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EVALUATION OF THE SCATS CONTROL SYSTEM

FINAL REPORT

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INTRODUCTION

Increasing travel demand and lack of sufficient highway capacity are serious problems in most major metropolitan areas in the United States. Large metropolitan areas have been experiencing increased traffic congestion problems over the past several years. The total delay that drivers experienced has increased from 0.7 billion hours in 1982 to 3.7 billion hours in 2003 [1]. Combining the 3.7 billion hours of delay and 2.3 billion gallons of fuel consumed due to congestion, leads to a total congestion cost of $63 billion dollars for drivers in 85 of the largest metropolitan areas of the nation [1].

In spite of the implementation of many demand management measures, the congestion in most urban areas is still increasing. In many areas congestion is no longer limited to two peak hours in a day; however, it is extended to two to three hours in the morning, afternoon and evening. Thus, the congestion experienced on urban and suburban freeways and arterial streets results in delays to the motorist, excess fuel consumption and a high level of pollutant emission not only during the peak hours in a day, but also for several hours throughout the day.

Traffic congestion has a significant impact on our nation's economy and to minimize this impact, the United States Department of Transportation (USDOT) has identified congestion mitigation as their top priority. Congestion on arterial roads can be attributable to heavy traffic volumes and poor traffic signal coordination. Recently, the NTOC 2005 National Report Card awarded the nation a "D-" grade for traffic signal operation stating that future efforts should be focused on "Mitigating bottlenecks on arterials resulting from signal timing" [2].

As with many urban areas across the nation, Oakland County, one of the largest counties in the State of Michigan has been experiencing congestion for the past two decades. During the 1990's, Oakland County experienced a surge of population growth and economic development. Associated growth in traffic required an excess of a billion dollars in road improvement needs. At the current level of funding, it will take 70 years to meet the capacity needs of the Oakland County roadways [3]. Looking for innovative and cost effective ways to improve road user mobility and safety, the Road Commission for Oakland County (RCOC) began investigating innovative traffic control strategies associated with Intelligent Transportation Systems (ITS). Subsequently, the County Board of Commissioners approved $2 million for the development of an advanced traffic management system in southeast Oakland County. This commitment by Oakland County toward congestion mitigation, prompted the United States Congress to financially support this effort as a Federal demonstration project with $10 million in funding. The innovative traffic control system created in Oakland County with the Federal and County funds is called “FAST-TRAC”, an acronym which stands for Faster and Safer Travel through Traffic Routing and Advanced Controls.

As a part of a field demonstration project, traffic signals at 28 intersections in the city of Troy within Oakland County were converted from a pre-timed coordinated traffic signal system to SCATS (Sydney Coordinated Adaptive Traffic System) control in 1992. SCATS is a computer controlled traffic signal system, developed in Australia and used widely in the Pacific Rim. SCATS uses anticipatory and adaptive techniques to increase the efficiency of the road network by minimizing the overall number of vehicular stops and delay experienced by motorists. The primary purpose of the SCATS system is to maximize the throughput of a roadway by controlling queue formation.

As a part of the SCATS system, vehicle presence at an intersection is detected by a video imaging processing system called ‘Autoscope’. The Autoscope system analyzes an intersection through a video imaging camera mounted above the intersection by detecting vehicles queued at the traffic signal along with other traffic flow parameters. The traffic flow parameters are then transmitted to a SCATS control box located at each intersection and coordinated with a central computer located at the Traffic Operation Center (TOC). The SCATS system has the ability to change the signal phasing, timing strategies, and the signal coordination within a network to alleviate congestion by automatically adjusting the signal parameters according to the real time traffic demand.

Since 1992, traffic signals in Oakland County and a portion of Macomb and Wayne Counties have been converted to the SCATS signal system. County traffic engineers have been adjusting various SCATS parameters to improve the roadway network’s effectiveness in terms of delay, traffic flow, queue length and crash or severity occurrences.

However, there have not been any comprehensive studies conducted that evaluated the performance of the SCATS systems in terms of delay, flow, queue length and other characteristics in the past several years. In order to quantify the long-term effectiveness of the SCATS systems on traffic congestion, a comprehensive study is needed. This research study was designed to evaluate the performance of the SCATS system by determining the statistical significance of the effectiveness of the SCATS system in terms of traffic flow, delay and other selected MOEs.

STATE-OF-THE-ART LITERATURE REVIEW

A literature review was performed to examine past research on the signal coordination and progression for corridors or networks. In order to identify past results related to the proposed research, literature searches were conducted through Internet queries and traditional library resources for the following subject areas:

- Signal coordination
- SCATS signal system
- SCOOT signal system
- Benefits (tangible and intangible) of signal coordination systems

Intelligent Transportation Systems (ITS) have been widely considered as methods to improve the efficiency and safety of a roadway system through real-time traffic data. For arterials with signalized intersections, the benefit of an ITS implemented strategy is the efficient allocation of green time for each intersection either along a corridor or in a network. While ITS strategies have been implemented, the benefits of such strategies have not been documented in terms of their impact on roadway capacity, operation or safety. In order to understand the benefits of ITS strategies, the United States Department of Transportation's (USDOT) Joint Program Office (JPO) created a National ITS Benefits Database to disseminate the most recent information to all transportation professionals [4].

