, before deployment of SynchroGreen, an ASCT system. The volume, delay, and queue length data from the field for the "before" conditions (which is 2013 data) were compared to the data from the first year after implementation conditions (which is 2015 data). The system was installed in early 2015 and fined tuned by the vendor to get the "best" performance. The field volumes were compared for 83 lane groups (approaches). While traffic volume on 48% of the lane groups significantly increased, 48% did not change significantly, and only 4% significantly decreased. The field delays were compared for 83 lane groups; out of which 22% showed significant increase, 64% showed no significant change, and 14% showed significant decrease. Queue length was compared for only 63 lane groups because the remaining 20 lane groups either did not have queue data, or the queue length was insignificant (two cars or less). Out of the 63 lane groups, 32% showed significant increase, but 49% showed no significant change, and 19% showed significant decrease in queue length. ASCT performance was evaluated based on the changes in volume, delay, and queue length combined. An overall performance indicator (PI) was determined as: Imp (Improved), Unch (Unchanged), Det (Deteriorated), or Mix (mixed results). Of the 83 lane groups analyzed, 51% showed improvement, 20% remained unchanged, 28% showed deterioration, and 1% showed a mixed result. The analyses indicated that ASCT made a compromise between the minor and major street performances and, in general, the minor street improvements were correlated with the major street deterioration or unchanged performances.

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EXECUTIVE SUMMARY

Traffic signals in the United States have evolved from pre-timed, to vehicle-actuated operation, 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) is 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 prior to ASCT deployment was measured. The data are used as a basis to compare the performance of the system after it is deployed. This report presents the study methodology, data collection, data reduction, and data analysis of the base conditions in the "before" (2013 data) and "the first year after" implementation of SynchroGreen (2015 data). The system was installed in early 2015 and fined tuned by the vendor to get the "best" performance. Traffic characteristics for four different time periods (AM peak, off 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 the 2013 conditions (before), were measured and compared with the data for 2015 conditions (after). The field volumes were compared for 83 lane groups (approaches). Although traffic volume on 48% of the lane groups did significantly increase, 48% did not change significantly, and only 4% significantly decreased. The field delays were compared for 83 lane groups; out of which 22% showed significant increase, 64% showed no significant change, and 14% showed significant decrease. Queue length was compared for only 63 lane groups because the remaining 20 lane groups either did not have queue data, or the queue length was insignificant (two cars or under). Out of these 63 lane groups, 32% showed significant increase in queue length, 49% showed no significant change, and 19% 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), Det (Deteriorated), or Mix (mixed results). Out of the total of 83 lane groups analyzed, in 51% of them the PI showed improvement, in 20% the PI remained unchanged, but in 28% the PI showed deterioration and in 1% of lane groups showed a mixed result. In summary, on 71% of the lane groups ASCT either improved or kept it the performance unchanged; however on 28% of the lane groups ASCT deteriorated the performance and in one percent it showed mixed results. Out of the 23 deteriorated cases (the 28%), in 4 of them volume significantly increased, in 18 of them volume did not change significantly, and in 1 of them volume significantly decreased. The deterioration in the 4 cases can be attributed to the increase in volume and the system's inability to respond adequately to the volume increase. However, in the 18 lane groups where volume did not significantly change, the deterioration in PI was not expected.

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

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 increasingly being deployed in different 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 (Schrank et al. 2015). Thus, increased deployment of more efficient signal systems is necessary to reduce those massive effects of 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. (Trafficware 2012). 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 (Stevanovic 2010), at locations such as Seminole County, Florida (Cheek et al. 2011) and Boca Raton, Florida (So et al. 2014).

Therefore, a “before and after” 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 data analysis results for the first year after the deployment of the SynchroGreen system (2015 data). The 2015 data is compared to base condition before ASCT implementation (2013 data). The installation of the 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 work in a coordinated manner.

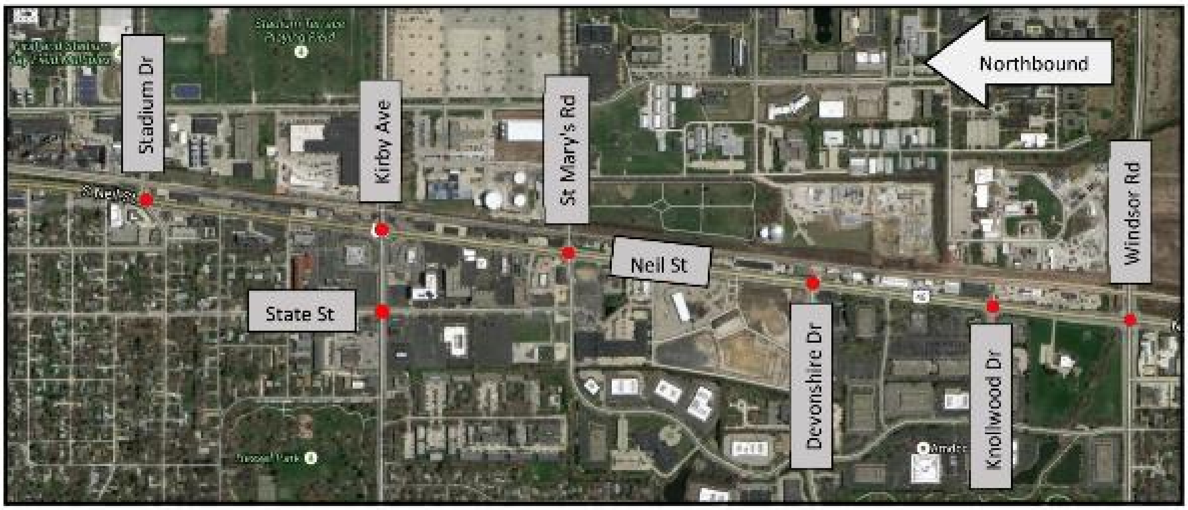

Figure 1. Deployment location on Neil Street in Champaign, Illinois.

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 the collection of the traffic data for 2015.

Chapter 4 discusses the statistical comparisons between 2013 and 2015 conditions in terms of volume, stopped delay, and queue length—as well as the relationships between delay & volume performance, and queue & volume performance. This chapter also evaluates the traffic performance at both corridor and intersection levels by analyzing the comparison results.

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 consists of six intersections along the Neil Street corridor, Champaign, IL (Figure 2). At the time of data collection, the six intersections on Neil Street were operating as time-based coordinated signals—and provided progression for northbound and southbound traffic (the major street). The traffic pattern on Neil Street is one that has higher volume going northbound in the morning (toward downtown Champaign), but in the afternoon it is the southbound that has higher volume. 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 crossing streets, the heavy volume direction in the morning is eastbound towards the campus of University of Illinois at Urbana-Champaign. In the afternoon, the heavy volume direction is westbound, away from campus. Schematic geometries of the six intersections are shown in Figures 3 through 8 (the drawings are not to scale).

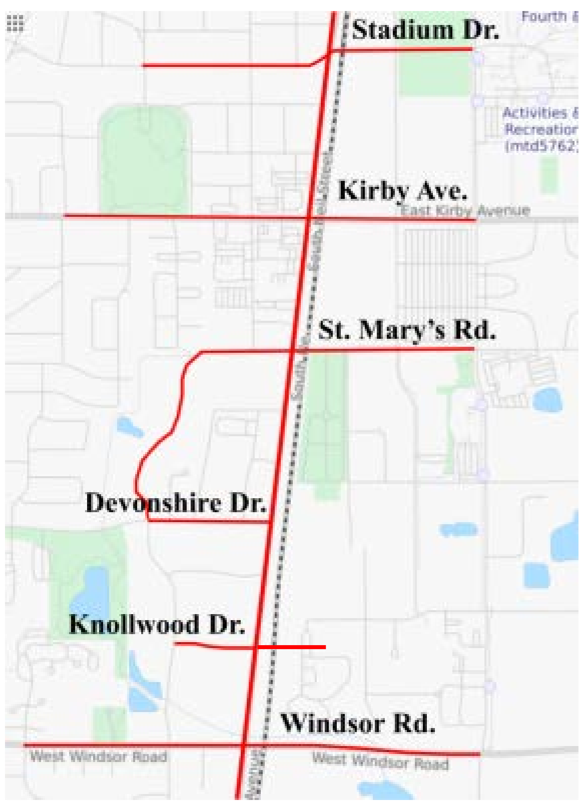

Figure 2. Six study intersections along the Neil Street corridor, Champaign, IL.

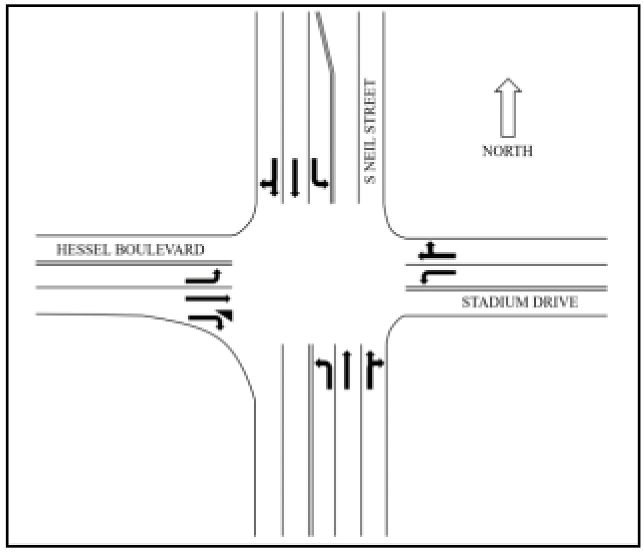

Figure 3. Geometry of the intersection of Neil Street and Stadium Drive.

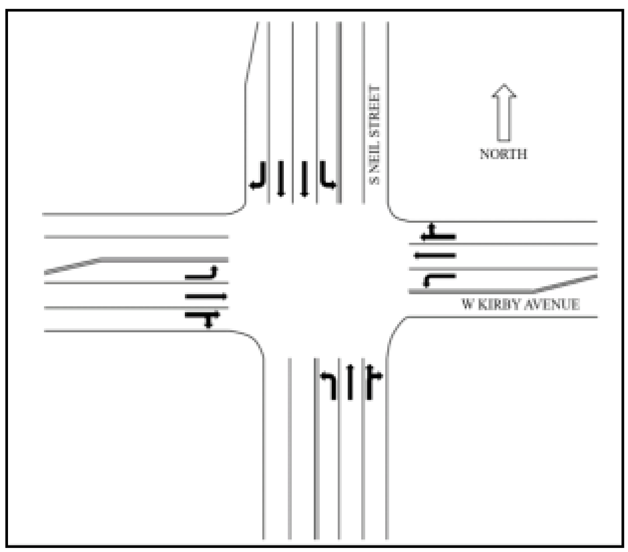

Figure 4. Geometry of the intersection of Neil Street and Kirby Avenue.

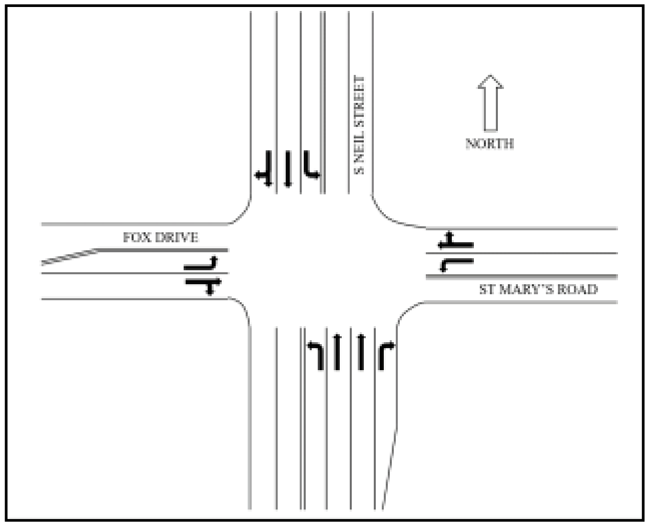

Figure 5. Geometry of the intersection of Neil Street and St. Mary's Road.

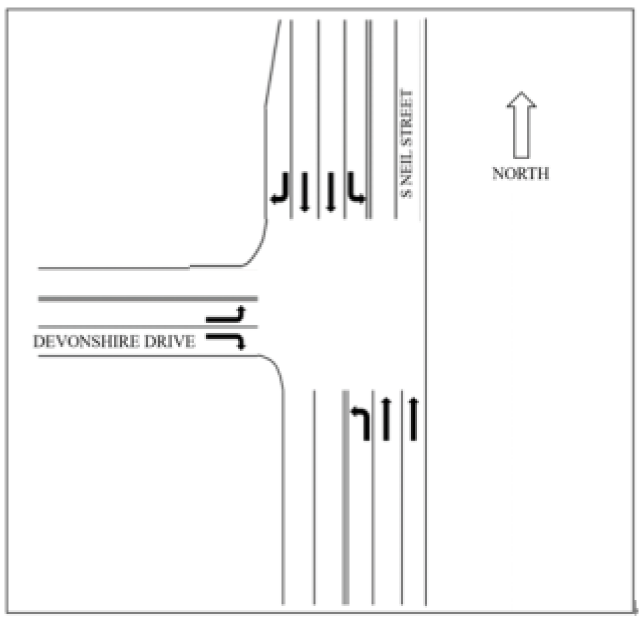

Figure 6. Geometry of the intersection of Neil Street and Devonshire Drive (since 2015).

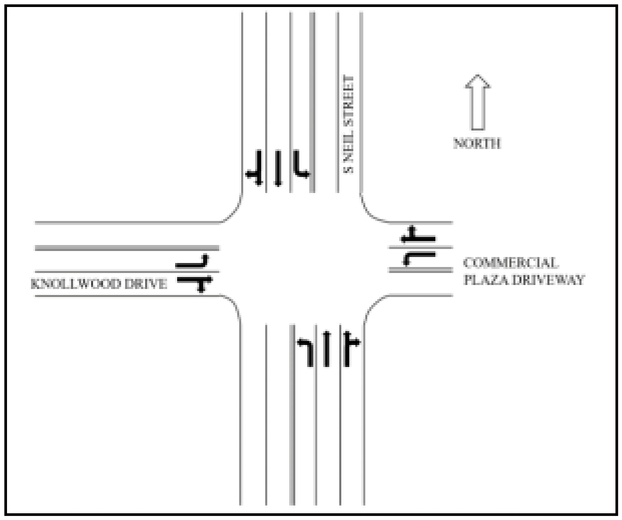

Figure 7. Geometry of the intersection of Neil Street and Knollwood Drive.

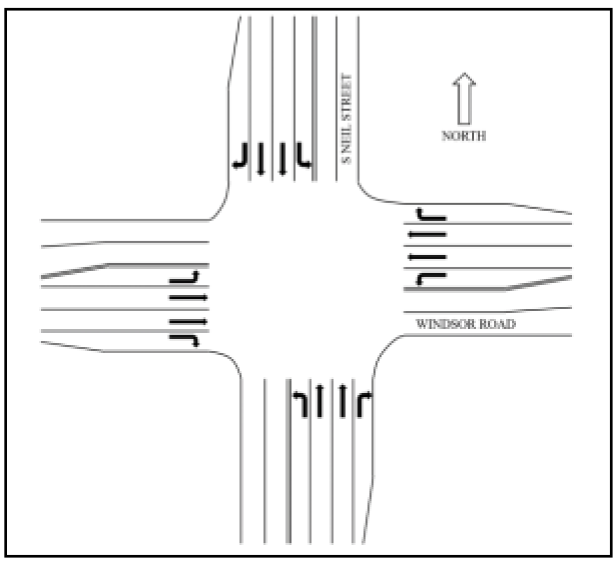

Figure 8. Geometry of the intersection of Neil Street and Windsor Drive.

2.2 FIELD DATA COLLECTION METHODOLOGY

For the “2015 conditions", the traffic data was collected at these six intersections between December 2 and December 15, 2015 on Tuesdays, Wednesdays and Thursdays. For each intersection, one day’s worth of data was collected—with the exception of Kirby and St. Mary’s—where one extra day’s worth of data was collected due to camera failures. During the data collection dates, there were no roadway construction activities and the weather conditions were normal. For the 2015 conditions, data collection was conducted by recording the online streaming traffic videos provided by the ASCT cameras at the six intersections. Data was recorded during morning peak (7:30-8:30 am), off peak

(10:40-11:40 am), noon peak (12:10-13:10 pm), and afternoon peak (16:40 – 17:40 pm) hours in a day—as determined in the 2013 conditions. The dates and days corresponding to the data collection at each intersection and data reduction are shown in Table 1.