Arterial management systems are ITS strategies used to reduced congestions and improve mobility along arterial roadways through the use of traffic signal control. Initial arterial management systems included pre-timed signal systems which correlate to specific periods of a day, such as the AM, noon or PM peak hour. Pre-timed signal systems do not change during the period and thereby cannot respond to changing traffic conditions. Therefore, the best pre-timed system is designed with signal progression through the use of signal offsets which optimizes the system. Actuated signal systems are an improvement to the pre-timed systems due to their ability to allow unused green time to be reallocated. However, the inability to modify the offsets at downstream intersections can create lower levels of progression along a corridor than a pre-timed system even through delay has been reduced. While the actuated signal systems can skip phases, the cycle lengths remain the same. Further improvements to traffic signal coordination have been made with the introduction of adaptive signal control systems which can modify the cycle length, signal phasing and signal timing based upon real-time traffic data. The benefits gained from an adaptive signal control systems have not defined since the ability to generalize the benefits may vary on corridor length, intersection spacing, traffic volumes or volume variation [4]. In addition, the limited number of evaluations conducted further constrains the definition of benefits from such systems. SCOOT (Split, Cycle, and Offset Optimization) and SCATS (Sydney Coordinated Adapted Traffic System) are the two most commonly used adaptive signal control systems. SCOOT was developed in the Transport Research Lab in the United Kingdom [5]. SCOOT measures traffic volumes and modifies the signal timings in order to minimize a performance index which incorporates delay, queue length and number of stops measures of effectiveness [5]. SCOOT has been utilized in Toronto, San Diego, Anaheim, London and Bangkok [6]. SCATS was developed by the Department of Main Roads (Roads and Traffic Authority) of New South Wales in Australia. SCATS collects traffic data near the intersection stop bar to adjust the signal timings to minimize number of stops and delay [5]. The SCATS system has been utilized in Hong Kohn, Sydney, Melbourne and Oakland County, Michigan [6].

Martin et. al. [5,7] conducted an evaluation study to compare three signal systems; Synchro-designed fixed-time system, TRANSYT-designed fixed-time system and SCOOT as simulated with CORSIM. The results of the study indicated that the SCOOT simulated system was more effective than either the Synchro or TRANSYT system. However, the differential between the SCOOT system and the other two signal systems declined as the traffic volumes approached saturation.

The SCATS systems was compared to a dynamic TRANSYT system which modified the signal timing and cycle length at 45 minute intervals in the research study conducted by Liu and Cheu

[8]. The researchers found that in simulations the dynamic TRANSYT system resulted in lower average delays per vehicle. They also found that the simulated SCATS system was replicated with the simulation program designed for the study, PARAMICS.

The SCOOT system in Anaheim, California was compared to a fixed time system. The results of the study ranged from a decrease in travel time by 10 percent with the SCOOT system to an increase in travel time by 15 percent [4]. The preferred location for the vehicle detectors for the SCOOT system is near the upstream intersection. However, existing mid-block vehicle detectors were utilized for the Anaheim system, which may have led to the poor performance of the system.

Abdel-Rahim and Taylor [9] also utilized a simulation program, CORSIM, to compare the benefits of adaptive signal systems to coordinated fixed-time systems. The study was conducted along Orchard Lake Road in Oakland County, Michigan with five signalized intersections. The researchers found that adaptive traffic signal systems reduced travel time along the corridor particularly when the demand was less than capacity. The study also found that actuated signals provided similar results to the adaptive signal system. In addition, the SCATS and SCOOT systems predicted arrivals in a similar fashion.

The comparison of an adaptive traffic signal system with a fixed time system in Vancouver, Washington along Mill Plain Boulevard, a six-lane divided arterial, found that the adaptive signal system performed more efficiently than the fixed time system for the eastbound direction during both the AM and PM peak periods [10]. However, the improvement for the westbound direction was not statistically significant at the 95 percent level of confidence. Eghtedari concluded that future research should incorporate travel time and delay studies for the minor streets as well as left-turn movements. This was one of the few studies that utilized actual field data for the comparison of systems and did not rely on simulation programs.

A study conducted for the Cobb County Department of Transportation found that the SCATS system did not provide significant improvements to the travel time or reductions in delay [11]. A driver satisfaction survey conducted by Petrella et. al. [11] found that a representative sample of the population concurred with the empirical results of the research study conducted by the Georgia Institute of Technology.

The JPO also established various measures of effectiveness in several ITS programs areas, such as mobility and efficiency, in order to assist researchers and practitioners in determining the impact of ITS strategies [4]. For mobility programs, the measures of effectiveness as defined by the JPO include delay and travel time. Delay can be measured in seconds per vehicle or number of stops. Travel time can be measured in the variability in travel time or the reduction in travel time. For efficiency ITS programs, measures of effectiveness include the measurement of effective capacity or throughput. Effective capacity is defined as the "Maximum potential rate at which persons or vehicles may traverse a link, node or network under a representative composite of roadway conditions," including "weather, incidents and variation in traffic demand patterns" [4]. Throughput is defined as "The number of persons, goods, or vehicles traversing a roadway section per unit time" [4]. Based upon the definitions of each possible measure of effectiveness, it is readily possible to measure throughput, while effective capacity can vary depending on various factors. Therefore, the JPO recommends utilizing throughput as a surrogate measure for effective capacity [4].

Past research projects have evaluated signal systems through various measures of effectiveness. Park et. al. [12] utilized travel time to calibrate an urban arterial network with 12 coordinated actuated signalized intersections and maximum queue length to validate the model. Al-Mudhaffar and Bang [13] also utilized travel time and queue length in their analysis as well as intersection delay in an evaluation between fixed time coordination and self-optimizing control for bus priority control. To compare traffic simulation models for a fixed-time system, an actuated-coordinated system, a SCATS system and a SCOOT system utilizing CORSIM, a microscopic simulation model, Abdel-Rahim and Taylor [9] utilized average travel time, intersection delay and average intersection approach delay for the major and minor streets. A similar study was conducted by Martin et. al. [5,7] to compare the delay, queue length and travel time between SCOOT and a fixed-time system with CORSIM. Wolshon and Taylor [14] utilized intersection delay for individual movements in order to analyze the implementation of the SCATS system in South Lyon, Michigan. Liu and Cheu [8] utilized average vehicle delay to compare traffic flow in network between a dynamic TRANSYT system and SCATS control. TRANSYT was also utilized to compare a SCOOT control system with a pre-timed signal system through the comparison of delay by Park and Chang [15]. Girianna and Benekohal [16] validated a two-way street network with ten signalized intersections utilizing total vehicles discharged and average link speed. To determine the effectiveness of an adaptive signal control system as compared to a time-of-day signal control, Eghtedari [10] examined travel time and average speed for a six-lane divided arterial in downtown Vancouver, Washington. Stevampvoc & Martin [17] utilized the performance index from Synchro, optimization software, to determine the benefits of updating traffic signal timings.