Table 1. Date and Day of Traffic Data Collection and Traffic Data Reduction in 2015

Intersection	Data Collection		Data Reduction	
	Date	Day	Date	Day
Neil St. & Stadium Dr.	December 1, 2015	Tuesday	December 1, 2015	Tuesday
Neil St. & Kirby Ave.	December 2, 2015	Wednesday	December 2, 2015	Wednesday
	December 3, 2015	Thursday	December 3, 2015 Only noon and PM data*	Thursday
Neil St. & St. Mary’s Rd.	December 3, 2015	Thursday	December 10, 2015	Thursday
	December 10, 2015	Thursday	December 15, 2015 Only PM data*	Tuesday
Neil St. & Devonshire Dr.	December 9, 2015	Wednesday	December 9, 2015	Wednesday
Neil St. & Knollwood Dr.	December 15, 2015	Tuesday	December 15, 2015	Tuesday
Neil St. & Windsor Rd.	December 8, 2015	Tuesday	December 8, 2015	Tuesday

* Neil & Kirby: Noon Peak and PM data at this intersection were obtained on December 3, 2015, because data were unavailable on December 2, 2015.

* Neil & St Mary’s: PM data at this intersection were obtained on December 15, 2015, because data were unavailable on December 10, 2015.

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 and they are as follows: hourly volume, signal timing, proportion of vehicles stopping, arrival type, field delay, and queue length. Data reduction was performed for the four time periods (am peak, off peak, noon peak and pm peak). In the following sections, a detailed description of data reduction, along with the outcomes for each item, are presented.

3.1 HOURLY VOLUME

The left, through, and right-turn movement volumes during the four time periods were determined for all approaches of the six intersections. Those hourly volumes were used in the delay and capacity analysis, which will be discussed later in the report.

3.1.1 Methodology

The turning movement volumes for one hour were manually counted using the recorded traffic videos. The volume counts were obtained at 15-second intervals for the entire time period.

3.1.2 Data

The hourly volume counts during the four time periods are presented in Table 2. It is evident from the data, that northbound traffic volume is higher than southbound in the AM peak hour, and vice versa in the PM peak hour at all intersections. It is also obvious from the information in Table 2, that the demand on cross streets at the intersections of Neil Street with Devonshire Drive and Knollwood Drive, is much lower than the others. The cells with entries of N/A (Not Applicable), at the intersection of Neil Street and Devonshire Drive (T intersection), indicate that the intersection does not contain the respective lane group. Also, the cells with entries of N/A at the intersection of Neil Street and Windsor, signify that the data for northbound traffic during off peak, was not available due to video failure. NB, SB, EB, and WB are the abbreviations of northbound, southbound, eastbound and westbound, respectively. The same abbreviations will be used in the following tables and figures. AM and PM also indicate the morning peak and afternoon peak, respectively and the same indicators will be used in the following tables and figures.

Table 2. Hourly Volume Counts

Intersection	Time Period	NB[1]			SB[1]			EB[1]			WB[1]		
		L	T	R	L	T	R	L	T	R	L	T	R
Neil St. & Stadium Dr.	AM[2] Peak	54	983	N/A	55	715	N/A	30	232	N/A	15	56	N/A
	Off Peak	24	738	N/A	26	687	N/A	24	77	N/A	36	61	N/A
	Noon Peak	55	938	N/A	39	950	N/A	43	90	N/A	36	75	N/A
	PM[2] Peak	35	831	N/A	43	1033	N/A	35	104	N/A	54	238	N/A
Neil St. & Kirby Ave.	AM Peak	98	964	N/A	190	601	66	139	745	N/A	111	336	N/A
	Off Peak	95	626	N/A	110	586	88	122	353	N/A	124	366	N/A
	Noon Peak	125	836	N/A	129	755	114	139	494	N/A	176	404	N/A
	PM Peak	165	808	N/A	102	983	184	130	483	N/A	156	720	N/A
Neil St. & St. Mary's Rd.	AM Peak	35	990	213	161	627	N/A	26	168	N/A	29	74	N/A
	Off Peak	27	639	58	60	712	N/A	38	89	N/A	55	89	N/A
	Noon Peak	38	821	107	99	918	N/A	48	112	N/A	77	125	N/A
	PM Peak	28	706	44	41	1138	N/A	52	127	N/A	187	257	N/A
Neil St. & Devonshire Dr.	AM Peak	97	1231	N/A	2	460	71	79	N/A	41	N/A	N/A	N/A
	Off Peak	65	671	N/A	3	616	82	75	N/A	72	N/A	N/A	N/A
	Noon Peak	108	815	N/A	2	804	109	88	N/A	105	N/A	N/A	N/A
	PM Peak	57	755	N/A	0	1284	117	99	N/A	123	N/A	N/A	N/A
Neil St. & Knollwood Dr.	AM Peak	53	1313	N/A	8	465	N/A	8	17	N/A	1	5	N/A
	Off Peak	52	658	N/A	32	631	N/A	29	52	N/A	18	23	N/A
	Noon Peak	57	850	N/A	59	898	N/A	46	93	N/A	25	59	N/A
	PM Peak	25	660	N/A	24	1313	N/A	21	96	N/A	27	42	N/A
Neil St. & Windsor Rd.	AM Peak	76	971	263	72	305	75	252	580	55	120	288	164
	Off Peak	N/A	N/A	N/A	84	441	88	141	246	82	130	220	108
	Noon Peak	78	585	151	133	645	162	157	270	83	136	265	128
	PM Peak	67	467	140	142	961	241	151	282	73	290	637	109

3.2 SIGNAL TIMING

The signal timing data was reduced in order to get the green time ratio data—which was used to estimate the arrival type for the through movement groups.

3.2.1 Methodology

The 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. And the green time ratio for each through movement per cycle can be computed, and thus the green time ratio for each through movement per time period is obtained.

3.2.2 Data

Tables 3 through 6 show the green time ratio for each through movement for the six intersections per time period.

Table 3. Green Time Ratio for Through Movements During AM Peak

AM PEAK	NBT	SBT	EBT	WBT
Neil St &			**EBL Devonshire**	
Stadium Dr	0.588	0.588	0.229	0.229
Kirby Ave	0.406	0.383	0.239	0.244
St Mary's Rd	0.492	0.588	0.232	0.228
Devonshire Dr	0.816	0.816	0.084	NA
Knollwood Dr	0.919	0.919	0.221	0.221
Windsor Rd	0.431	0.417	0.250	0.216

NBT, SBT, EBT, and WBT are the abbreviations of northbound through, southbound through, eastbound through and westbound through traffics, respectively. The same abbreviations will be used in the following tables and figures. These values are compouted from the information stored in Sybchrogreen

Table 4. Green Time Ratio for Through Movements During Off Peak

Off PEAK **Neil St &**	**NBT**	**SBT**	**EBT** **EBL Devonshire**	**WBT**
Stadium Dr	0.694	0.694	0.174	0.174
Kirby Ave	0.455	0.348	0.225	0.215
St Mary's Rd	0.569	0.606	0.164	0.191
Devonshire Dr	0.800	0.800	0.091	NA
Knollwood Dr	0.828	0.817	0.065	0.065
Windsor Rd	0.438	0.467	0.202	0.194

Table 5. Green Time Ratio for Through Movements During Noon Peak

Noon PEAK **Neil St at**	NBT	SBT	EBT **EBL Devonshire**	WBT
Stadium Dr	0.719	0.719	0.160	0.160
Kirby Ave	0.366	0.311	0.271	0.282
St Mary's Rd	0.502	0.537	0.179	0.209
Devonshire Dr	0.764	0.764	0.104	NA
Knollwood Dr	0.788	0.780	0.082	0.082
Windsor Rd	0.380	0.412	0.225	0.216

Table 6. Green Time Ratio for Through Movements During PM Peak

PM PEAK **Neil St at**	**NBT**	**SBT**	**EBT** **EBL Devonshire**	**WBT**
Stadium Dr	0.725	0.725	0.178	0.178
Kirby Ave	0.423	0.381	0.274	0.288
St Mary's Rd	0.612	0.621	0.130	0.195
Devonshire Dr	0.816	0.816	0.094	NA
Knollwood Dr	0.863	0.848	0.052	0.052
Windsor Rd	0.439	0.475	0.194	0.244

3.3 PROPORTION OF VEHICLES STOPPING

The proportion of vehicles stopped in each lane group was calculated. This may be used to estimate the arrival type for that lane group.

3.3.1 Methodology

The proportion of vehicles stopped in each lane group is equal to the number of stopped vehicles, divided by the total volume for that lane group.

3.3.2 Data

Tables 7 through 10 present the proportion of vehicles stopped in each lane group during the 4 time periods. The N/A entries indicate that an exclusive right-turn or left-turn was not present. The entries for Devonshire Drive WB are N/A because there is no westbound approach present at this intersection.

Table 7. Proportion of Vehicles Stopped During AM Peak Hour

AM PEAK	NB			SB			EB			WB		
Neil St at	L	T	R	L	T	R	L	T	R	L	T	R
Stadium Dr	59%	26%	N/A	78%	33%	N/A	53%	49%	N/A	67%	64%	N/A
Kirby Ave	39%	38%	N/A	83%	50%	N/A	81%	64%	N/A	96%	73%	N/A
St Mary's Rd	51%	36%	15%	74%	44%	N/A	77%	71%	N/A	55%	57%	N/A
Devonshire Dr	34%	11%	N/A	100%	6%	0%	85%	N/A	56%	N/A	N/A	N/A
Knollwood Dr	6%	2%	N/A	13%	3%	N/A	88%	35%	N/A	100%	80%	N/A
Windsor Rd	75%	72%	32%	79%	44%	6%	85%	72%	24%	86%	76%	59%

L, T, R: stand for Left-Turn, Through, and Right-turn, respectively.

Table 8. Proportion of Vehicles Stopped During Off Peak Hour

Off PEAK	NB			SB			EB			WB		
Neil St at	L	T	R	L	T	R	L	T	R	L	T	R
Stadium Dr	38%	18%	N/A	50%	23%	N/A	79%	61%	N/A	89%	51%	N/A
Kirby Ave	57%	29%	N/A	68%	60%	N/A	74%	63%	N/A	64%	59%	N/A
St Mary's Rd	33%	26%	3%	57%	40%	N/A	71%	45%	N/A	60%	57%	N/A
Devonshire Dr	37%	14%	N/A	33%	10%	4%	91%	N/A	43%	N/A	N/A	N/A
Knollwood Dr	33%	7%	N/A	13%	11%	N/A	86%	40%	N/A	94%	39%	N/A
Windsor Rd	N/A	N/A	N/A	69%	39%	11%	79%	74%	38%	84%	76%	44%

Table 9. Proportion of Vehicles Stopped During Noon Peak Hour

Noon PEAK	NB			SB			EB			WB		
Neil St at	L	T	R	L	T	R	L	T	R	L	T	R
Stadium Dr	64%	13%	N/A	59%	22%	N/A	72%	59%	N/A	75%	61%	N/A
Kirby Ave	70%	50%	N/A	82%	73%	N/A	76%	65%	N/A	77%	60%	N/A
St Mary's Rd	63%	35%	5%	72%	35%	N/A	75%	56%	N/A	69%	53%	N/A
Devonshire Dr	39%	12%	N/A	50%	24%	3%	92%	N/A	62%	N/A	N/A	N/A
Knollwood Dr	53%	15%	N/A	31%	12%	N/A	91%	55%	N/A	96%	53%	N/A
Windsor Rd	71%	55%	20%	72%	52%	13%	77%	74%	47%	65%	60%	38%

Table 10. Proportion of Vehicles Stopped During PM Peak Hour

PM PEAK	NB			SB			EB			WB		
Neil St at	L	T	R	L	T	R	L	T	R	L	T	R
Stadium Dr	63%	14%	N/A	58%	24%	N/A	95%	53%	N/A	67%	63%	N/A
Kirby Ave	82%	57%	N/A	62%	65%	N/A	92%	47%	N/A	80%	53%	N/A
St Mary's Rd	68%	27%	9%	49%	22%	N/A	79%	71%	N/A	70%	59%	N/A
Devonshire Dr	60%	12%	N/A	0%	19%	0%	86%	N/A	66%	N/A	N/A	N/A
Knollwood Dr	72%	6%	N/A	29%	7%	N/A	100%	64%	N/A	82%	45%	N/A
Windsor Rd	78%	52%	11%	61%	54%	27%	87%	76%	47%	81%	74%	46%

3.4 ARRIVAL TYPE

Rather than assuming random arrival type, field arrival types were estimated and used as inputs in the capacity and delay estimations.

3.4.1 Methodology

The arrival type for through movements on Neil Street at all intersections, was estimated based on the proportion of vehicles stopped at each intersection—and also by viewing the video to check when the platoons arrived during the cycle. However, random arrival (i.e., arrival type 3), was assumed for all movements on the cross streets, and for left-turn movements from Neil Street at all intersections.

Based on field observation, arrival types 1, 5, and 6 were not usually present on Neil Street through movements at any intersection. Thus, only arrival types 2, 3, and 4 were considered for those movements. The proportion of vehicles stopped on a subject through movement was used to estimate the proportaion of vehicles that arrived during green (assuming the arriving vehicles during green did not stop)—and then to estimate the “platoon ratio”. The computed “platoon ratio” is used to tentatively estimate the arrival type using Exhibit 18-8 of Highway Capacity Manual (HCM), 2010. The tentative arrival type was compared to the arrival time of the platoon at the intersection as was recorded on a video.

3.4.2 Data

The tentative arrival types determined for Neil Street through movements are as shown in Table 11. The entry for the Neil St. & Windsor Road during off peak is N/A because the data for northbound during off peak were not available due to the video failure. As previously discussed in the section on methodology, the arrival type of all remaining movements in the study (i.e., Neil Street left-turn movements and all cross-street turning movements) is 3 for all four time periods.

Table 11. Arrival Types Determined from Neil Street Through Movements

	AM Peak		Off Peak		Noon Peak		PM Peak	
Intersection	**NBT**	**SBT**	**NBT**	**SBT**	**NBT**	**SBT**	**NBT**	**SBT**
Neil St. & Stadium Dr.	3	3	4	3	3	4	3	4
Neil St. & Kirby Ave.	4	3	4	3	3	3	3	3
Neil St. & St. Mary's Rd.	3	3	3	3	3	3	3	3
Neil St. & Devonshire Dr.	3	3	3	3	3	3	3	3
Neil St. & Knollwood Dr.	3	3	3	3	3	3	3	3
Neil St. & Windsor Rd.	3	3	N/A	3	3	3	3	3

3.5 FIELD DELAY

The control delay and stopped delay in the field were calculated from the video data for 2015. The field measurements presented in this section will later be compared with those for the 2013 conditions (see Appendix A.3).

3.5.1 Methodology

The field measurement technique for intersection control delay, as described in Chapter 31 of HCM 2010, was adopted to calculate time-in-queue (i.e., stopped delay) and control delay using the field videos. The measurements were carried out on a lane-group basis for each approach of the six intersections. The procedure was performed for all four time periods.

The procedure requires identifying the approach speed during each study period. The speed limit of each approach in the field was assumed to be its approach speed for each intersection. The duration of the survey period was essentially equal to 1 hour for each peak hour and off peak hour. The count interval of 15 seconds was selected for this study because it is an integral divisor of the duration of survey period (1 hour) as required by the HCM.

3.5.2 Data

The control delay and stopped delay obtained for each lane group in the study (using the HCM field measurement methodology) are presented in Table 12 and Table 13, respectively. The cells with N/A entries signify that the respective lane group was not present at the subject approach except for NB of Neil St. & Windsor—for which the data was not available due to the video failure.

Table 12. Control Delay at Lane Group Level Calculated Using the HCM 2010 Field Measurement Technique

Intersection	Time Period	NB			SB			EB			WB		
		L	T	R	L	T	R	L	T	R	L	T	R
Neil St. & Stadium Dr.	AM Peak	20.2	4.7	N/A	28.5	5.6	N/A	16.2	16.0	N/A	25.8	12.9	N/A
	Off Peak	6.9	3.1	N/A	10.6	3.9	N/A	31.5	20.8	N/A	36.7	15.2	N/A
	Noon Peak	3.2	2.4	N/A	12.8	4.1	N/A	26.2	20.0	N/A	35.6	21.1	N/A
	PM Peak	3.1	2.9	N/A	15.3	5.1	N/A	69.5	22.2	N/A	36.8	30.0	N/A
Neil St. & Kirby Ave.	AM Peak	7.2	10.1	N/A	25.7	18.3	2.7	46.5	37.1	N/A	52.7	38.5	N/A
	Off Peak	15.1	8.1	N/A	19.2	19.3	1.7	28.7	22.3	N/A	25.2	22.1	N/A
	Noon Peak	21.7	17.0	N/A	24.5	26.2	3.8	26.2	23.5	N/A	32.0	21.5	N/A
	PM Peak	32.8	20.7	N/A	21.8	35.5	11.7	57.0	25.3	N/A	56.8	37.2	N/A
Neil St. & St. Mary's Rd.	AM Peak	14.0	14.2	2.4	23.6	10.6	N/A	36.0	28.2	N/A	20.4	21.4	N/A
	Off Peak	9.8	6.7	0.5	6.8	8.5	N/A	21.3	17.3	N/A	20.4	13.5	N/A
	Noon Peak	20.4	10.8	0.6	15.5	8.5	N/A	27.4	20.5	N/A	26.1	14.7	N/A
	PM Peak	18.7	1.9	1.6	8.6	6.8	N/A	41.3	33.6	N/A	39.5	30.6	N/A
Neil St. & Devonshire Dr.	AM Peak	5.7	1.8	N/A	13.8	1.0	0.0	50.9	N/A	9.1	N/A	N/A	N/A
	Off Peak	7.4	2.5	N/A	6.8	2.0	1.1	51.2	N/A	7.0	N/A	N/A	N/A
	Noon Peak	7.7	1.8	N/A	17.0	4.5	0.4	40.3	N/A	11.5	N/A	N/A	N/A
	PM Peak	18.1	1.9	N/A	0.0	3.8	0.0	56.7	N/A	21.7	N/A	N/A	N/A
Neil St. & Knollwood Dr.	AM Peak	1.2	0.5	N/A	4.3	0.5	N/A	53.3	10.5	N/A	45.5	17.5	N/A
	Off Peak	6.7	1.6	N/A	3.0	2.2	N/A	45.3	7.5	N/A	40.0	9.6	N/A
	Noon Peak	12.9	2.7	N/A	7.6	2.2	N/A	39.8	13.6	N/A	49.6	10.9	N/A
	PM Peak	23.4	1.1	N/A	6.0	1.8	N/A	70.6	22.6	N/A	59.6	18.7	N/A
Neil St. & Windsor Rd.	AM Peak	24.8	28.3	6.9	32.3	13.2	0.8	48.7	39.0	5.1	31.3	32.2	14.8
	Off Peak	N/A	N/A	N/A	11.7	11.0	0.8	26.4	29.4	7.6	26.2	31.2	7.1
	Noon Peak	18.6	18.9	2.6	16.9	12.1	1.1	27.7	29.8	8.8	19.7	20.0	5.8
	PM Peak	21.6	18.7	2.9	15.5	16.3	4.2	50.1	37.6	13.6	53.6	47.5	9.0

Table 13. Stopped Delay at Lane Group Level Calculated Using the HCM 2010 Field Measurement Technique

Intersection	Time Period	NB			SB			EB			WB		
		L	T	R	L	T	R	L	T	R	L	T	R
Neil St. & Stadium Dr.	AM Peak	17.3	3.4	N/A	24.5	3.9	N/A	13.5	13.6	N/A	22.5	9.6	N/A
	Off Peak	5.1	2.2	N/A	10.4	2.8	N/A	27.6	17.7	N/A	32.3	12.6	N/A
	Noon Peak	16.0	1.8	N/A	12.5	3.0	N/A	22.6	17.1	N/A	31.9	18.0	N/A
	PM Peak	25.8	2.2	N/A	14.8	3.9	N/A	64.8	19.3	N/A	33.3	26.8	N/A
Neil St. & Kirby Ave.	AM Peak	5.2	8.3	N/A	21.6	15.8	2.0	42.4	35.8	N/A	47.9	34.8	N/A
	Off Peak	12.2	6.6	N/A	15.8	16.0	1.1	25.0	19.2	N/A	22.0	19.2	N/A
	Noon Peak	18.1	14.5	N/A	20.4	24.6	2.0	22.4	20.3	N/A	28.2	18.5	N/A
	PM Peak	28.6	19.5	N/A	18.7	34.1	9.6	52.4	22.9	N/A	52.9	34.5	N/A
Neil St. & St. Mary's Rd.	AM Peak	10.4	11.7	1.4	18.4	7.5	N/A	32.2	14.6	N/A	17.7	18.6	N/A
	Off Peak	7.5	4.9	0.2	6.3	5.7	N/A	17.8	15.0	N/A	17.4	10.6	N/A
	Noon Peak	16.0	8.4	0.3	14.2	6.0	N/A	23.6	17.7	N/A	22.6	12.1	N/A
	PM Peak	14.0	6.5	0.9	8.2	5.3	N/A	37.4	30.1	N/A	36.0	27.6	N/A
Neil St. & Devonshire Dr.	AM Peak	3.3	1.0	N/A	6.8	0.6	0.0	46.7	N/A	6.3	N/A	N/A	N/A
	Off Peak	4.8	1.5	N/A	4.5	1.3	0.8	46.6	N/A	4.9	N/A	N/A	N/A
	Noon Peak	5.0	1.0	N/A	13.5	2.8	0.2	35.7	N/A	8.4	N/A	N/A	N/A
	PM Peak	14.0	1.1	N/A	0.0	2.5	0.0	52.4	N/A	18.4	N/A	N/A	N/A
Neil St. & Knollwood Dr.	AM Peak	0.8	0.3	N/A	3.4	0.3	N/A	48.9	8.7	N/A	40.5	13.5	N/A
	Off Peak	4.4	1.1	N/A	2.1	1.4	N/A	41.0	5.5	N/A	35.3	7.6	N/A
	Noon Peak	9.2	1.6	N/A	5.5	1.3	N/A	35.2	10.9	N/A	44.8	8.2	N/A
	PM Peak	18.4	0.8	N/A	3.9	1.3	N/A	65.6	19.4	N/A	55.5	16.4	N/A
Neil St. & Windsor Rd.	AM Peak	19.5	25.5	4.7	26.8	10.1	0.4	42.8	34.0	3.4	27.0	28.4	11.9
	Off Peak	N/A	N/A	N/A	10.6	8.3	0.8	20.9	24.3	4.9	22.0	27.4	4.9
	Noon Peak	13.7	15.0	1.3	15.1	9.1	1.0	22.3	24.6	5.5	16.4	17.0	3.9
	PM Peak	16.1	15.1	2.1	13.6	14.2	3.6	44.0	32.3	10.3	52.0	46.0	6.8

3.6 QUEUE LENGTH

The queue lengths in the field were determined using the video images of the approaches. They are compared to their estimations later in this section.

3.6.1 Methodology

The queue length of a through-lane group of an intersection was determined by manually counting the number of stopped vehicles at the beginning of the green light. This counting also includes vehicles that joined the queue after the end of the red light, and came to a complete stop. In the 2013 conditions, only the lane groups with a maximum queue length of at least two vehicles were considered in the data reduction procedure. Thus, the queue data for the 2015 condition lane groups were reduced to compare the average queues to that of the 2013 conditions.

3.6.2 Data

The average queue data were calculated from the raw field data. Those values are as shown in Table 14. The N/A entry for NB of Neil St. & Windsor signify that the data was not available for that approach due to video failure.

Table 14. Average Queue Lengths Calculated from Field Data

Intersection	Peak Period	NBT	SBT	EBT	WBT
Neil St & Stadium Dr	AM Peak	2.9	2.4	0.9	0.2
	Noon Peak	1.8	2.9	N/A	N/A
	PM Peak	2.0	3.7	1.3	4.5
Neil St & Kirby Ave	AM Peak	6.7	5.1	7.6	3.5
	Off Peak	2.2	5.1	2.6	2.6
	Noon Peak	5.8	7.9	4.4	3.9
	PM Peak	8.1	12.0	3.6	7.7
Neil St & St Marys Rd	AM Peak	5.2	0.0	3.6	1.0
	Noon Peak	3.8	4.3	N/A	N/A
	PM Peak	3.7	4.6	2.5	4.3
Neil St & Devonshire Dr	AM Peak	2.7	0.5	N/A	N/A
	Noon Peak	1.6	3.1	N/A	N/A
	PM Peak	1.8	4.6	N/A	N/A
Neil St & Knollwood Dr	AM Peak	1.9	0.8	N/A	N/A
	Noon Peak	1.8	1.7	N/A	N/A
	PM Peak	0.8	2.2	N/A	N/A
Neil St & Windsor Rd	AM Peak	10.3	2.1	6.7	3.5
	Off Peak	N/A	2.5	2.4	2.3
	Noon Peak	4.0	3.2	2.5	2.1
	PM Peak	4.4	8.1	3.8	8.9

CHAPTER 4: DATA ANALYSIS

This chapter explains three steps of data analysis: field stopped delay comparison of 2013 and 2015 conditions; field queue length comparison of 2013 and 2015 conditions; and exploring the relationships between the findings of these two comparisons. First, the methodology for the analyses is explained. Then, the comparisons for all approaches combined (corridor level) is discussed. Finally, the results at the intersection level are analyzed.

4.1 METHODOLOGY

Statistical comparisons were performed using two-sample t-tests (unpaired) at 0.5 significance levels (two-sided). The null hypothesis of the test is that the field measurements in the 2013 and 2015 condtions are not significantly different. The t values were computed using means and variances:

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

Where

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

In this equation, $\overline{X_1}$ and $\overline{X_2}$ are the average field stopped delays of the subject lane group for the 2013 and 2015 conditions, respectively; n_1 and n_2 are their numbers of observations, and ${s_1}^2$ and ${s_2}^2$ are their variances. The field variance of stopped delay of a lane group was obtained by measuring average 3-minute stopped delays. Therefore, each lane group ideally had 20 stopped delays during every hour (60 minutes), and the variance of those 20 observations is equal to the variance s^2. The observation time of 3 minutes was deliberately chosen in order to capture traffic data of at least one complete cycle (110 or 120 seconds) in each time interval.

Similarly, in the volume comparison, $\overline{X_1}$ and $\overline{X_2}$ are the average traffic volumes of the subject lane group for the 2013 and 2015 conditions, respectively; n_1 and n_2 are their numbers of observations, and ${s_1}^2$ and ${s_2}^2$ are their variances. An average of 3-minute volumes were used to obtain the variance, and ideally 20 observations of volume can be obtained for each hour.

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 83 cases, and the detailed results are available in Appendix A.3.

4.1.1 Volume Comparison

From field data, traffic volume in 3-minute time intervals were determined for each lane group. Each lane group had about 20 three-minute volumes (60 minutes total). The average and variance of those 20 volumes were computed. The observation time of 3 minutes was deliberately chosen to capture traffic volume data for at least one complete cycle (110 or 120 seconds) in each three-minute time interval. Consequently, the volume comparison, $\overline{X_1}$ and $\overline{X_2}$ are the average traffic volumes of the subject lane group for the 2013 and 2015 conditions, respectively; n_1 and n_2 are their numbers of observations, and ${s_1}^2$ and ${s_2}^2$ are their variances.

4.1.2 Delay Comparison

The delay comparison was made between the field stopped delay measured for the 2013 and 2015 conditions on a lane-group basis. The updated stopped delays for the 2013 conditions were used (see Appendix A.1). The data analysis procedure of this report is the same one used in Report Volume 1 of this research project. Comparisons are only for through-lane groups, except at at Neil Street and Devonshire (a T intersection)—where the comparisons are for the eastbound left-turn lane. The changes in traffic volume (increase or decrease) may affect the magnitude of stopped delay, so volumes in the 2013 and 2015 conditions were taken into account.

4.1.3 Queue Length Comparison

Similar to the delay comparison, the queue length comparison in this study was made between the average field queue lengths measured for the 2013 and 2015 conditions based on lane groups. The only lane groups considered are through lanes, which had a queue length of at least two vehicles in the 2013 conditions. The Changes in traffic volume in the 2013 and 2015 conditions, were also considered in the queue length comparisons.

A two-sample t-test was used in the comparison of delay and queue length. For each subject lane group, the queue lengths for all of the cycles during the subject peak hour were used to calculate the mean $\bar{X}$ and variance s^2 of the queue length—and n is the number of signal timing cycles in this time period.

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

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

4.1.4 Data Analysis at the Approach Level

For each of the 83 cases, any significant changes that may have occurred when comparing the 2013 and 2015 conditions—such as changes in volume, delay, and queue length—were taken into consideration. The results are given in Table 15. Any significant increase is indicated by “Inc” and any significant decrease is indicated by “Dec”. The unchanged ones are labeled “Unch”, and “NA” is labeled for not applicable ones (in addition to shading). In the Table 15, AM, OP, NP, and PM indicate morning peak, off peak, noon peak and afternoon peak, respectively.

Table 15. Volume, Delay, and Queue Length 2013 and 2015 Data Comparison Results

Intersection	Time Period	Approach	Volume Change	Delay Change	2013 Delay	2015 Delay	Queue Change	2013 Queue	2015 Queue
Stadium	AM	NBT	Unch	Unch	3.693	3.378	Unch	2.633	2.875
		SBT	Inc	Dec	5.362	3.946	Unch	3.183	2.375
		EBT	Inc	Unch	10.925	13.558	Dec	1.917	0.896
		WBT	Inc	Unch	10.5	9.643	Dec	0.452	0.17
	OP	NBT	Inc	Unch	2.339	2.195	NA	NA	NA
		SBT	Inc	Dec	5.013	2.771	NA	NA	NA
		EBT	Inc	Unch	20.25	17.708	NA	NA	NA
		WBT	Inc	Unch	14.159	12.867	NA	NA	NA
	NP	NBT	Inc	Unch	2.009	1.772	Inc	1.167	1.819
		SBT	Inc	Unch	2.817	3.044	Unch	2.333	2.861
		EBT	Inc	Unch	14.798	16.989	NA	NA	NA
		WBT	Unch	Unch	13.05	18.167	NA	NA	NA
	PM	NBT	Unch	Dec	4.063	2.143	Dec	3.1	1.983
		SBT	Unch	Dec	6.313	4.087	Unch	3.759	3.717
		EBT	Inc	Inc	10.241	18.847	Inc	0.489	1.276
		WBT	Unch	Inc	10.549	26.546	Inc	2.867	4.517
Kirby	AM	NBT	Inc	Dec	19.438	8.262	Dec	10.933	6.672
		SBT	Inc	Unch	15.959	15.814	Unch	4.367	5.078
		EBT	Unch	Inc	19.396	35.807	Inc	6.367	7.621
		WBT	Inc	Unch	35.226	34.835	Unch	3.7	3.455
	OP	NBT	Inc	Dec	17.992	6.599	Dec	7.5	2.243
		SBT	Inc	Unch	16.704	15.988	Inc	3.867	5.135
		EBT	Inc	Unch	21.992	20.3	Unch	3.433	2.625
		WBT	Inc	Unch	16.82	19.18	Unch	1.967	2.597
	NP	NBT	Inc	Dec	24.975	14.533	Dec	9.067	5.829
		SBT	Unch	Unch	24.589	24.604	Unch	8.117	7.914
		EBT	Inc	Unch	20.537	20.25	Unch	4.1	4.426
		WBT	Inc	Unch	17.262	18.512	Inc	3.05	3.853
	PM	NBT	Inc	Dec	29.973	19.515	Dec	11.167	8.054
		SBT	Unch	Inc	21.872	34.128	Inc	8.167	12
		EBT	Unch	Unch	21.756	22.919	Unch	3.9	3.593
		WBT	Inc	Unch	35.801	34.519	Unch	8.417	7.685
St Mary's	AM	NBT	Unch	Inc	5.807	11.689	Unch	3.133	5.212
		SBT	Inc	Unch	8.746	7.51	Dec	4.45	0.03
		EBT	Inc	Unch	34.247	24.59	Inc	2.576	3.581
		WBT	Unch	Unch	22.154	18.61	Unch	1.121	1
	OP	NBT	Unch	Inc	2.691	4.86	NA	NA	NA
		SBT	Unch	Inc	1.99	5.71	NA	NA	NA
		EBT	Inc	Dec	29.641	15.02	NA	NA	NA
		WBT	Inc	Dec	29.813	10.618	NA	NA	NA
	NP	NBT	Unch	Inc	5.664	8.35	Inc	3.083	3.842
		SBT	Unch	Inc	2.771	6.03	Inc	1.967	4.303
		EBT	Unch	Unch	23.686	17.72	NA	NA	NA
		WBT	Dec	Unch	17.175	12.1	NA	NA	NA
	PM	NBT	Unch	Unch	7.717	6.5	Unch	3.5	3.673
		SBT	Unch	Unch	4.958	5.26	Inc	3	4.635
		EBT	Inc	Unch	32.516	30.08	Unch	2.067	2.481
		WBT	Unch	Unch	26.196	27.63	Unch	3.931	4.333