Based upon the literature review, it was determined that appropriate measures of effectiveness to determine the impact of the two signal systems would be travel time, travel time delay, intersection delay, queue length, fuel consumption and emission data.

RESEARCH OBJECTIVES

The objective of this evaluation study was to assess the effectiveness of the SCATS signal system on the reduction of traffic congestion in terms of delay, queue length and other traffic characteristics. The evaluation of the effectiveness of the SCATS system was accomplished through a field experiment to meet the following objectives:

- Select study corridor and intersections for inclusion in the evaluation study
- Determine the traffic volumes along the corridor to design the pre-timed signal system with Synchro, a traffic optimization program
- Collect the measures of effectiveness (MOE) of traffic flow for each of the two signal timing scenarios (pre-timed and SCATS) such as:
    - Travel time
    - Travel speed
    - Fuel Consumption
    - Hydrocarbon Emissions
    - Carbon Monoxide Emissions
    - Nitrogen Oxide Emissions
    - Number of stops
    - Total delay
    - Number of vehicles stopping at intersections along the corridor
    - Maximum Queue length at intersections along the corridor
- Determine the effectiveness of the two signal system scenarios based upon field data collected.

STUDY AREA

A four-mile segment along M-59 between Pontiac Lake Road West to Pontiac Lake Road East was selected as the corridor for the data collection and analysis for the field experiment. The M-59 corridor selected for this research project includes seven intersections as follows:

- Pontiac Lake Road West
- Williams Lake Road
- Oakland Boulevard
- Service Drive
- Airport Road
- Crescent Lake Road
- Pontiac Lake Road East

The M-59 corridor selected for the research project is depicted in Figure 1.

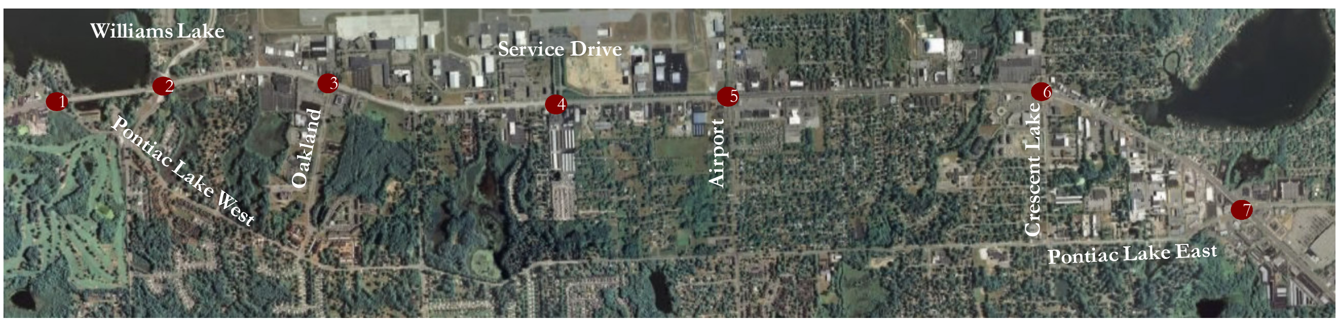

Figure 1. M-59 Corridor for Analysis

Traffic operational data was collected for each intersection as follows:

- Existing geometric conditions
- Traffic volume
- Travel time
- Travel speed
- Fuel Consumption
- Emissions
- Number of stops
- Total delay
- Number of vehicles stopping at intersections along the corridor
- Maximum queue length at intersections along the corridor

Except for the traffic volume data, the data was collected for a typical weekday (Tuesday, Wednesday or Thursday) and Friday during the noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak periods, as well for a Saturday morning peak (9 AM to 11 AM). The traffic volume data was only collected for a typical weekday noon and PM peak periods. Due to the low traffic volumes at the intersection with Service Drive, traffic operational data, other than traffic volumes and geometric conditions, were not collected at the intersection.

Existing Geometric Conditions and Traffic Volumes

As a part of this study, a field survey was conducted for each intersection. The field survey included visiting the intersection sites, collecting the existing conditions of the intersection, taking photographs in order to capture the existing lane use and other potential physical characteristics in the vicinity of the intersections, and assessing the existing traffic control devices. The existing condition data that was collected included the lane widths, lane use, lengths of turn bays, location of stop bars and crosswalks, length and width of crosswalks, location of overhead signals and post-mounted signals, and signs relating to traffic control. The existing condition data was entered into Synchro, a traffic signal optimization software package, to design the pre-timed signal operation recommended for each intersection for implementation in the field in order to compare the operational characteristics with the SCATS system. The Synchro signal system file was submitted to MDOT for review and implementation. During the course of this study, MDOT has implemented their pre-timed signal design for evaluation.

The manual turning movement volume counts were collected for each intersection using two-person data collection teams between May 22nd and June 7th of 2007. Each team member recorded the through and turning movement traffic separately, for each of the intersection approaches. The counts included the identification of trucks, buses and school buses at the intersection. The counts were taken in 15-minute intervals for the entire duration of the peak periods. Once the turning movement data were finalized, it was analyzed and summarized. Tables were prepared for each intersection and analysis period, including the following:

- Number of passenger cars, trucks, and school buses counted for each 15-minute interval for each approach and each movement.
- Highest hourly volume observed in the period.
- Peak hour factors.
- Percent of trucks and school buses for each movement, approach and intersection.