Table 15. (Continued) Volume, Delay and Queue Length 2013 and 2015 Data Comparison Results

Intersection	Time Period	Approach	Volume Change	Delay Change	2013 Delay	2015 Delay	Queue Change	2013 Queue	2015 Queue
Devonshire	AM	NBT	Unch	Unch	0.875	0.99	Inc	1.214	2.654
		SBT	Unch	Dec	1.254	0.59	Unch	0.793	0.519
		EBL	Unch	Unch	43.971	46.65	NA	NA	NA
	OP	NBT	Inc	Dec	2.873	1.49	NA	NA	NA
		SBT	Unch	Unch	0.989	1.31	NA	NA	NA
		EBL	Inc	Unch	37	46.62	NA	NA	NA
	NP	NBT	Unch	Unch	1.111	1.03	Unch	1.1	1.603
		SBT	Unch	Inc	0.796	2.82	Inc	1.185	3.059
		EBL	Inc	Unch	44.471	35.28	NA	NA	NA
	PM	NBT	Inc	Unch	1.067	1.05	Inc	0.958	1.84
		SBT	Unch	Inc	0.938	2.46	Inc	1.652	4.62
		EBL	Inc	Unch	43.557	52.37	NA	NA	NA
Knollwood	AM	NBT	Inc	Unch	0.331	0.32	Unch	1.182	1.875
		SBT	Unch	Unch	1.033	0.29	Unch	1.231	0.75
	OP	NBT	Inc	Unch	0.495	1.15	NA	NA	NA
		SBT	Unch	Inc	0.095	1.37	NA	NA	NA
	NP	NBT	Inc	Inc	0.717	1.64	Inc	1.1	1.788
		SBT	Inc	Inc	0.674	1.34	Inc	1.033	1.712
	PM	NBT	Inc	Unch	0.335	0.76	Unch	0.767	0.762
		SBT	Unch	Unch	0.691	1.27	Unch	2.607	2.167
Windsor	AM	NBT	Unch	Inc	10.47	25.471	Inc	6.567	10.303
		SBT	Unch	Inc	6.539	10.092	Inc	1.3	2.136
		EBT	Unch	Inc	15.228	33.983	Unch	6.467	6.656
		WBT	Dec	Unch	23.207	28.406	Unch	4.233	3.452
	OP	NBT	NA	NA	NA	NA	NA	NA	NA
		SBT	Unch	Unch	6.31	8.296	Unch	2.2	2.472
		EBT	Unch	Unch	23.778	24.256	Unch	2.125	2.446
		WBT	Unch	Unch	20.419	27.43	Unch	2.781	2.284
	NP	NBT	Unch	Unch	14.538	15	Dec	5.367	4.039
		SBT	Inc	Unch	8.194	9.147	Unch	3.2	3.197
		EBT	Unch	Unch	24.089	24.6	Dec	3.424	2.487
		WBT	Unch	Unch	21.288	16.964	Dec	3.091	2.066
	PM	NBT	Inc	Unch	16.081	15.09	Unch	3.567	4.414
		SBT	Unch	Unch	12.317	14.174	Inc	4.667	8.089
		EBT	Dec	Unch	27.073	32.314	Dec	5.571	3.796
		WBT	Unch	Inc	26.481	45.989	Unch	7.667	8.907

4.1.4.1 Summary of Volume, Delay, and Queue length Individual Comparison

The results of volume, delay, and queue length comparisons (compared individually) in Table 15, can be grouped into three categories: 1) 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 16 Shows the number and percentange of lane groups in each group. The column with heading "%" gives the ratio of number of lane groups, divided by the total number of lane groups. For delay and volume, the total is 83—and for queue length, the total is 63.

Table 16. Summary of T-Test Results

Categories	No. of Lane groups	%
VOLUME		
Total	83	
Unchanged (Unch)	40	48%
Significantly Increased (Inc)	40	48%
Significantly Decreased (Dec)	3	4%
DELAY		
Total	83	
Unchanged (Unch)	53	64%
Significantly Increased (Inc)	18	22%
Significantly Decreased(Dec)	12	14%
QUEUE LENGTH		
Total	63	
Unchanged (Unch)	31	49%
Significantly Increased (Inc)	20	32%
Significantly Decreased (Dec)	12	19%

- Volume Comparisons: 40 lane groups out of 83 (or 48%), showed no significant change in volume. However, 40 lane groups (or 48%) had significant increases in volume—and 3 lane groups (or 4%) had significant decrease in volume.
- Delay Comparisons: 53 lane groups our of 83 (or 64%), had no significant change in delay. However, 18 lane groups (or 22%) showed significant increases in delay—and 12 lane groups (or 14%) showed significant decreases in delay.
- Queue Length Comparisons: 31 lane groups out of 63 (or 49%), had no significant change in queue length. However, 20 lane groups (or 32%) showed significant increases in queue length—and 12 lane groups (or 19%) had significant decreases in queue length.
- Even though volume significantly increased in 48% of the lane groups, delay significantly increased in only 22%—and queue significantly increased in only 32% of the lane groups. Similarly, volume decreased significantly on 4% of lane groups, but delay and queue length significantly decreased in 14% and 19% of the lane groups, respectively. These are indications that the ASCT, in general, was improving traffic operation conditions. Further discusion of this will follow.

4.1.4.2 Delay and Volume Combination Analysis

Looking at the changes in delay without paying attention to the changes in traffic volume, may not reveal the true 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 is not indication of ACST not working properly. To consider the influence of volume changes on the delay changes, a combined analysis approach is used where delay-volume, D_V, performance measure is analyzed. Table 17 shows the number of lane groups that belong to the combinations of delay and volume changes.

- In the 40 lane groups where volume remained unchanged, delay significantly increased in 15 of them—remained unchanged in 22 of them—and decreased in 3 lane groups.
- In the 40 lane groups where volume significantly increased, delay significantly increased only in 3 of them—remained unchanged in 28 of them—and decreased in 9 lane groups.
- In the 3 lane groups where volume significantly decreased, delay remained unchanged in all three of them.

Table 17. Summary of Volume and Delay Combination Analysis

Number of Lane Groups					
Categories	Delay Increased	Delay Unchanged	Delay Decreased	**Total**	**%**
Volume Increased	3	28	9	**40**	**48%**
Volume Unchanged	15	22	3	**40**	**48%**
Volume Decreased	0	3	0	**3**	**4%**
Total				**83**	

The final decision of whether or not these changes should be considered improvement or deterioration, will be made when all three variables (volume, delay and queue length) are considered (as discussed in section 4.2). Based on volume and delay combinations (only two variables), the results can be grouped into three categories (this is not a complete picture): 1) In 22 lane groups, both delay and volume were unchanged (white cell in Table 17); 2) In 28 lane groups, delay remained unchanged while volume increased—in 9 lane groups, delay decreased while volume increased—and in 3 cases, delay decreased while volume remained unchanged (Green cells in Table 17); and 3) In 15 lane groups, delay increased while volume remained unchanged—or delay remained unchanged while volume significantly decreased in 3 lane groups (Blue cells in Table 17). For the lane groups where both delay and volume significantly increased/decreased (Yellow cells), HCS 2010 was used to estimate the expected delay increases/decreases due to the volume changes (HCS, 2010). More detailed information on these special cases, including intersection level delay and volume combination analysis are given in Appendix A.4.

4.1.4.3 Queue Length and Volume Combination Analysis

To consider the influence of the volume changes on the queue length changes a combined analysis approach is used where queue length-volume, Q_V, performance measures are analyzed. Table 18 shows the summary of the volume and queue length condition for all cases in the study.

- In the 28 lane groups that volume remained unchanged, queue length significantly increased in 12 of them, remained unchanged in 17 of them, and decreased in 4 lane groups.
- In the 33 lane groups that volume significantly increased, queue length significantly increased in 8 of them, remained unchanged in 13 of them, and decreased in 7 lane groups.
- In the 2 lane groups that volume significantly decreased, queue length remained unchanged in one of them and decreased significantly in the other lane group.

Table 18. Summary of Volume and Queue Length Combination Analysis

Number of Lane Groups					
	Queue Increased	Queue Unchanged	Queue Decreased	**Total**	**%**
Volume Increased	8	13	7	**33**	**52%**
Volume Unchanged	12	17	4	**28**	**45%**
Volume Decreased	0	1	1	**2**	**3%**
Total				**63**	

As mentioned before, the final decision regarding whether these changes should be considered improvement or deterioration, will be made when all three variables (volume, delay, and queue length) are considered (as discussed in section 4.2). Based on volume and queue length combination (only two variables), the results can be grouped into three categories (this is not a complete picture): 1) In 17 lane groups, both queue length and volume remained unchanged (white cell in Table 18); 2) In 13 lane groups, queue length remained unchanged while volume increased—in 7 lane groups, queue length decreased while volume increased—and in 4 cases, queue length decresed while volume remained unchanged (Green cells in Table 18); 3) In 12 lane groups, queue length increased while volume remained unchanged—and in only 1 lane group, queue length remained unchanged while volume significantly decreased (Blue cells in Table 18). For the lane groups where 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, and intersection level queue length and volume combination analyses are given in Appendix A. 4.

4.2 ANALYSIS OF ASCT PERFORMANCE

Considering the volume, delay, and queue length changes discussed in the previos section, an overall performance indicator (PI) was determined for each lane group, of each intersection, at each time period. For almost all of the lane groups, the changes clearly indicated that those lane groups can be designated as one of the three PI classes: Imp (Improved), Unch (Unchanged), or Det (Deteriorated). For example, class Imp is assigned to an approach when volume increased significantly, while delay and queue length significantly decreased. Class Unch is assigned to an approach when volume, delay, and queue length remained unchanged. Finally, class Det is assigned to an approach when volume did not change significantly, while delay and queue length significantly increased. However, in a very small number of cases, careful considertation is needed to determine the class they belong to. If they did not belong to any of the three classes, it was placed in a class called Mix (Mixed Results). For example, class Mix is assigned to an approach when volume and delay increased significantly, while queue length remained unchanged. The results of such determinations are summarized in Tables 19 (a-c).

Table 19. PI for Three Volume Groups Considering Delay and Queue

(a) when VOLUME INCREASED SIGNIFICANTLY (on 40 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	Imp$^{\#}$ (1), Det$^{\#}$ (1), Mix$^{\#}$ (1)	Imp$^{\#}$ (2), Det$^{\#}$ (3)	-
Unchanged	-	Imp (12), Imp* (8)	Imp (1), Imp*(4)
Decreased	-	Imp (3)	Imp (4)

(b) when VOLUME DECREASED SIGNIFICANTLY (on 3 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	-	-	-
Unchanged	-	Unch*(1), Det(1)	-
Decreased	-	Imp$^{\#}$(1)	-

(c) when VOLUME DID NOT CHANGE SIGNIFICANTLY (on 40 approaches)

Queue \ Delay	Increased	Unchanged	Decreased
Increased	Det (9)	Det (3)	-
Unchanged	Det (4), Det*(2)	Unch (12), Unch*(4)	Imp (2)
Decreased	-	Imp (3)	Imp (1)

The Imp$^{\#}$, Det$^{\#}$ and Mix$^{\#}$ indicate that the PIs are as a result of the HCS runs mentioned in previous sections. The Imp*, Dec,* and Unch* indicate that the corresponding PI is only based on the delay data.

Now that the PI for each lane group is determined, Table 20 summarizes the outcome of the analyses for each lane group during the four time periods (am peak, off peak, noon peak, and pm peak).

Table 20. Performance Indicator (PI) for Each Lane Group

Intersections	Approach/ Peak	AM	OP	NP	PM
Stadium	NBT	Unch	Imp	Det	Imp
	SBT	Imp	Imp	Imp	Imp
	EBT	Imp	Imp	Imp	Det
	WBT	Imp	Imp	Unch	Det
Kirby	NBT	Imp	Imp	Imp	Imp
	SBT	Imp	Det	Unch	Det
	EBT	Det	Imp	Imp	Unch
	WBT	Imp	Imp	Imp	Imp
St Mary's	NBT	Det	Det	Det	Unch
	SBT	Imp	Det	Det	Det
	EBT	Imp	Imp	Unch	Imp
	WBT	Unch	Imp	Unch	Unch
Devonshire	NBT	Det	Imp	Unch	Det
	SBT	Imp	Unch	Det	Det
	EBL	Unch	Imp	Imp	Imp
Knollwood	NBT	Imp	Imp	Imp	Imp
	SBT	Unch	Det	Mix	Unch
Windsor	NBT	Det	NA[2]	Imp	Imp
	SBT	Det	Unch	Imp	Det
	EBT	Det	Unch	Imp	Imp
	WBT	Det	Unch	Imp	Det

[1] **Mix:** Indicates Mixed Results, improvement in queue length performance, and deterioration in delay performance.

[2] **NA:** Not Applicable, i.e. no analysis was performed for this approach because the videos from the field data were not clear.

Table 21 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 the Table 21, the ratio for corridor levels are given.

Table 21. Performance Indicator (PI) at Intersection and Corridor Levels

Performance / Intersections	Improved	Deteriorated	Unchanged	Mixed Results
Stadium	11/16	3/16	2/16	0/16
Kirby	11/16	3/16	2/16	0/16
St Mary's	5/16	6/16	5/16	0/16
Devonshire	5/12	4/12	3/12	0/12
Knollwood	4/8	1/8	2/8	1/8
Windsor	6/15	6/15	3/15	0/15
Total at Corridor Level (%)	42/83 (51%)	23/83 (28%)	17/83 (20%)	1/83 (1%)

Out of the 83 lane groups, PI improved on 42 lane groups (51%), remained unchanged on 17 lane groups (20%), deteriorated on 23 lane groups (28%) and showed mixed results in 1 lane group (1%)—as shown in Table 21.

Overall, PI either improved or remained unchanged in 71% of the lane groups. However, in 28% of them, PI deteriorated—and in 1%, it showed mixed results. Out of the 23 deteriorated cases (the 28%), volume significantly increased in 4 of them, volume did not change significantly in 18 of them, and volume significantly decreased in 1 of them. The deterioration in the 4 cases can be attributed to the volume increase, which indicates the systems inability to respond adequately to the volume increase. However, in the 18 lane groups where volume did not significatly change, the detrioration in PI is not expected.

Schematically, Figure 9 reflects the improvements and deteriorations at each intersection.

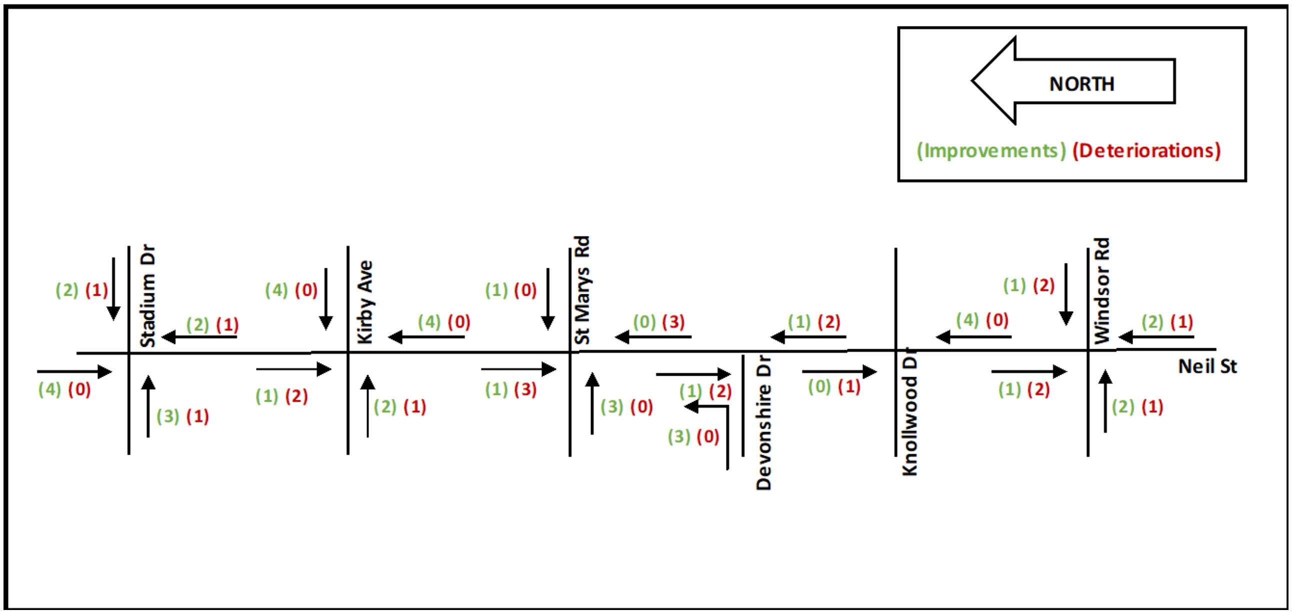

Figure 9. Improvements and Deteriorations at Intersections on Neil Street.

Based on the information in Figure 9 and Table 20, one may claim that at some intersections the major street performance may have been compromised to improve the minor street performance. Such a compromise may have happened at Kirby during PM peak; at St. Mary's during off peak, Noon peak, and PM peak; and at Devonshire during Noon peak and PM peak. Further investigation of this claim was carried out by finding the ratio of green time to cycle length (G/C), as shown in Table 22.

Table 22. Green Time Ratio for Intersections that Compromises May Have Happened

Intersections	Peak	Approach	G/C change	2015 G/C	2013 G/C	PI
Kirby	PM	NBT	Inc	0.423	0.334	Imp
		SBT	Inc	0.381	0.334	Det
		EB	Dec	0.274	0.318	Unch
		WB	Dec	0.288	0.318	Imp
St Mary's	OP	NBT	Inc	0.569	0.525	Det
		SBT	Unch	0.606	0.597	Det
		EB	Inc	0.164	0.132	Imp
		WB	Inc	0.191	0.132	Imp
	NP	NBT	Dec	0.502	0.617	Det
		SBT	Dec	0.537	0.617	Det
		EB	Inc	0.179	0.150	Unch
		WB	Inc	0.209	0.167	Unch
	PM	NBT	Dec	0.612	0.682	Unch
		SBT	Dec	0.621	0.682	Det
		EB	Inc	0.130	0.100	Imp
		WB	Inc	0.195	0.100	Unch
Devonshire	NP	NBT	Dec	0.764	0.808	Unch
		SBT	Dec	0.764	0.808	Det
		EBL	Unch	0.104	0.099	Imp
	PM	NBT	Inc	0.816	0.790	Det
		SBT	Inc	0.816	0.790	Det
		EBL	Dec	0.094	0.109	Imp

As shown in Table 22, at the intersection of Neil and Kirby during PM peak such a compromise did not happen. At the intersection of Neil and St. Mary's during off peak period, the green ratio for NB increased and for SB it remained unchanged; however, the performance deteriorated on both approaches. In contrast, for the minor street the green ratio were increased and the performances were improved, thus indicating a compromise. A more clear case of the compromise was during NP at St. Mary's where green ratio significantly decreased on the major street and significantly increased on the minor street. A similar compromise happened during PM peak at St. Mary's, though the compromise is not as clear as the compromise on NB. At Devonshire during NP, major street green ratio is significantly decreased and the green ratio for minor streets remained unchanged. This resulted in improved performance on the minor street and either unchanged or deteriorated performance on the major street; thus a compromise. At Devonshire during PM peak, green ratio significantly increased on the major street, but this increase was not large enough to offset the effects of significant volume increase on NB which resulted in significant queue increase. On the SB the delay and queue length significantly increased, so performance was considered a deterioration. On the EBL even though the green ratio decreased, volume increased and delay remained unchanged, so the performance was considered an improvement. The analysis indicate that ASCT made a compromise between the minor and major street performances and, in general, the minor street improvements were correlated with the major street deterioration or unchanged performances.

In the next section, the changes on PI at each intersection is disscussed.

4.3 DETAILED ANALYSIS OF PI AT INTERSECTION LEVEL

In the following, 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.

4.3.1 Neil St & Stadium

AM peak (AM): During this period, queue or delay significantly decreased even though the thru volumes significantly increased on three approaches (SB, EB, WB). For NB, the volume, delay and queue length did not change significantly. Thus, ASCT improved the intersection performance on three approaches (SB, EB, and WB)—but did not improve or deteriorate on the fourth approach (NB).

Off peak (OP): It should be noted that during this period, only delay performance was analyzed because queue length was negligible. Volume on all four approaches increased significantly, but delay did not change significantly on three of them (NB, EB, and WB)—and decreased on the fourth approach (SB). Thus, it was concluded that the system showed improvements on delay for all approaches.

Noon peak (NP): It should be noted that during this period, only delay performance on the major street was analyzed because the queue length was negligible. While volume increased on three approaches (EB, NB, and SB)—and remained unchanged on WB—delay did not change significantly on any of the approaches. Queue length significantly increased on NB, but did not change significantly on SB. The queue length increase on NB was only 0.6 vehicle (from 1.2 to 1.8 vehicles). However, this increase was much higher than the expected increase due to volume increase (based on the HCS runs mentioned in the previous chapter). Thus, the intersection performance either improved or showed no changes on all approaches, except NB.

PM peak (PM): Generally, there were improvements on the major street approaches, but deteriorations on the minor street approaches.

Major street: On NB and SB, volume did not change significantly, but delay decreased significantly. Also, queue length significantly decreased on NB, and remained unchanged on SB.

Minor street: On WB, volume did not change significantly, but delay and queue length increased significantly. On EB, volume, delay, and queue length increased significantly. The increase in the delay and queue length were much higher than the expected increase due to volume increase (based on the HCS runs mentioned in the previous chapter).

Summary: Among all 16 approaches during all four time periods, the system performance improved on 11 approaches—remained unchanged on 2 approaches—and deteriorated on 3 approaches (EB and WB in PM and NB in NP).

4.3.2 Neil St & Kirby

AM peak (AM): Generally, performance improved on all approaches for this intersection, except EB.

Major street: While volume increased significantly on NB and SB, delay and queue length significantly decreased on NB—and remained unchanged on SB. Thus, performance was improved during this period on the major street approaches.

Minor Street: Volume did not change significantly on EB, but delay and queue length did increase significantly. Volume significantly increased on WB, but delay and queue length did not change significantly. Thus, performance showed deterioration on EB and improvement on WB.

Off peak (OP): Generally, there were improvements on all approaches, except SB.

While volume on all approaches increased significantly, delay did not change significantly on three approaches (SB, EB, and WB)—and decreased significantly on NB. Queue length significantly decreased on NB, remained unchanged on EB and WB, but significantly increased on SB. The increase in SB queue length was much higher than the expected increase due to the increased volume (based on the HCS runs mentioned in the previous chapter).

Noon peak (NP): Generally, performance improved on three approaches and remained unchanged on SB.

Major street: Volume significantly increased on NB, but delay and queue length significantly decreased. On SB, volume, delay, and queue length did not change significantly. Thus, performance improved on NB and remained unchanged on SB.

Minor street: Volume significantly increased on EB and WB, but delay and queue length did not change significantly on EB. On WB, delay remained unchanged, but queue length significantly increased. The increase in queue length on WB was less than the expected increase due to volume increase (based on the HCS runs). Thus, performance improved on EB and WB.

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

Major street: On NB, while volume significantly increased, delay and queue length significantly decreased. On SB, volume did not change significantly, but delay and queue significantly increased. Thus, performance improved on NB, and deteriorated on SB.

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

Summary: Among all 16 approaches during all four time periods, the system performance improved on 11 approaches—remained unchanged on 2 approaches—and deteriorated on 3 approaches (EB in AM, SB in OP, and SB in PM).

4.3.3 Neil St & St. Mary's

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

Major street: While NB volume and queue length did not change significantly, delay increased significantly. Thus, performance deteriorated on NB. Although SB volume increased significantly, queue length decreased significantly, and delay remained unchanged. Overall the performance improved on SB.

Minor street: On EB, volume and queue length increased and delay remained uncahnged. Thus, the overall performance on EB was improved. On WB, volume, delay, and queue length did not change significantly. Thus, overall performance remained unchanged on WB.

Off peak (OP): It was noted that during this period, only delay performance was analyzed because queue length was negligible. Generally, the performance was deteriorated on NB and SB, but improved on EB and WB.

Major street: Volume did not change significantly on NB and SB, but delay did significantly increase on both of them.

Minor street: Volume increased on EB and WB, but delay significantly decreased on both of them, by nearly half (from 29.64 to 15.02 sec/veh on EB, and 29.81 to 10.62 sec/veh on WB). Thus, performance improved.

Noon peak (NP): It is importatnt to note that queue length on the minor street is not considered during this analysis period. Generally, the performance deteriorated on the major street and remained unchanged on the minor street.

Major street: While volume did not change significantly on NB and SB, delay and queue length increased significantly. Thus, the system deteriorated on major street approaches.

Minor street: On EB, volume and delay did not change significantly. On WB, volume significantly decreased and delay remained unchanged.

Summary: Among all 16 approaches during four time periods, system performance improved on 6 approaches—remained unchanged on 4 approaches—and deteriorated on 6 approaches (NB in AM, NB and SB in OP, NB and SB in NP, and SB in PM).

4.3.4 Neil St & Devonshire

AM peak (AM): It is noted that during this period, queue length was not considered in the analysis of eastbound left-lane group (EBL). Generally, the performance improved on SB, remained unchanged on EBL, and deteriorated on NB.

On NB, volume and delay did not change significantly, while queue length increased significantly. On SB, volume and queue length did not change significantly, but delay significantly decreased. On EBL, volume and delay did not change significantly.

Off peak (OP): It important to note that during this period, only delay performance was analyzed because queue length was negligible. Generally, the performance improved on NB and EBL, and remained unchanged on SB during this period.

On NB, volume significantly increased, and delay significantly decreased. On SB, volume and delay did not change significantly. On EBL, volume significantly increased and delay did not change significantly. Thus, the performance improved on NB and EBL, and remained unchanged on SB.

Noon peak (NP): It is noted that during this period, queue length was not considered in the analysis of EBL. In general, the performance either improved or remained unchanged on all approaches except SB.

Volume did not change significantly on NB and SB. On NB, delay and queue length did not change significantly. However, on SB, delay and queue length both significantly increased. On EBL, volume significantly increased, but delay did not change significantly. Thus, performance remained unchanged on NB—improved on EBL—and deteriorated on SB.

PM peak (PM): During this period, queue length was not considered in the analysis of EBL. Generally, the performance deteriorated on NB and SB—and improved on EBL.

On NB, volume significantly increased; so did the queue length—but delay did not significantly change. The increase in queue length was much higher than the expected increase due to volume increase (based on the HCS runs). Thus, performance deteriorated on NB. On SB, volume did not change significantly, but both delay and queue significantly increased. On EBL, volume significantly increased, but delay did not change significantly.

Summary: Among the 12 approaches during four time periods, system performance improved on 5 approaches—remained unchanged on 3 approaches—and deteriorated on 4 approaches (NB in AM, SB in NP, NB and SB in PM).

4.3.5 Neil St & Knollwood

The analysis at this intersection is only performed on NB and SB approaches because of very low volumes on EB and WB.

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

The volume significantly increased on NB and remained unchanged on SB. However, delay and queue did not change significantly on NB and SB.

Off peak (OP): Queue length is not considered during this analysis period. Generally**,** performance improved on NB and deteriorated on SB.

On NB, volume significantly increased, but delay did not change significantly. On SB, volume did not significantly increase, but delay did significantly increase.

Noon peak (NP): Generally**,** performance improved on NB, and showed mixed results on SB.

Volume significantly increased on both NB and SB. Delay and queue also significantly increased on these two approaches. Based on the HCS runs mentioned before, the increase in delay on NB and SB were higher than the expected increase due to volume increase. The increase in queue length on NB was less than the expected increase due to the increased volume; while on SB, it was higher than the expected increase due to increased volume. Thus, performance is improved on NB, and showed mixed results on SB.

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

Volume significantly increased on NB, but did not change significantly on SB. Whereas delay and queue did not change significantly on both approaches.

Summary: Among the 8 approaches during four time periods, system performance improved on 4 approaches—remained unchanged on 2 approaches—and deteriorated on 2 approaches (SB in OP)—and showed mixed results on 1 approach (SB in NP).

4.3.6 Neil St & Windsor

AM peak (AM): Generally, performance deteriorated on all major and minor street approaches.

Major street: On NB and SB, traffic volume did not change significantly, but delay and queue length did significantly increase. Thus, performance deteriorated on NB and SB.

Minor street: On EB, volume and queue length did not change significantly, but delay did significantly increased. On WB, volume significantly decreased, while delay and queue length did not change significantly. Thus, performance is deteriorated on EB and WB.

Off peak (OP): The NB approach is not considered in the analysis for this period because video from field data was not clear. Generally, performance remained unchanged on all major and minor street approaches.

Volume, delay, and queue length did not change significantly on any of the approaches. Thus, performance remained unchanged.

Noon peak (NP): Generally, performance improved on all major and minor street approaches during this period.

On NB, EB, and WB, volume and queue length did not change significantly; but delay significantly decreased. On SB, volume significantly increased, but delay and queue length did not change significantly. Thus, performance improved on all approaches.

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

Major street: On NB, volume significantly increased, but delay and queue length did not change significantly. On SB, volume and delay did not change significantly, but queue length did significantly increase. Therefore, performance improved on NB and deteriorated on SB.

Minor street: On EB, volume significantly decreased, so did the queue length—but delay did not change significantly. The decrease in the queue length was more than the expected decrease due to the volume decrease (based on the HCS runs). On WB, volume and queue length did not change significantly; while delay significantly increased. Thus, performance improved on EB and deteriorated on WB.

Summary: Among the 15 (16-1=15) cases during four time periods and on all approaches, system performance improved in 6 cases—remained unchanged in 3 cases—and deteriorated in 6 cases (NB, SB, EB, and WB in AM; SB and WB in PM).

CHAPTER 5: CONCLUSIONS

The field volume, delay, and queue length data for the 2013 “before” conditions, were measured and compared to the 2015 data. Traffic volume on 48% of the lane groups significantly increased, 48% did not change significantly, and 4% significantly decreased. The field delay was compared for 83 lane groups (approaches). Out of which, 22% showed significant increase, 64% showed no significant change, and 14% showed significant decrease. Queue length was compared for only 63 lane groups because the remaining 20 lane groups either did not have queue data or queue length was insignificant (two cars or less). Out of these 63 lane groups, 32% showed significant increase in queue length, 49% showed no significant change, and 19% showed significant decrease in queue length.

Further analysis was carried out to determine ASCT performance at the approach (lane group), intersection, and corridor levels. Based on the changes in volume, delay, and queue lenth 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), Det (Deteriorated), or Mix (mixed results). Out of the total of 83 lane groups analyzed, 51% of them showed improvement, 20% remained unchanged, 28% showed deterioration, and 1% of lane groups showed a mixed result. In summary, ASCT either improved or kept the performance unchanged in 71% of the lane groups. However, ASCT deteriorated the performance 28% of the lane groups—and in 1% of the groups, it showed mixed results. Out of the 23 deteriorated cases (the 28%), 4 of them showed a significant increase in volume. On the other hand, 18 of them did not show significant changes in volume, and 1 of them has a significant decrease in volume. The deterioration in the 4 cases can be attributed to the increase in volume and the system’s inability to respond adequately to the volume increase. However, in the 18 lane groups where volume did not significantly change, the detrioration in PI was not expected.

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

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APPENDICES

A.1 DELAY DATA UPDATES FOR "BEFORE" CONDITIONS (2013 DATA)

This section gives the updated delay values for the "before" conditions and the accordingly updated analysis results and the findings in Report Volume 1. The updates are on limited number of lane groups that had a large number of vehicle in queue at the end the 15 sec intervals used in delay data reduction. Dividing these cars to two consecutive time intervals was made more logical and consistant.

A.1.1 Delay Data Updates

At Neil Street and Kirby Avenue, the stopped and control delays for the heavy directions during AM and PM peak, NBT and SBT through-lane groups during noon peak, and NBT during PM peak were updated. And for Neil Street and Windsor Road, the delays for NBT lane groups during AM peak were updated. Table 23 shows the updated stopped and control delays for "before" conditions for these lane groups.

Table 23. Updated Stopped and Control Delays for "Before" Conditions

Intersections	Time Periods	Lane Groups	Stopped Delay	Control Delay
Neil St & Kirby Ave	AM Peak	NBT	19.5	20.8
		EBT	19.4	20.4
	Noon Peak	NBT	25.3	26.9
		SBT	24.3	25.6
	PM Peak	NBT	29.7	31.1
		SBT	21.7	22.7
		WBT	35.8	37.6
Neil St & Windsor Rd	AM Peak	NBT	10.0	12.6

A.1.2 HCS Estimates vs. Field Stopped Delay Comparison Result Updates

A.1.2.1 Delay Comparison

With the data updates above, the statistical test results between the HCS estimates and field stopped delay for these 8 lane groups changed numerically. However, the significant levels of descrepancies for these lane groups stayed the same except for southbound through at Neil Street and Kirby Avenue during noon peak, which changed from significant overestimation to insignificant difference. Table 24 shows the t-test results for the 8 lane groups.