The noon and PM peak hour diagrams for each intersection are provided in Appendix A.

Travel Time Sample Size Calculation

In order to evaluate the effectiveness of the SCATS system, travel time studies were conducted along the M-59 corridor for the two signal system scenarios (MDOT pre-timed and SCATS) after the area schools began in September. In order to determine the minimum number of required travel time runs during the peak period, preliminary travel time data was collected along M-59 during the week of June 4, 2007. The following equation was used to calculate the number of runs required [18,19]:

$$n = \left\{ \frac{\hat{\sigma} x Z}{\varepsilon} \right\}^2$$

Where,

n = Estimated sample size for number of runs at the desired precision and level of confidence

$\hat{\sigma}$ = Preliminary estimate of the population standard deviation for average travel speed among the sample runs

Z = Two-tailed value of the standardized normal deviate associated with the desired level of confidence (at a 95% level of confidence, Z = 1.96)

ε = Acceptable error (mph) (assumed as 2 mph)

The calculated sample size was based on the intended use of the travel time information. According to Oppenlander [18], the range of permitted errors in the estimate of the mean travel speed (ε) is ± 1.0 mph to ± 3.0 mph for 'before and after' studies involving operational improvements of roadways, such as signal modifications. The allowable error used in this analysis were based upon the preliminary travel time runs conducted in June of 2007. According to Oppenlander, "If no travel time and delay studies have been conducted on the route under evaluation, an initial study of 4 to 5 test runs provides a sample of data for estimating the average range in travel speeds" [18]. Therefore, the preliminary number of runs for the sample size estimation were a minimum of five runs.

The preliminary travel time data were taken during the Noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak periods on a typical weekday on June 7, 2007. The data used in the analysis to determine the sample size requirements are shown in Table 1 with a summary of the travel data in Table 2. The calculation for the minimum number of runs for the analysis is as follows:

Table 1. Preliminary Travel Time Data

Peak Period and Travel Time Run Number	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
Noon Peak Period	**Eastbound**		**Westbound**	
1	422	39.07	549	30.03
2	484	34.07	465	35.46
3	489	33.72	463	35.61
4	510	32.33	452	36.48
5	496	33.24	537	30.70
6	402	41.02	502	32.84
7	409	40.31	N/A	N/A
PM Peak Period	**Eastbound**		**Westbound**	
1	451	36.56	625	26.38
2	527	31.29	634	26.00
3	428	38.52	897	18.38
4	431	38.26	849	19.42
5	412	40.02	727	22.68
6	484	34.07	590	27.95
7	481	34.28	716	23.03
8	420	39.26	741	22.25
9	425	38.80	688	23.97
10	463	35.61	N/A	N/A
11	479	34.42	N/A	N/A

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 2. Travel Time Statistical Data from Preliminary Runs

Peak Period and Direction of Travel	Number of Runs	Mean Travel Time (sec)	Mean Travel Speed (mph)	Standard Deviation of the Travel Speed (mph)
Noon Peak Period				
Eastbound	8	458.59	35.93	3.71
Westbound	7	494.67	33.33	2.73
PM Peak Hour				
Eastbound	11	454.64	36.27	2.75
Westbound	10	718.56	22.94	3.15

$$\text{Noon Peak Eastbound Minimum Number of Runs} = \left(\frac{3.71 \times 1.96}{2}\right)^2 = 13.22 \text{ runs}$$

$$\text{Noon Peak Westbound Minimum Number of Runs} = \left(\frac{2.73 \times 1.96}{2}\right)^2 = 7.16 \text{ runs}$$

$$\text{PM Peak Eastbound Minimum Number of Runs} = \left(\frac{2.75 \times 1.96}{2}\right)^2 = 7.26 \text{ runs}$$

$$\text{Noon Peak Eastbound Minimum Number of Runs} = \left(\frac{3.15 \times 1.96}{2}\right)^2 = 9.53 \text{ runs}$$

Therefore, ten to fourteen runs should satisfy the sample size requirements for travel time.

Statistical Analyses

Student's t-test with Welch's Modification for the Comparison of Means (Travel Time and Travel Time Delay)

The Student's t-test was considered to determine if the differences in mean travel time, travel speed, total delay or number of stops along the corridor are significant. In order for the Student's t-test to maintain its power and robustness, the data must follow several assumptions. Only continuous data, or data which can assume a range of numerical value should be tested with the Student's t-test [20]. In addition, the data must exhibit a distribution that is approximately normal with variances that are equal between the two groups being tested [20]. The data observations must also be independent, implying that the observations of the first group are different from the observations of the second group [20]. Additional tests were conducted to verify that the data's distribution was normal and the variances of the two groups were equal.

Once the underlying assumptions were verified, a two-tailed Student's t-test was conducted with a null hypothesis stating there was no difference between the two means of the signal systems. The alternative hypothesis states that one signal system is better or worse than the other. A one-tailed test requires the direction of the difference in travel time or delay to be specified prior to the analysis. The two-tailed test was used for this research as the effect on travel time in regards to the signal system is not previously known. Specifically, it cannot be stated whether the SCATS system increases or reduces travel time. If the calculated t-value is greater than the critical t-value obtained in available statistical tables, the difference in means was determined to be statistically significant. The calculated t-value was found with the following equation [20] for $[N_B + N_A - 2]$ degrees of freedom assuming the collection of unequal sample sizes:

$$t_{calc} = \frac{\left(\overline{X}_B - \overline{X}_A\right)}{\sqrt{\sigma^2\left(\frac{1}{N_B} + \frac{1}{N_A}\right)}}$$