Table 24. T-Test Results Updates for "Before" Conditions

Intersections	Time Periods	Lane Groups	HCS Delay	Field					
				n	Mean	Variance	df	T-statistic	P-value
Neil St & Kirby Ave	AM Peak	NBT	36.505	20	19.438	171.976	19	5.8202	0.000013
		EBT	30.48208	20	19.396	86.716	19	5.3239	0.000039
	Noon Peak	NBT	32.07775	20	24.975	67.253	19	3.8733	0.001023
		SBT	26.73051	20	24.589	74.344	19	1.1109	0.280472
	PM Peak	NBT	26.15912	20	29.973	106.188	19	-1.6552	0.114349
		SBT	19.81226	20	21.872	142.172	19	-0.7725	0.449033
		WBT	36.83611	20	35.801	179.348	19	0.3455	0.733514
Neil St & Windsor Rd	AM Peak	NBT	19.75272	20	10.470	71.822	19	4.8983	0.0001

Tables 25-27 show the updated summaries of HCS estimates vs. field stopped delay comparisons in terms of all lane groups, lane groups for typical intersections, and lane groups for major street approaches at typical intersections. And Figure 10 is the updated graph describing the lane groups with significant discrepancies for typical intersections.

Table 25. Summary of Delay Comparison

Overall			
	No. of Lane Groups	**%**	**Range of (HCM – Field)/Field%**
Total	84	—	—
Significant Discrepancy	48	57%	(-97) – 145%
Overestimation	35	73%	19 – 145%
Underestimation	13	27%	(-97) – (-39%)

Table 26. Summary of Delay Comparison for Typical Intersections

Category 1: Typical Intersections			
	No. of Lane Groups	**%**	**Range of (HCM – Field)/Field%**
Total	64	—	—
Significant Discrepancy	38	59%	(-55) – 145%
Overestimation	35	92%	19– 145%
Underestimation	3	8%	(-55) – (-39%)

Table 27. Summary of Delay Comparison for Major Street Cases at Typical Intersections

Category 3: Typical Intersections, Major Street				
	No. of Lane Groups	**%**	**Range of (HCM – Field)/Field%**	**Average Discrepancy %**
Total	32	—	—	—
Significant Discrepancy	22	69 %	(-55) – 135%	—
Overestimation	20	91 %	26 – 135%	70%
Underestimation	2	9%	(-55)-(-46)%	–50%

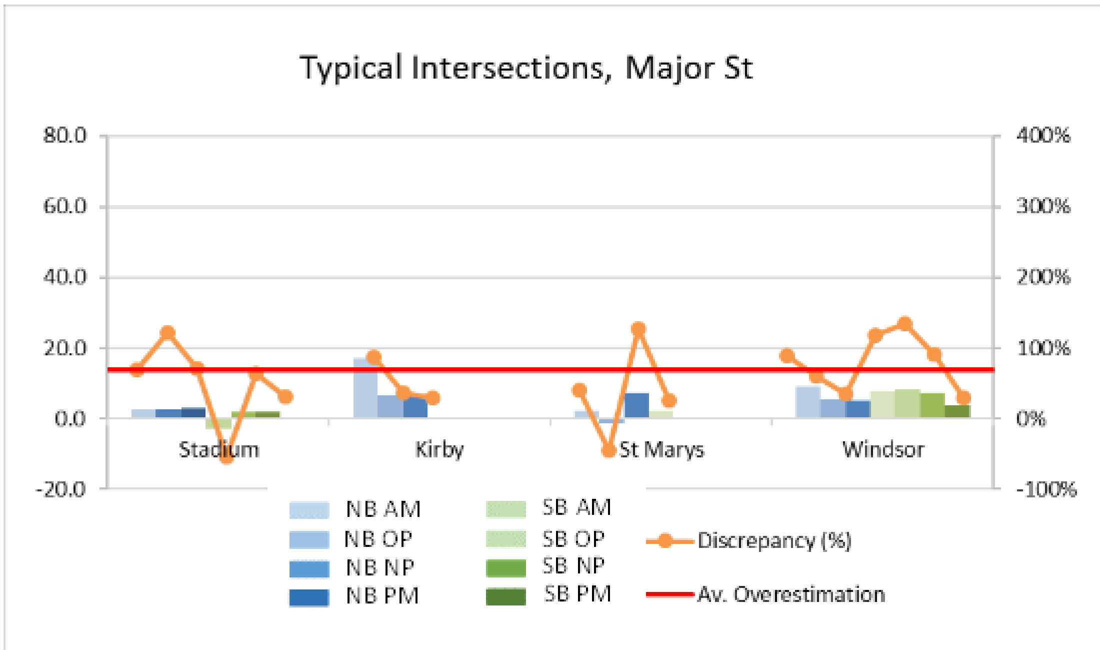

Figure 10. Lane Groups with significant discrepancies for typical intersections in delay comparisons.

With all these numerical changes above, the general findings stay similar: The HCM estimates of stopped delay were significantly different in 48 of 84 lane groups (57%), representing overestimation in 73% of the lane groups and underestimation in 27%. For typical intersections on the major street, 69% of the lane groups had significant discrepancies between HCM delay estimates and field data—in 91% of the lane groups, HCM overestimated delay by an average by 70%. On minor streets, 56% of the lane groups had significant discrepancies, and, in 94% of them, HCM overestimated the delay on average by 52%.

A.1.2.2 Relationships between Results of Delay and Queue Comparison

Based on the aforementioned changes, the relationships between delay and queue comparison results were also updated. Table 28 shows the updated summary of the relationship results. Only the relationship between the queue and delay discrepancies to HCS estimates for one lane group (i.e. the southbound through-lane group at Neil Street and Kirby Avenue during noon peak) changed, but these discrepancies were still consistent in trend. Therefore, the general finding in the relationships between delay and queue comparisons stays the same: in 58 of 64 cases (91%), the HCM's over/underestimation of delay and queue length was consistent or there was no significantly conflict between them; however, in six of the 64 cases (9%), there were significant inconsistencies between the delay comparisons and queue length comparisons.

Table 28. Summary of Relationships Between Results of Delay and Queue Comparison

Overall		
	No. of Lane Groups	**%**
Total	64	—
Consistent trend	50	78%
Inconsistent trend	14	22%
Category 1:Lane Groups with Consistent Trend		
Total	50	—
Significant discrepancies both in queue and delay	26	52%
One significant discrepancy (either queue or delay)	20	40%
No significant discrepancies in queue or delay	4	8%
Category 2: Lane Groups with Inconsistent Trend		
Total	14	—
Significant discrepancies both in queue and delay	0	0%
One significant discrepancy (either queue or delay)	6	43%
No significant discrepancies in queue or delay	8	57%

A.2 DATA REDUCTION SIMPLIFICATION

This chapter explains the four ways of reducing the time and efforts for data reduction in the future: eliminate the lane group uninterested, reduce length of the 1-hour time period, increase the delay reduction interval, and reduce number of lanes in each multi-lane through-lane group. For the first one, the reasons are discussed. For the latter three analyses, methodology used for comparison is first explained. It is then followed by statistical comparison, detailed results, and discussion.

A.2.1 Eliminate Uninterested Lane Groups

In the data reduction procedure for 2013 and 2015 conditions, the traffic data for all through, protected left-turn, and protected right-turn lane groups were reduced. However, only the data for through traffic and the eastbound left-turn traffic at the intersection of Neil Street and Devonshire Drive were used in the data analysis, for which the reason is explained in Chapter 5. Therefore, it is decided that the data reduction can be done only on the through land groups for all the intersections and the eastbound left-turn lane group at Neil Street and Devonshire Drive.

A.2.2 Shortening Data Reduction Time Periods

A.2.2.1 Methodology

In previous data reduction procedure, 1-hour traffic data per intersection per time period were obtained for data analysis. To increase the data reduction efficiency, attempts were made to shorten the data reduction time period from 1 hour to 45 minutes. The 3-min delay data for 2015 conditions were used to perform the data analysis, as all of them, except for the data of northbound approach at Neil Street and Windsor Road during Noon peak, are available for 1 hour and 20 observations can be obtained.

The means of the 3-min delays per through-lane group per time period for the first 45 minutes (i.e. 0-45 min), middle 45 minutes (i.e. 9-54 min), and the last 45 minutes (i.e. 15-60 min) were firstly obtained. Then the descrepancies between these values and the corresponding average 3-min delays for the 1-hour traffic were computed. For each time period the mean and variance of these descrepancies were computed and statistically compared to 0 using one-sample t-test.

A.2.2.2 Statistical Comparison and Results

Using the aforementioned methodology for comparison, the t-tests were performed for all through-lane groups in the study area for the four time periods, except for the eastbound approach of the intersection of Neil Street and Devonshire Drive, where the tests were for the protected left-turning lane. The data for the northbound approach of the intersection of Neil Street and Windsor Road were unavailable, and thus the t-test was not performed for this lane group. There were 20 through-lane groups present at the six intersections (the lane groups on Devonshire Drive and Knollwood Drive do not classify as through lanes).

Table 29. T-Test Results

AM							
Categories	Field Descrepancy			T-Test Results			
	Mean	Variance	Std	t-Value	p-Value	Significant (95%)	Significant (90%)
0-45 min	-0.10491	1.385941	1.17726	-0.4087	0.6871	NO	NO
9-54 min	0.197167	1.218922	1.104048	0.8186	0.4227	NO	NO
15-60 min	-0.05607	1.363104	1.16752	-0.2198	0.8282	NO	NO
OP							
0-45 min	0.026872	0.927324	0.962977	0.1249	0.9019	NO	NO
9-54 min	0.005599	1.96239	1.400853	0.0179	0.9859	NO	NO
15-60 min	0.183971	1.917413	1.384707	0.5943	0.5593	NO	NO
NP							
0-45 min	0.234247	1.124096	1.060234	1.0123	0.3235	NO	NO
9-54 min	0.39614	1.352716	1.163063	1.5606	0.1343	NO	NO
15-60 min	0.063405	0.804225	0.896786	0.324	0.7493	NO	NO
PM							
0-45 min	0.027312	3.933236	1.983239	0.0631	0.9503	NO	NO
9-54 min	0.534677	5.286524	2.299244	1.0657	0.2992	NO	NO
15-60 min	1.230929	4.35069	2.085831	2.7043	0.0136	YES	YES

Table 29 shows the statistical test results. It is observed that for all time periods the measured stopped delays for the first 45 minutes and the middle 45 minutes were the same as those for 1 hour with both 90% and 95% confidence. For the last 45 minutes, the measured stopped delays during AM peak, off peak and Noon peak were the same as those for 1 hour with 90% and 95% confidence, but it is significantly different from the 1-hour delay at both significant level during PM peak. As it is assumed that the 45-min stopped delay should be the same as 1-hour delay, and the values of variances for the first 45 minute delays are all smaller than the corresponding ones for the middle 45 minutes, further data reduction can be conducted on the first 45 minutes of each peak/off peak hour to get representative traffic data.

A.2.3 Increasing the Time Interval for Delay Data Reduction

A.2.3.1 Methodology

In previous delay reduction procedure, an interval of 15 seconds was used to get accurate delay data for each lane group. This means the delay counting have to be conduct 240 times per lane group. To reduce the number of counts in delay reduction while maintain relatively high accuracy, another attempt can be made to enlarge the time interval from 15 seconds to 20 seconds, i.e. to reduce the delay counts from 240 to 180.

To check the data quality of 20-sec interval counts compared to 15-sec, the lane group of northbound through traffic at St. Mary's during AM peak in fall 2015 was selected to conduct the 20-sec interval delay reduction. The 3-min stopped delays calculated by the 15-sec and 20-sec data were statistically analyzed using two-sample t-test.

A.2.3.2 Statistical Comparison and Results

Table 30. T-Test Results between 15-sec Count and 20-sec Count

15-sec Count			20-sec Count			T-Test Results			
mean	variance	n	mean	variance	n	t-value	p-value	significant (95%)	significant (90%)
11.168	50.345	20	11.045	53.541	20	0.054	0.957	NO	NO

As shown in Table 30, the discrepancy in stopped delay between 15-sec and 20-sec counts was insignificant at both 90% and 95% confidential levels. Thus further delay reduction can be conducted using 20-sec intervals to acquire accurate data.

A.3. STATISTICAL COMPARISON AT CORRIDOR LEVEL

A.3.1 Statistical Delay Comparison

A.3.1.1 Data

Using the the methodology for comparison in chapter 4, the t-tests were performed for all through-lane groups in the study area for the four time periods, except for the eastbound approach of the intersection of Neil Street and Devonshire Drive, where the tests performed for the protected left-turning lane rather than the through-lane. The data for the northbound approach of the intersection of Neil Street and Windsor Road were unavailable, and thus the t-test was not performed for this lane group. There were 20 through-lane groups present at the six intersections (the lane groups on Devonshire Drive and Knollwood Drive do not classify as through lanes).

The details of the t-tests performed are presented in Table 36 and 37. For each table, the column heading "n" stands for the number of 3-minute 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 eastbound left-lane group. Some tests in the table have the number of observations (n) less than 20 because the data for those time periods were available for less than 1 hour.

There were a total of 83 tests performed over the four time periods for both stopped delay and volume: 79 tests for the through-lane groups and 4 test for the protected left-turning lane groups. An observed error in a comparison is considered as significant only if the p-value of its t-test was less than 10%. The tests in which field stopped delay for 2015 conditions is significantly larger than that for 2013 conditions are highlighted with red, while those in which 2015 conditions delay is significantly lower than 2013 are highlighted with blue.

In Tables 31 and 32, the tests in which volume for 2015 conditions is significantly larger than that for 2013 conditions are highlighted with red, while those in which 2015 conditions delay is significantly lower than 2013 are highlighted with blue.

Table 31. Statistical Comparison Between 2013 and 2015 Conditions Stopped Delay

			"2015 Conditions"				"Before Conditions"					
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
Stadium	AM	NBT	3.378	3.626	1.904	20	3.693	3.315	1.821	20	-0.534189654	0.596452
		SBT	3.946	5.595	2.365	20	5.362	8.186	2.861	20	-1.705862509	0.09617
		EBT	13.558	119.167	10.916	20	10.925	15.999	4.000	19	1.009733842	0.322468
		WBT	9.643	96.416	9.819	20	10.500	95.765	9.786	19	-0.272931014	0.786371
	OP	NBT	2.195	3.540	1.882	20	2.339	4.542	2.131	20	-0.225962014	0.776432
		SBT	2.771	6.084	2.467	20	5.013	12.128	3.483	20	-2.349690353	0.024069
		EBT	17.708	225.317	15.011	20	20.250	328.494	18.124	20	-0.483109153	0.631867
		WBT	12.867	241.098	15.527	20	14.159	150.708	12.276	20	-0.291758071	0.771875
	NP	NBT	1.772	1.715	1.310	20	2.009	1.758	1.326	20	-0.570652656	0.571361
		SBT	3.044	3.852	1.963	20	2.817	1.846	1.359	20	0.424231861	0.673812
		EBT	16.989	95.754	9.785	20	14.798	87.858	9.373	20	0.72301112	0.474107
		WBT	18.167	217.413	14.745	20	13.050	91.207	9.550	20	1.302535995	0.200585
	PM	NBT	2.143	3.626	1.904	20	4.063	5.381	2.320	20	-2.862312267	0.006811
		SBT	4.087	6.884	2.624	20	6.313	6.971	2.640	19	-2.640475883	0.012067
		EBT	18.847	184.364	13.578	20	10.241	125.672	11.210	14	1.949095584	0.060095
		WBT	26.546	132.157	11.496	20	10.549	17.359	4.166	18	5.813358286	<0.00001
Kirby	AM	NBT	8.262	17.350	4.165	20	19.438	171.976	13.114	20	-3.632436245	0.000827
		SBT	15.814	34.244	5.852	20	15.959	53.706	7.328	20	-0.069480885	0.945351
		EBT	35.807	278.242	16.681	20	19.396	86.716	9.312	20	3.841670819	0.00045
		WBT	34.835	498.651	22.330	20	35.226	185.857	13.633	20	-0.066797392	0.946933
	OP	NBT	6.599	41.033	6.406	20	17.992	34.790	5.898	20	-5.851050387	<0.00001
		SBT	15.988	35.212	5.934	20	16.704	35.814	5.985	20	-0.380065621	0.706061
		EBT	20.300	118.480	10.885	20	21.992	38.105	6.173	20	-0.604678004	0.324592
		WBT	19.180	102.993	10.149	20	16.820	91.563	9.569	20	0.756877146	0.453777
	NP	NBT	14.533	79.343	8.907	20	24.975	67.253	8.201	20	-3.856717461	0.001493
		SBT	24.604	66.507	8.155	20	24.589	74.344	8.622	20	0.005791729	0.995403
		EBT	20.250	51.718	7.192	20	20.537	41.863	6.470	20	-0.132599339	0.894895
		WBT	18.512	94.904	9.742	20	17.262	88.695	9.418	20	0.412590443	0.681928
	PM	NBT	19.515	87.661	9.363	20	29.973	106.188	10.305	20	-3.359215348	0.00179
		SBT	34.128	258.174	16.068	20	21.872	142.172	11.924	20	2.739344533	0.009323
		EBT	22.919	191.878	13.852	20	21.756	98.346	9.917	20	0.305251886	0.762031
		WBT	34.519	265.793	16.303	20	35.801	179.348	13.392	20	-0.271869769	0.787094

Table 31. (continued)

			"2015 Conditions"				"Before Conditions"					
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
St Marys	AM	NBT	11.689	59.235	7.696	20	5.807	12.571	3.546	20	3.104154729	0.004344
		SBT	7.510	20.870	4.568	20	8.746	11.963	3.459	20	-0.964486923	0.3408
		EBT	24.590	110.350	10.505	20	34.247	1228.195	35.046	20	-1.180476231	0.2452
		WBT	18.610	233.890	15.293	20	22.154	230.998	15.199	20	-0.735048291	0.4668
	OP	NBT	4.860	9.910	3.148	20	2.691	2.671	1.634	20	2.735232208	0.0094
		SBT	5.710	17.530	4.187	20	1.990	2.792	1.671	20	3.690751388	0.0011
		EBT	15.020	213.110	14.598	20	29.641	573.941	23.957	20	-2.330771453	0.0252
		WBT	10.618	77.180	8.785	20	29.813	746.569	27.323	20	-2.990848294	0.0065
	NP	NBT	8.350	8.300	2.881	20	5.664	12.400	3.521	20	2.640189689	0.0119
		SBT	6.030	6.110	2.472	20	2.771	4.100	2.025	20	4.560940448	0.000052
		EBT	17.720	125.000	11.180	20	23.686	174.334	13.204	20	-1.542222203	0.1313
		WBT	12.100	86.350	9.292	20	17.175	175.417	13.245	20	-1.402669791	0.1688
	PM	NBT	6.500	14.360	3.789	20	7.717	17.959	4.238	20	-0.957558086	0.3444
		SBT	5.260	14.930	3.864	20	4.958	12.667	3.559	20	0.25722373	0.7985
		EBT	30.080	422.760	20.561	20	32.516	773.410	27.810	20	-0.315005966	0.7545
		WBT	27.630	415.050	20.373	20	26.196	133.494	11.554	20	0.273864394	0.8923
Knollwood	AM	NBT	0.320	0.250	0.500	20	0.331	0.155	0.393	13	-0.064534498	0.9471
		SBT	0.290	0.470	0.686	20	1.033	8.475	2.911	15	-0.967965287	0.3479
	OP	NBT	1.150	3.890	1.972	20	0.495	0.657	0.810	20	1.372896217	0.1815
		SBT	1.370	2.600	1.612	20	0.095	0.048	0.218	20	3.503678305	0.0023
	NP	NBT	1.640	1.930	1.389	20	0.717	0.443	0.666	20	2.679936972	0.0123
		SBT	1.340	1.690	1.300	20	0.674	1.145	1.070	20	1.768554156	0.0849
	PM	NBT	0.760	1.190	1.091	20	0.335	0.447	0.668	20	1.485362122	0.1456
		SBT	1.270	2.980	1.726	20	0.691	0.735	0.857	20	1.342871688	0.1899

Table 31. (continued)

			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
Devonshire	AM	NBT	0.990	0.410	0.640	20	0.875	0.459	0.677	20	0.550091975	0.5842
		SBT	0.590	0.730	0.854	20	1.254	1.035	1.017	20	-2.236413831	0.0313
		EBL	46.650	638.220	25.263	20	43.971	314.163	17.725	20	0.388161364	0.7
	OP	NBT	1.490	1.780	1.334	20	2.873	8.776	2.962	20	-1.903503157	0.0679
		SBT	1.310	2.580	1.606	20	0.989	1.137	1.066	20	0.74385625	0.461
		EBL	46.620	873.910	29.562	20	37.000	324.628	18.017	20	1.242693821	0.2216
	NP	NBT	1.030	1.230	1.109	20	1.111	1.151	1.073	20	-0.235720179	0.8157
		SBT	2.820	3.570	1.889	20	0.796	0.470	0.685	20	4.502740481	0.0001
		EBL	35.280	257.420	16.044	20	44.471	700.865	26.474	20	-1.327733909	0.1922
	PM	NBT	1.050	1.420	1.192	20	1.067	1.883	1.372	20	-0.041857807	0.9669
		SBT	2.460	4.660	2.159	20	0.938	1.427	1.195	20	2.758554414	0.0089
		EBL	52.370	1448.120	38.054	20	43.557	1078.859	32.846	20	0.78407483	0.4379
Windsor	AM	NBT	25.471	67.535	8.218	20	10.470	71.822	8.475	20	5.68263836	<0.00001
		SBT	10.092	32.806	5.728	20	6.539	23.301	4.827	20	2.121140042	0.040496
		EBT	33.983	197.869	14.067	20	15.228	20.447	4.522	20	5.676546236	<0.00001
		WBT	28.406	249.280	15.789	20	23.207	113.032	10.632	20	1.221571435	0.229234
	OP	SBT	8.296	21.454	4.632	20	6.310	14.173	3.765	20	1.487869179	0.145003
		EBT	24.256	132.108	11.494	20	23.778	144.227	12.009	20	0.128681977	0.898038
		WBT	27.430	306.074	17.495	20	20.419	126.743	11.258	20	1.507060752	0.14008
	NP	NBT	15.000	52.713	7.260	20	14.538	45.497	6.745	20	0.208278779	0.836107
		SBT	9.147	16.642	4.079	20	8.194	23.824	4.881	20	0.669696023	0.507098
		EBT	24.600	104.754	10.235	20	24.089	91.220	9.551	20	0.163174012	0.871226
		WBT	16.964	100.700	10.035	20	21.288	214.936	14.661	20	-1.088525694	0.283012
	PM	NBT	15.090	65.755	8.109	20	16.081	71.054	8.429	20	-0.379079717	0.706797
		SBT	14.174	46.059	6.787	20	12.317	45.556	6.749	16	0.817726561	0.419222
		EBT	32.314	367.031	19.158	20	27.073	124.702	11.167	20	1.056946256	0.297185
		WBT	45.989	1809.064	42.533	20	26.481	54.594	7.389	9	1.985689901	0.060024

Table 31. Statistical Comparison Between 2013 and 2015 Conditions Volume

			"2015 Conditions"				"Before Conditions"					
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
Stadium	AM	NBT	49.150	168.450	12.979	20	45.150	162.661	12.754	20	0.983079212	0.65234
		SBT	35.750	56.513	7.518	20	28.450	98.682	9.934	20	2.62059135	0.01255
		EBT	11.600	14.253	3.775	20	8.650	9.818	3.133	19	2.647712474	0.011836
		WBT	2.800	2.905	1.704	20	1.800	2.484	1.576	19	1.89951797	0.065315
	OP	NBT	36.900	70.937	8.422	20	29.150	33.818	5.815	20	3.386327092	0.001656
		SBT	34.350	25.818	5.081	20	28.950	60.682	7.790	20	2.596574299	0.013303
		EBT	3.850	2.871	1.694	20	1.400	1.937	1.392	20	4.996935348	0.000013
		WBT	3.200	3.642	1.908	20	2.050	1.734	1.317	20	2.218044437	0.032607
	NP	NBT	46.100	77.779	8.819	20	36.950	80.682	8.982	20	3.250690192	0.002412
		SBT	46.350	33.187	5.761	20	41.450	28.155	5.306	20	2.79789814	0.00803
		EBT	4.450	3.629	1.905	20	2.600	1.726	1.314	20	3.575165926	0.000973
		WBT	4.050	10.997	3.316	20	3.000	5.684	2.384	20	1.14970204	0.257452
	PM	NBT	41.900	77.674	8.813	20	40.200	98.484	9.924	20	0.572812972	0.570154
		SBT	51.200	90.905	9.534	20	50.421	93.591	9.674	19	0.253207232	0.801515
		EBT	5.050	6.155	2.481	20	2.071	1.918	1.385	14	4.059420997	0.000296
		WBT	11.900	28.726	5.360	20	9.632	19.690	4.437	19	1.435520832	0.159545
Kirby	AM	NBT	48.200	76.695	8.758	20	41.150	157.397	12.546	20	2.060682614	0.046235
		SBT	30.050	73.945	8.599	20	25.800	44.484	6.670	20	1.746526026	0.088804
		EBT	37.250	122.829	11.083	20	34.000	53.263	7.298	20	1.095288048	0.280279
		WBT	16.800	36.168	6.014	20	10.750	8.408	2.900	20	4.052456746	0.000377
	OP	NBT	31.300	62.221	7.888	20	26.600	40.042	6.328	20	2.078514915	0.044467
		SBT	29.300	45.379	6.736	20	25.700	21.695	4.658	20	1.965809362	0.05666
		EBT	17.650	11.818	3.438	20	12.400	6.568	2.563	20	5.47546477	<0.00001
		WBT	18.300	6.537	2.557	20	9.150	6.871	2.621	20	11.17521338	<0.00001
	NP	NBT	41.800	54.800	7.403	20	32.100	40.411	6.357	20	4.445741847	0.000074
		SBT	37.750	53.671	7.326	20	36.950	69.945	8.363	20	0.321786641	0.749368
		EBT	24.700	33.905	5.823	20	17.650	27.503	5.244	20	4.023387718	0.000263
		WBT	20.200	10.484	3.238	20	12.200	10.168	3.189	20	7.872585894	<0.00001
	PM	NBT	40.400	60.779	7.796	20	36.100	57.568	7.587	20	1.767682407	0.085141
		SBT	49.150	134.029	11.577	20	47.650	113.187	10.639	20	0.426646545	0.672078
		EBT	24.150	19.292	4.392	20	23.300	30.116	5.488	20	0.540798863	0.591802
		WBT	36.000	86.421	9.296	20	29.450	29.524	5.434	20	2.720387041	0.00978

Table 31. (Continued)

			"2015 Conditions"				"Before Conditions"					
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
St Marys	AM	NBT	49.500	133.105	11.537	20	44.400	134.147	11.582	20	0.441189016	0.66164
		SBT	31.350	54.240	7.365	20	26.550	74.261	8.617	20	1.893671624	0.065897
		EBT	8.400	12.779	3.575	20	4.750	4.618	2.149	20	3.913512037	0.000462
		WBT	3.700	7.695	2.774	20	3.900	2.621	1.619	20	-0.278479831	0.782519
	OP	NBT	31.950	48.471	6.962	20	28.850	31.503	5.613	20	1.550254553	0.129359
		SBT	35.600	66.779	8.172	20	31.550	67.103	8.192	20	1.56534362	0.125803
		EBT	4.450	5.103	2.259	20	2.300	1.695	1.302	20	3.687933644	0.000704
		WBT	4.450	4.366	2.089	20	1.200	2.274	1.508	20	5.640680766	<0.00001
	NP	NBT	41.050	60.366	7.770	20	40.400	52.463	7.243	20	0.273664247	0.785797
		SBT	45.900	98.411	9.920	20	43.600	69.305	8.325	20	0.794247573	0.432011
		EBT	5.600	5.516	2.349	20	5.500	3.947	1.987	20	0.145377418	0.885164
		WBT	6.250	8.513	2.918	20	8.450	7.208	2.685	20	-2.481400327	0.017643
	PM	NBT	35.300	75.274	8.676	20	32.450	46.471	6.817	20	1.155140066	0.255302
		SBT	56.900	114.305	10.691	20	51.600	115.937	10.767	20	1.562063849	0.126555
		EBT	6.350	5.397	2.323	20	4.650	7.397	2.720	20	2.125436922	0.040113
		WBT	12.850	32.345	5.687	20	11.750	11.776	3.432	20	0.740602052	0.463488
Knollwood	AM	NBT	65.850	239.503	15.476	20	56.538	178.103	13.346	13	1.779470566	0.084965
		SBT	23.250	38.724	6.223	20	23.533	56.124	7.492	15	-0.118893363	0.906159
	OP	NBT	32.900	51.147	7.152	20	27.250	22.829	4.778	20	2.937764618	0.005591
		SBT	31.550	82.050	9.058	20	28.350	30.976	5.566	20	1.34609348	0.186246
	NP	NBT	42.500	65.526	8.095	20	33.900	68.305	8.265	20	3.324560028	0.001969
		SBT	44.900	87.042	9.330	20	37.050	61.945	7.870	20	2.876144876	0.006566
	PM	NBT	33.000	48.526	6.966	20	28.200	42.379	6.510	20	2.251447127	0.030223
		SBT	65.650	73.503	8.573	20	62.750	326.829	18.078	20	0.648191094	0.520753

Table 31. (Continued)

			"2015 Conditions"				"Before Conditions"					
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value
Devonshire	AM	NBT	60.800	159.642	12.635	20	54.750	233.987	15.297	20	1.363725085	0.180686
		SBT	23.000	43.053	6.561	20	22.600	68.463	8.274	20	0.169397449	0.866381
		EBL	3.950	3.524	1.877	20	3.500	3.316	1.821	20	0.769513634	0.446354
	OP	NBT	33.550	41.629	6.452	20	26.550	29.313	5.414	20	3.716731088	0.000667
		SBT	30.800	35.432	5.952	20	32.750	85.250	9.233	20	-0.793832873	0.432126
		EBL	3.750	2.829	1.682	20	2.700	2.326	1.525	20	2.068134395	0.045487
	NP	NBT	39.850	44.661	6.683	20	37.050	51.629	7.185	20	1.276096966	0.209665
		SBT	39.950	27.208	5.216	20	36.450	85.629	9.254	20	1.473525193	0.151044
		EBL	4.400	4.989	2.234	20	2.550	2.050	1.432	20	3.118291745	0.003461
	PM	NBT	37.750	47.882	6.920	20	29.100	33.674	5.803	20	4.283562064	0.000121
		SBT	64.200	180.589	13.438	20	59.000	143.474	11.978	20	1.291825397	0.204228
		EBL	4.950	3.945	1.986	20	2.650	3.397	1.843	20	3.796054593	0.00515
Windsor	AM	NBT	48.550	177.734	13.332	20	43.000	187.895	13.707	20	1.298039301	0.202111
		SBT	15.250	14.303	3.782	20	16.000	10.632	3.261	20	-0.671705209	0.505649
		EBT	29.000	82.737	9.096	20	31.250	90.513	9.514	20	-0.764470875	0.449585
		WBT	14.400	16.358	4.044	20	16.550	12.261	3.502	20	-1.797341306	0.080287
	OP	SBT	22.050	24.471	4.947	20	22.250	50.829	7.129	20	-0.10307358	0.918505
		EBT	12.300	29.274	5.411	20	12.150	17.503	4.184	20	0.098082874	0.332798
		WBT	13.250	13.461	3.669	20	12.000	21.158	4.600	20	0.950104943	0.348065
	NP	NBT	29.250	60.934	7.806	20	26.000	34.842	5.903	20	1.485146542	0.145767
		SBT	32.250	26.408	5.139	20	28.750	33.776	5.812	20	2.017630916	0.050736
		EBT	13.500	13.842	3.720	20	13.450	25.313	5.031	20	0.035734684	0.971708
		WBT	11.000	15.158	3.893	20	13.000	23.895	4.888	20	-1.431264154	0.160603
	PM	NBT	23.350	23.713	4.870	20	19.350	9.292	3.048	20	3.113745508	0.003504
		SBT	48.050	117.524	10.841	20	46.375	131.983	11.488	16	0.448639449	0.656566
		EBT	14.100	20.832	4.564	20	18.500	15.632	3.954	20	-3.258670159	0.00236
		WBT	31.850	106.239	10.307	20	26.000	46.750	6.837	9	1.54826504	0.133217

A.3.2 Statistical Queue Length Comparison

A.3.2.1 Data

Using the aforementioned methodology for comparison, the t-tests were performed for all the lane groups having a maximum queue length of at least two vehicles in 2013 conditions. These include all through movements at the intersections of Neil Street with Kirby Avenue and Windsor Road during the four time periods, all through movements at Neil Street with Stadium Drive and St. Mary's Road during AM, Noon and PM Peak, and northbound and southbound through movements at Neil Street with Knollwood Drive and Devonshire Drive during AM, Noon and PM Peak. Note that he NBT movement data at Neil Street and Windsor Road during Off Peak was unavailable because of the low quality of the video.