Where:

$\overline{X}_B$ = sample mean of signal system one

$\overline{X}_A$ = sample mean of signal system two

N_B = number of observations

N_A = number of observations

σ = common standard deviation

If the data was determined to follow a normal distribution but the variances were not equal, the Welch's modification to the Student's t-test was utilized to test the differences in the means of the signal system groups. The Welch's method has shorter confidence intervals and more power than the Student's t-test when the variances are found to be substantially different. The Welch's test statistic [20] is as follows:

$$W = \frac{\left(\overline{X}_B - \overline{X}_A\right)}{\sqrt{\left(\frac{\hat{\sigma}_B^2}{N_B} + \frac{\hat{\sigma}_A^2}{N_A}\right)}}$$

$$k' = \frac{\left(\frac{\hat{\sigma}_B^2}{N_B} + \frac{\hat{\sigma}_A^2}{N_A}\right)^2}{\frac{\left(\frac{\hat{\sigma}_B^2}{N_B}\right)^2}{N_B - 1} + \frac{\left(\frac{\hat{\sigma}_A^2}{N_A}\right)^2}{N_A - 1}}$$

Where:

$\overline{X}_B$ = sample mean of signal system one

$\overline{X}_A$ = sample mean of signal system two

N_B = number of observations of signal system one

N_A = number of observations of signal system two

$\hat{\sigma}_B$ = standard deviation of signal system one

$\hat{\sigma}_A$ = standard deviation of signal system two

k' = degrees of freedom

One-way Analysis of Variance for the Comparison of Means (Travel Time and Travel Time Delay)

In order to compare several means simultaneously, a one-way analysis of variance (ANOVA) was utilized to determine if the means were similar. Although a Student's t-test could have been conducted on the same data, several iterations of the t-test would be required in order to compare all possible scenarios. However, the Type I error rate is greater when multiple t-tests are conducted and can be calculated as follows [20]:

$$\text{Type I Error Rate} = 1 - (1 - \alpha)^c$$

Where:

α = the level of confidence for each t-test

c = the number of independent t-tests

The ANOVA determines the level of confidence based upon the number of dependent variable categories that are being compared. For instance, if the mean travel time for each roadway type was compared, there would be three individual t-tests that would be conducted; SCATS, pre-timed and MDOT pre-timed. Although a desired Type I error of 0.05 was selected, the calculated Type I error rate would be equal to 0.14. However, the ANOVA would utilize a level of confidence of 31.7 percent or alpha equal to 0.017 for each of the comparisons which would yield an alpha of 0.05 for the entire analysis.

The one-way ANOVA required the comparison of one independent variable, illumination, with several categories of the dependent variable, mean speed, mean speed deviation or lateral placement. The assumptions for the ANOVA were similar to those for the Student's t-test. The data must be continuous, independent, follow the normal distribution and have equal variances [20]. Violations of these assumptions impact the results of the test; however, the robustness of the ANOVA varied from the Student's t-test. For instance, the ANOVA is considered a very robust test even with the violation of normality, unless the variances and sample sizes are unequal [20]. To perform the ANOVA, an F-statistic is calculated which is equal to the mean squares between the groups divided by the mean squares within the groups. If F- calculated was greater than the F-critical obtained in available statistical tables, the difference in the means was statistically significant. When conducting the ANOVA test, the Levene's test for equal variances was performed simultaneously. When the Levene's test indicated that the variances were equal, the ANOVA calculated F-statistic was reported. If the variances were determined not to be equal, the Welch's modification to the ANOVA was conducted and the calculated F value based upon an asymptotically distribution was reported. The equations used to perform this test are as follows [21]:

$$SS_T = \sum_{k=1}^{K} \sum_{i=1}^{n_k} X_{ik}^2 - \frac{T^2}{N}$$

Where:

SS_T = Total sum of squares

$\sum_{k=1}^{K} \sum_{i=1}^{n_k} X_{ik}^2$ = squared scores summed across all individuals and groups

K = Number of groups

n = Number of observations

T = sum of scores summed across all observations and groups

N = total number of scores

$$SS_B = \sum_{k=1}^{K} \frac{T_k^2}{n_k} - \frac{T^2}{N}$$

Where:

SS_B = Sum of squares between-groups

T_k= sum of observations for kth group

$$SS_W = \sum_{k=1}^{K} \sum_{i=1}^{n_k} X_{ik}^2 - \sum_{k=1}^{k} \frac{T_k^2}{n_k}$$

Where:

SS_W = Sum of squares within-groups

$$MS_B = \frac{SS_B}{K - 1}$$

$$MS_W = \frac{SS_W}{N - K}$$

$$F_{calc} = \frac{MS_B}{MS_W}$$

Where:

MS_B = Mean sum of squares between-groups

MS_W = Mean sum of squares within-groups

When statistically significant results are obtained in the ANOVA, the only conclusion that can be drawn from the test is that differences exist between the means. However, the determination of which two means are in fact not equal cannot be concluded. Therefore, in order to solve this issue, post-hoc tests were utilized to assist in specific comparisons among groups. There are numerous post-hoc tests that have been established for various assumptions or violation of assumptions. Most of the post-hoc tests have been shown in past statistical research to withstand small deviations from normality. The determination of the post hoc tests conducted during this research was based upon summaries of past research [20,22]. For this research, the Bonferroni test was utilized when the sample sizes and variances were equal and a small number of comparisons were needed. For requirements of a larger number of comparisons with equal sample sizes and variances, the Tukey test was utilized. When the samples sizes were not equal but the variances were equal, the Hochberg test was conducted. If the variances were not assumed equal and the sample sizes were not equal, the Games-Howell test was conducted.

Paired t-test for the Comparison of Means (Intersection Delay and Queue Length)

In order to test the effectiveness of the signal systems based upon the mean measure of effectiveness, the paired t-test was used to determine if the differences in the variables are significant. Continuous data, or data which can assume a range of numerical values, such as the variables of intersection delay and queue length, can be tested in the paired t-test. In addition to assuring the data is appropriate for the test, there are two underlying assumptions of the data before the paired t-test can be performed. The data must exhibit a distribution that is approximately normal. In addition, the data observations must be dependent, indicating matched pairs. For the paired t-test, a two-tailed test was used which utilizes a null hypothesis that states there is no difference between two means. A one-tailed test requires the direction of the difference to be specified prior to the analysis. The two-tailed test will be used for this research as the difference between the effectiveness of the signal systems is not known. Specifically, it cannot be stated whether the use of the SCATS systems would increase or decrease the measure of effectiveness.

The following equations will be used to calculate the paired t-statistic and the sample variance.

$$P_t = \frac{\overline{X}_B - \overline{X}_A}{\frac{s_D}{\sqrt{n}}}$$

$$s_D^2 = s_B^2 + s_A^2 - 2\left[\frac{1}{N-1}\sum_{i=1}^{N}\left(X_{Bi} - \overline{X}_B\right)\left(X_{Ai} - \overline{X}_A\right)\right]$$

Where:

$\overline{X}_B$ = sample mean of signal system one

$\overline{X}_A$ = sample mean of signal system two

N = number of study locations

S_B = standard deviation of signal system one

S_A = standard deviation of signal system two

If the calculated Pt-value is greater than the critical Pt-value obtained in available statistical tables, the difference in means is statistically significant with the degrees of freedom equal to the number of study locations less one.

Wilcoxon Signed Rank Test

If the assumption of normality was violated in the paired t-test, other statistical tests was performed to maintain a Type I error of 0.05 without infinitely increasing the Type II error or loss of power. If the assumption of normality was violated, the Wilcoxon Signed Rank Test was used. This statistical analysis tests the hypothesis that the signal systems have similar distributions for the measures of effectiveness. The first step in the procedure was to calculate the difference between the variables. Any difference of zero was ignored and the remaining number of variables was used as the sample size. The absolute values of the differences was then determined and ranks were assigned to each value. The sign of the differences was then applied to the ranks. The following test statistic was calculated [22].

$$W = \frac{\sum R_i}{\sqrt{\sum R_i^2}}$$

Where:

R_i= the signed rank values

If there were no ties found among the absolute value differences, the following test statistic is calculated [22].

$$W = \frac{\left(\sqrt{6}\right)\sum R_i}{\sqrt{\left[n(n+1)(2n+1)\right]}}$$

Where:

R_i = the signed rank values

n = the final sample size

The null hypothesis, that the distributions were similar, was rejected if the absolute value of the Wilcoxon statistic exceeded the z-value of 1.96 based upon an alpha equal to 0.05.

TRAFFIC OPERATIONAL DATA COLLECTION

Travel Time Data and Travel Speed

The travel time and travel speed for the M-59 corridor were collected for two of the signal systems scenarios (MDOT pre-timed and SCATS). Travel time and travel speed studies were performed along M-59 on a typical weekday and Friday for the noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak periods, as well for a Saturday morning peak (9 AM to 11 AM). The travel data was collected using computerized equipment available from JAMAR Technologies. The travel data collection methods was based upon the 'Average Vehicle, Floating Car' method as outlined in the Institute of Transportation Engineers (ITE) Manual of Traffic Engineering Studies [19]. In this method, a two-person data collection team was used for each 'test vehicle'. One person was the driver and the second person operated the data recorder. The data recorder was responsible for recording travel time between consecutive signalized intersections, as well as recording of the types, number and location of stops and duration of the stopped time. In the 'Average Vehicle, Floating Car' method the driver of the test vehicle was instructed to pass as many vehicles as vehicles that passed the test car. This ensured that the average position of the test vehicle in the traffic was maintained, and the measurements reflect average conditions within the traffic stream. The travel runs were conducted only on days in which the weather conditions were clear and dry.

The travel time and travel speed data collected by signal system, peak period and direction of travel for the typical weekday is documented in Table 3, for Friday in Table 4 and for Saturday in Table 5.

Table 3. Typical Weekday Travel Time and Travel Speed Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	457	31.2	438	32.3	359	39.7	407	34.9
2	458	31.1	343	41.3	409	35.0	430	33.0
3	399	35.7	442	32.0	363	39.4	381	37.3
4	437	32.5	437	32.4	328	43.5	403	35.2
5	450	31.7	414	34.2	342	41.7	340	41.5
6	441	32.3	346	40.9	358	39.7	411	34.5
7	363	39.3	381	37.2	370	38.7	360	39.4
8	341	41.9	356	39.7	430	33.3	431	33.0
9	437	32.7	366	35.2	412	34.5	367	38.6
10	419	34.0	371	38.1	442	32.4	415	34.2
11	414	34.5	252	35.8	370	38.5	424	33.4
12	427	33.4	387	36.4	388	36.8	394	36.1
13	N/A	N/A	N/A	N/A	440	32.5	373	38.1
14	N/A	N/A	N/A	N/A	386	37.1	449	31.4
15	N/A	N/A	N/A	N/A	N/A	N/A	398	35.7

Table 3. Typical Weekday Travel Time and Travel Speed Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	426	33.5	467	30.3	421	33.8	414	34.2
2	460	30.9	542	26.1	330	43.0	427	33.2
3	431	33.1	457	31.0	397	35.9	430	32.9
4	305	46.6	452	31.3	408	34.9	446	31.8
5	394	36.2	479	29.6	386	37.0	341	41.5
6	440	32.4	463	30.6	476	29.9	438	32.3
7	456	31.3	388	36.5	366	38.9	345	41.1
8	420	33.9	405	34.9	376	37.9	436	32.4
9	510	28.0	493	28.7	404	35.3	446	31.8
10	409	34.8	480	29.5	420	33.9	495	28.6
11	397	35.9	434	32.5	398	35.8	436	32.4
12	415	34.4	501	28.3	323	44.1	451	31.4
13	N/A	N/A	N/A	N/A	431	33.0	467	30.2
14	N/A	N/A	N/A	N/A	391	36.4	473	29.9
15	N/A	N/A	N/A	N/A	408	34.9	N/A	N/A