The details of the t-tests performed are presented in Table 38. In this table, the column heading "n" in the table stands for the number of observations obtained from the field for the subject lane group. There were a total of 64 tests performed for the average queue length comparisons. An observed error in a comparison was significant only if the p-value of its t-test was less than 10%. The tests in which field mean queue length for 2015 conditions is significantly larger than that for 2013 conditions are highlighted with red, while those where 2015 mean queue length is significantly lower than 2013 one are highlighted with blue.

Table 32. Statistical Comparison Between 2013 and 2015 Average Queue Length

			"2015 Conditions"				"Before Conditions"						
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value	Significant?
Stadium	AM	NBT	2.875	7.293	2.701	52	2.633	4.999	2.236	30	0.415	0.679253	NO
		SBT	2.375	3.940	1.985	52	3.183	10.405	3.226	20	-1.287	0.202334	NO
		EBT	0.896	0.773	0.879	53	1.917	3.095	1.759	60	-3.821	0.00022	YES
		WBT	0.170	0.105	0.324	53	0.452	0.383	0.619	62	-2.982	0.003508	YES
	NP	NBT	1.819	2.602	1.613	36	1.167	1.109	1.053	30	1.903	0.061541	YES
		SBT	2.861	4.023	2.006	36	2.333	3.747	1.936	30	1.081	0.283754	NO
	PM	NBT	1.983	2.250	1.500	30	3.100	7.679	2.771	30	-1.941	0.057123	YES
		SBT	3.717	3.615	1.901	30	3.759	8.475	2.911	29	-0.066	0.947609	NO
		EBT	1.276	1.850	1.360	29	0.489	0.983	0.991	45	2.877	0.005279	YES
		WBT	4.517	2.830	1.682	29	2.867	7.085	2.662	30	2.836	0.006313	YES
Kirby	AM	NBT	6.672	5.978	2.445	32	10.933	52.547	7.249	30	-3.142	0.002606	YES
		SBT	5.078	5.179	2.276	32	4.367	5.758	2.399	30	1.198	0.235628	NO
		EBT	7.621	7.000	2.646	33	6.367	10.637	3.261	30	1.683	0.097487	YES
		WBT	3.455	3.068	1.752	33	3.700	2.476	1.573	30	-0.583	0.562042	NO
	OP	NBT	2.243	4.509	2.123	37	7.500	7.362	2.713	30	-8.898	<0.00001	YES
		SBT	5.135	3.856	1.964	37	3.867	3.085	1.756	30	2.755	0.007605	YES
		EBT	2.625	3.063	1.750	36	3.433	6.323	2.515	30	-1.535	0.129713	NO
		WBT	2.597	3.055	1.748	36	1.967	2.085	1.444	30	1.577	0.119726	NO
	NP	NBT	5.829	8.264	2.875	35	9.067	8.064	2.840	30	-4.553	0.000025	YES
		SBT	7.914	4.257	2.063	35	8.117	6.598	2.569	30	-0.352	0.726013	NO
		EBT	4.426	3.381	1.839	34	4.100	6.162	2.482	30	0.602	0.549369	NO
		WBT	3.853	3.978	1.994	34	3.050	2.041	1.428	30	1.829	0.07221	YES
	PM	NBT	8.054	6.451	2.540	28	11.167	13.641	3.693	13	-3.152	0.003113	YES
		SBT	12.000	9.241	3.040	28	8.167	7.090	2.663	13	3.900	0.000369	YES
		EBT	3.593	5.424	2.329	27	3.900	3.059	1.749	30	-0.567	0.573021	NO
		WBT	7.685	3.464	1.861	27	8.417	4.415	2.101	30	-1.385	0.171645	NO
St Marys	AM	NBT	5.212	8.329	2.886	33	3.133	6.878	2.623	30	0.752	0.454943	NO
		SBT	0.030	2.408	1.552	33	4.450	3.972	1.993	30	-9.869	<0.00001	YES
		EBT	3.581	4.852	2.203	31	2.576	2.939	1.714	33	2.044	0.045207	YES
		WBT	1.000	1.133	1.065	31	1.121	1.922	1.386	33	-0.390	0.697873	NO
	NP	NBT	3.842	2.731	1.653	38	3.083	1.795	1.340	30	2.040	0.045356	YES
		SBT	4.303	2.710	1.646	38	1.967	3.430	1.852	30	5.498	<0.00001	YES
	PM	NBT	3.673	3.719	1.928	26	3.500	5.224	2.286	30	0.304	0.762296	NO
		SBT	4.635	3.511	1.874	26	3.000	2.069	1.438	30	3.688	0.00526	YES
		EBT	2.481	4.644	2.155	27	2.067	3.858	1.964	30	0.760	0.4505	NO
		WBT	4.333	3.692	1.922	27	3.931	10.862	3.296	23	0.537	0.593748	NO

Table 32. Statistical Comparison Between 2013 and 2015 Average Queue Length (Continued)

			"2015 Conditions"				"Before Conditions"						
			Mean	Variance	Std	n	Mean	Variance	Std	n	T-statistic	P-value	Significant?
Devonshire	AM	NBT	2.654	3.315	1.821	26	1.214	0.989	0.995	28	3.641	0.000626	YES
		SBT	0.519	0.330	0.574	26	0.793	0.527	0.726	29	-1.539	0.129754	NO
	NP	NBT	1.603	1.300	1.140	34	1.100	1.748	1.322	30	1.634	0.107327	NO
		SBT	3.059	3.390	1.841	34	1.185	0.772	0.879	27	5.231	<0.00001	YES
	PM	NBT	1.840	1.932	1.390	25	0.958	0.390	0.624	24	2.884	0.006805	YES
		SBT	4.620	7.610	2.759	25	1.652	1.510	1.229	23	4.879	0.068902	YES
Knollwood	AM	NBT	1.875	1.339	1.157	8	1.182	0.964	0.982	11	1.411	0.176283	NO
		SBT	0.750	0.500	0.707	8	1.231	2.692	1.641	13	-0.779	0.446689	NO
	NP	NBT	1.788	2.188	1.479	33	1.100	1.266	1.125	30	2.062	0.043475	YES
		SBT	1.712	2.157	1.469	33	1.033	0.654	0.809	30	2.241	0.028677	YES
	PM	NBT	0.762	1.215	1.102	21	0.767	0.461	0.679	30	-0.019	0.984918	NO
		SBT	2.167	4.558	2.135	21	2.607	2.247	1.499	28	-0.849	0.400185	NO
Windsor	AM	NBT	10.303	18.312	4.279	33	6.567	19.289	4.392	30	3.418	0.001129	YES
		SBT	2.136	2.723	1.650	33	1.300	0.769	0.877	30	2.475	0.016118	YES
		EBT	6.656	14.184	3.766	32	6.467	10.257	3.203	30	0.213	0.832049	NO
		WBT	3.452	4.489	2.119	32	4.233	7.495	2.738	30	-1.262	0.211833	NO
	OP	SBT	2.472	2.256	1.502	36	2.200	2.855	1.690	30	0.693	0.490817	NO
		EBT	2.446	1.747	1.322	37	2.125	3.145	1.773	32	0.859	0.393403	NO
		WBT	2.284	1.952	1.397	37	2.781	2.564	1.601	32	-1.379	0.172481	NO
	NP	NBT	4.039	6.208	2.492	38	5.367	3.999	2.000	30	-2.375	0.020463	YES
		SBT	3.197	3.210	1.792	38	3.200	3.148	1.774	30	-0.006	0.995231	NO
		EBT	2.487	1.844	1.358	38	3.424	2.939	1.714	33	-2.569	0.012365	YES
		WBT	2.066	1.975	1.405	38	3.091	3.648	1.910	33	-2.597	0.011485	YES
	PM	NBT	4.414	4.483	2.117	27	3.567	4.254	2.063	30	1.529	0.131996	NO
		SBT	8.089	12.964	3.601	27	4.667	13.152	3.627	12	2.734	0.009544	YES
		EBT	3.796	3.082	1.756	27	5.571	7.958	2.821	28	-2.790	0.007309	YES
		WBT	8.907	19.962	4.468	27	7.667	4.061	2.015	12	1.195	0.239701	NO

A.4. COMBINATION ANALYSIS (DELAY VS. VOLUME , QUEUE LENGTH VS. VOLUME)

A.4.1 Delay and Volume Combination Analysis

Table 33 shows the combined analysis results for delay and volume. In the table, "D" is the abbreviation of delay, and "V" is the abbreviation of volume. The upward arrow "↑" stands for increase, downward arrow "↓" stands for decrease, and dash "-" stands for unchange. For instance, the column heading "D ↑ & V ↓" stands for the category with increased delay and decreased volume volume. And the cells with entries "Yes" signify that these lane groups (row heads) fall into the coresponding categories (column heads).

Table 33. 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			Yes						
	OP	NBT			Yes						
		SBT	Yes								
		EBT			Yes						
		WBT			Yes						
	NP	NBT			Yes						
		SBT			Yes						
		EBT			Yes						
		WBT				Yes					
	PM	NBT		Yes							
		SBT		Yes							
		EBT								Yes (Deteriorated)	
		WBT						Yes			
Kirby	AM	NBT	Yes								
		SBT			Yes						
		EBT						Yes			
		WBT			Yes						
	OP	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						

Table 33. (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 ↓
St Marys	AM	NBT						Yes			
		SBT			Yes						
		EBT			Yes						
		WBT				Yes					
	OP	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					
Knollwood	AM	NBT			Yes						
		SBT				Yes					
	OP	NBT			Yes						
		SBT						Yes			
	NP	NBT								Yes (Deteriorated)	
		SBT								Yes (Deteriorated)	
	PM	NBT			Yes						
		SBT				Yes					

Table 33. (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 ↓
Devonshire	AM	NBT				Yes					
		SBT		Yes							
		EBL				Yes					
	OP	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				
	OP	SBT				Yes					
		EBT				Yes					
		WBT				Yes					
	NP	NBT				Yes					
		SBT			Yes						
		EBT				Yes					
		WBT				Yes					
	PM	NBT			Yes						
		SBT				Yes					
		EBT					Yes				
		WBT						Yes			
Sub Total			9	3	28	22	3	15		3 (Deteriorated)	
Total			40 (D_V improved)			22 (D_V Unchanged)	18 (D_V Deteriorated)			3 (D_V Deteriorated)	

A.4.2 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 where both delay and volume significantly increased (or decreased), HCS 2010 was used to estimate the expected delay increases (or decreases) due to the volume changes. In the HCS estimations, all the inputs, except for volume, were the same as those used in the HCS runs for 2013 conditions. And thus by entering the 2013 and 2015 conditions volumes 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 is larger than the estimated increase due to the volume, it indicates that the ASCT implementation leads to a longer delay, and thus the traffic performance for the subject lane group is potientially deteriorated. And if the field discrepancy equals to the estimated values, the delay change for the subject lane group is solely due to the volume change. Otherwise the ASCT implementation shortens the field delay for the subject lane group and improve its traffic performance.

In the study, three lane groups were found that 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 Noon peak. Table 34 shows the discrepancy comparison results. For all the three lane groups, the field delay discrepancies were larger than the HCS estimates both numerically and in percentage. This means in these three lane groups the field delay increases after ASCT implementation are not only due to the volume increases, but also the system inappropriate performance. Therefore, these three lane groups were also considered as lane groups with potentially deteriorated D_V.

Table 34. Delay Discrepancy Comparison: HCS vs. Field

Lane groups	HCS Discrepancy		Field Discrepancy		Results
	No	%	No	%	
STADIUM PM EB	0.1	1%	9.1	89%	Deteriorated D_V
KNOLLWOOD NP NB	0.2	67%	0.9	129%	Deteriorated D_V
KNOLLWOOD NP SB	0	0	0.6	86%	Deteriorated D_V

A.4.3 Queue Length and Volume Combination Analysis

Table 35 shows the combined analysis results for queue and volume. In the table, “Q” is the abbreviation of queue, and “V” is the abbreviation of volume. The upward arrow “↑” stands for increase, downward arrow “↓” stands for decrease, and dash “-” stands for unchange. For instance, the column heading “Q↑ & V↓” stands for the category with increased queue length and decreased volume. And the cells with entries “1” signify that these lane groups (row heads) fall into the cooresponding categories (column heads).

Table 35. 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	Yes								
	NP	NBT								Yes (Deteriorated)	
		SBT			Yes						
	PM	NBT		Yes							
		SBT				Yes					
		EBT								Yes (Deteriorated)	
		WBT						Yes			
Kirby	AM	NBT	Yes								
		SBT			Yes						
		EBT						Yes			
		WBT			Yes						
	OP	NBT	Yes								
		SBT								Yes (Deteriorated)	
		EBT			Yes						
		WBT			Yes						
	NP	NBT	Yes								
		SBT				Yes					
		EBT			Yes						
		WBT								Yes (Improved)	
	PM	NBT	Yes								
		SBT						Yes			
		EBT				Yes					
		WBT			Yes						
St Marys	AM	NBT				Yes					
		SBT	Yes								
		EBT								Yes (Improved)	
		WBT				Yes					
	NP	NBT						Yes			
		SBT						Yes			
	PM	NBT				Yes					
		SBT						Yes			
		EBT			Yes						
		WBT				Yes					

Table 35. (Continued)

			Improved			Unchanged	Deteriorated			To be Determined	
			Q↓ & V↑	Q↓ & V -	Q - & V ↑	Q - & V -	Q↑ & V ↓	Q↑ & V -	Q - & V ↓	Q↑& V↑	Q↓ & V ↓
Knollwood	AM	NBT			Yes						
		SBT				Yes					
	NP	NBT								Yes (Improved)	
		SBT								Yes (Deteriorated)	
	PM	NBT			Yes						
		SBT				Yes					
Devonshire	AM	NBT						Yes			
		SBT				Yes					
	NP	NBT				Yes					
		SBT						Yes			
	PM	NBT								Yes (Deteriorated)	
		SBT						Yes			
Windsor	AM	NBT						Yes			
		SBT						Yes			
		EBT				Yes					
		WBT							Yes		
		SBT				Yes					
		EBT				Yes					
		WBT				Yes					
	NP	NBT		Yes							
		SBT			Yes						
		EBT		Yes							
		WBT		Yes							
	PM	NBT			Yes						
		SBT						Yes			
		EBT									Yes (Improved)
		WBT				Yes					
Subtotal			7	4	13	17	0	12	1	5 (Deteriorated) 3 (Improved)	1(Improved)
Total			24 (Q_V Improved)			17 (Q_V Unchanged)	13 (Q_V Deteriorated)			5 (Q_V Deteriorated) 4 (Q_V Improved)	

A.4.4 Application of HCS in Determining Condition of cases with both Increased or Decreased Queue Length and Volume

For the cases of "To be Determined", including 8 lane groups with both queue and volume significantly increased, and 1 both significantly decreased, the same method in delay comparison was used to estimate the expect queue changes due to the volume changes. For the lane groups where both queue and volume significantly increased, the performance was potentially deteriorated if the field-measured queue increased more than the expected value due to volume increase. And Imptoved Q_V was defined when the field queue increase was less than the expected value. For the lane groups with significantly decreased queue and volume, deteriorated Q_V was defined if 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. And the comparison results of the field-measured and expected queue changes are shown in Table 36.

Table 36. Queue Discrepancy Comparison: HCS vs. Field

Lane Groups	HCS Discrepancy		Field Discrepancy		Results
	No	%	No	%	
STADIUM NP NB	0.5	33%	0.652	56%	Q_V Deteriorated
STADIUM PM EB	0.7	70%	0.787	161%	Q_V Deteriorated
KIRBY OP SB	0.7	16%	1.268	33%	Q_V Deteriorated
KIRBY NP WB	2.1	58%	0.803	26%	Q_V Improved
ST MARYS AM EB	5	116%	1.005	39%	Q_V Improved
KNOLLWOOD NP NB	0.1	100%	0.688	63%	Q_V Improved
KNOLLWOOD NP SB	0	0%	0.679	66%	Q_V Deteriorated
DEVONSHIRE PM NB	0	0%	0.882	92%	Q_V Deteriorated
WINDSOR PM EB	-1.2	-26%	-1.775	-32%	Q_V Improved