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 4. Friday Travel Time and Travel Speed Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	447	32.0	343	41.1	427	33.4	327	43.3
2	457	31.3	397	35.5	446	32.0	382	37.0
3	457	31.2	360	39.2	407	35.0	394	35.6
4	457	31.2	397	35.5	378	37.7	412	34.3
5	444	32.1	424	33.3	352	40.4	417	33.9

Table 4. Friday Travel Time and Travel Speed Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
6	455	31.3	464	30.4	N/A	N/A	N/A	N/A
7	438	32.5	346	40.8	N/A	N/A	N/A	N/A
8	411	34.7	414	34.1	N/A	N/A	N/A	N/A
9	427	33.4	392	35.9	N/A	N/A	N/A	N/A
10	412	34.6	378	37.4	N/A	N/A	N/A	N/A
11	423	33.8	391	36.1	N/A	N/A	N/A	N/A
12	437	32.6	403	35.1	N/A	N/A	N/A	N/A
13	N/A	N/A	371	38.0	N/A	N/A	N/A	N/A
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	407	35.1	403	35.0	386	36.7	340	41.6
2	405	35.2	489	28.9	406	34.8	467	30.3
3	418	34.2	507	27.7	389	36.3	587	24.1
4	365	39.2	505	28.0	403	35.1	613	23.0
5	463	30.9	486	29.0	453	31.2	632	22.4
6	474	30.2	513	27.5	405	34.9	452	31.1
7	511	27.9	414	34.0	397	35.6	443	31.9
8	456	31.3	474	29.8	409	34.6	467	30.3
9	428	33.4	398	35.3	465	30.4	460	30.8
10	521	27.5	388	28.9	384	36.9	471	30.1
11	N/A	N/A	505	28.0	315	44.9	394	35.9
12	N/A	N/A	470	30.0	384	36.7	497	28.5
13	N/A	N/A	N/A	N/A	296	42.1	532	26.6
14	N/A	N/A	N/A	N/A	394	35.8	435	32.5
15	N/A	N/A	N/A	N/A	384	36.8	459	30.8
16	N/A	N/A	N/A	N/A	347	40.8	571	24.8

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 5. Saturday Travel Time and Travel Speed Data

Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)	Travel Time (sec)	Travel Speed (mph)
	Eastbound		Westbound		Eastbound		Westbound	
1	431	33.2	378	37.4	401	35.6	404	35.1
2	358	39.9	322	43.9	343	41.6	389	36.3
3	384	38.2	318	44.4	309	46.2	323	43.9
4	438	32.7	362	38.9	395	36.1	383	37.0
5	495	28.9	434	32.4	455	31.3	407	34.8
6	583	24.5	347	40.6	390	36.5	387	36.7
7	369	38.6	326	43.3	383	37.2	389	36.5
8	367	38.9	315	44.9	336	42.4	414	34.1
9	450	31.9	317	44.6	336	42.4	420	33.8
10	462	31.7	370	38.2	312	45.7	333	42.5
11	455	32.2	379	37.2	325	43.8	439	32.3

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Fuel Consumption

The total fuel consumed per directional length of travel for the M-59 corridor was collected for two signal systems scenarios (MDOT pre-timed and SCATS). The data was collected in a similar manner as that of the travel time and travel speed data described in the previous section. The total fuel consumed data collected by signal system, peak period and direction of travel for the typical weekday is documented in Table 6, for Friday in Table 7 and for Saturday in Table 8.

Table 6. Typical Weekday Total Fuel Consumption Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
Noon Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	0.2268	0.2209	0.1865	0.1970
2	0.2225	0.2109	0.2092	0.2094
3	0.2148	0.2231	0.2121	0.2041
4	0.2183	0.2226	0.2113	0.2170
5	0.2251	0.2106	0.1867	0.2058
6	0.2240	0.2199	0.2145	0.2102
7	0.2244	0.2249	0.2083	0.1923
8	0.2217	0.2219	0.2138	0.2265
9	0.2282	0.2182	0.2195	0.2084
10	0.2207	0.2313	0.2311	0.2128
11	0.2170	0.1482	0.1966	0.2010
12	0.2200	0.2148	0.2175	0.2256
13	N/A	N/A	0.2405	0.2101
14	N/A	N/A	0.2330	0.2306
15	N/A	N/A	N/A	0.2039
PM Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	0.2140	0.2165	0.2302	0.2227
2	0.2147	0.2465	0.2055	0.2066
3	0.2293	0.2268	0.2170	0.2233
4	0.2010	0.2246	0.1995	0.2232
5	0.2286	0.2361	0.2019	0.2037
6	0.2401	0.2301	0.2292	0.2225
7	0.2383	0.2243	0.2016	0.1978
8	0.2264	0.2163	0.2151	0.2329

Table 6. Typical Weekday Total Fuel Consumption Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
PM Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
9	0.2457	0.2339	0.2363	0.2197
10	0.2252	0.2188	0.2268	0.2224
11	0.2278	0.2257	0.2101	0.2149
12	0.2203	0.2336	0.1852	0.2144
13	N/A	N/A	0.2258	0.2235
14	N/A	N/A	0.2134	0.2180
15	N/A	N/A	0.2039	N/A

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 7. Friday Total Fuel Consumption Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
Noon Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	0.2292	0.2040	0.2115	0.1857
2	0.2087	0.2087	0.2347	0.2106
3	0.2123	0.1857	0.2217	0.2299
4	0.2410	0.2172	0.1951	0.2219
5	0.2405	0.2356	0.2133	0.2148
6	0.2184	0.2170	N/A	N/A
7	0.2297	0.2059	N/A	N/A
8	0.2358	0.2315	N/A	N/A
9	0.2315	0.2254	N/A	N/A
10	0.2211	0.2181	N/A	N/A
11	0.2322	0.2239	N/A	N/A
12	0.2252	0.2325	N/A	N/A
13	N/A	0.2179	N/A	N/A

Table 7. Friday Total Fuel Consumption Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
PM Peak Period	Eastbound	Westbound	Eastbound	Westbound
1	0.2253	0.2148	0.2143	0.1928
2	0.2273	0.2275	0.2187	0.2183
3	0.2271	0.2296	0.1986	0.2429
4	0.2070	0.2349	0.2102	0.2424
5	0.2295	0.2320	0.2165	0.2536
6	0.2447	0.2335	0.2270	0.2281
7	0.2250	0.2194	0.2169	0.2114
8	0.2209	0.2360	0.2013	0.2169
9	0.2094	0.2110	0.2347	0.2246
10	0.2323	0.2298	0.2166	0.2175
11	N/A	0.2235	0.2072	0.2076
12	N/A	0.2231	0.2327	0.2181
13	N/A	N/A	0.1710	0.2496
14	N/A	N/A	0.2258	0.2252
15	N/A	N/A	0.2227	0.2359
16	N/A	N/A	0.2095	0.2608

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 8. Saturday Total Fuel Consumption Data

Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
	Eastbound	Westbound	Eastbound	Westbound
1	0.2230	0.2032	0.2238	0.2099
2	0.2006	0.1769	0.2047	0.2340
3	0.2104	0.1833	0.2090	0.2175
4	0.2273	0.2086	0.2090	0.2014
5	0.2392	0.2374	0.2018	0.2437

Table 8. Saturday Total Fuel Consumption Data (continued)

Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)	Fuel Consumption (gal)
	Eastbound	Westbound	Eastbound	Westbound
6	0.2450	0.2119	0.1976	0.2070
7	0.2035	0.1898	0.1925	0.2063
8	0.2180	0.1946	0.1877	0.1793
9	0.2316	0.1932	0.2059	0.2077
10	0.2417	0.2117	0.2084	0.2035
11	0.2257	0.2113	0.1905	0.1915

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Emissions

The hydrocarbon, carbon monoxide and nitrogen oxide emissions for the M-59 corridor were collected, and measured in grams, for two signal systems scenarios (MDOT pre-timed and SCATS). The data was collected in a similar manner as that of the travel time and travel speed data described in the previous section. The hydrocarbon, carbon monoxide and nitrogen oxides emissions data collected by signal system, peak period and direction of travel for the typical weekday is documented in Tables 9 and 10, for Friday in Tables 11 and 12 and for Saturday in Tables 13 and 14.

Table 9. Typical Weekday Hydrocarbon and Carbon Monoxide Emissions Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)
Noon Peak Period	Eastbound		Westbound		Eastbound		Westbound	
1	21.62	261.74	22.93	276.97	16.54	205.35	15.63	193.80
2	21.23	260.05	18.11	248.84	18.61	235.86	18.16	218.64
3	18.65	246.05	19.23	237.00	19.08	266.55	18.51	234.13
4	20.77	056.73	21.45	260.52	19.31	267.40	20.94	253.63
5	22.62	271.79	19.56	246.41	15.46	200.46	16.42	213.00
6	20.15	250.12	19.63	269.98	17.64	249.55	19.60	253.42
7	18.85	271.45	21.95	290.46	17.95	246.07	16.24	213.51

Table 9. Typical Weekday Hydrocarbon and Carbon Monoxide Emissions Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
8	16.95	251.05	21.06	284.76	21.27	251.42	20.70	266.37
9	21.83	277.96	23.34	304.52	19.03	254.28	18.59	258.47
10	18.95	253.00	19.06	239.00	22.35	276.01	20.31	257.27
11	17.64	223.14	14.58	190.50	15.16	193.98	15.83	196.46
12	18.90	232.87	19.43	241.56	20.03	268.68	20.04	249.06
13	N/A	N/A	N/A	N/A	23.31	304.59	19.29	249.58
14	N/A	N/A	N/A	N/A	21.28	278.04	21.55	266.63
15	N/A	N/A	N/A	N/A	N/A	N/A	16.92	205.23
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	20.57	244.04	18.92	231.56	21.99	263.69	19.40	249.63
2	20.55	233.99	24.02	288.28	16.91	225.57	17.64	213.73
3	22.78	275.55	20.98	267.25	19.49	250.62	20.84	265.41
4	16.09	229.69	20.54	265.92	18.05	221.20	21.28	267.39
5	20.40	294.33	21.61	273.09	17.49	233.04	17.62	231.83
6	24.06	294.09	20.57	267.53	20.82	260.81	21.19	271.33
7	23.92	299.16	20.36	283.07	16.86	221.21	16.19	211.31
8	21.34	260.69	19.17	244.00	21.14	278.04	21.01	259.76
9	23.88	283.84	23.52	281.22	24.38	326.19	21.02	248.01
10	18.41	236.57	19.92	228.15	21.08	280.42	19.38	227.15
11	21.25	285.12	19.72	255.23	19.45	233.66	18.29	218.99
12	18.36	233.45	22.16	254.12	13.55	185.62	18.86	230.58
13	N/A	N/A	N/A	N/A	21.40	259.53	19.97	230.20
14	N/A	N/A	N/A	N/A	18.05	235.90	19.19	220.00
15	N/A	N/A	N/A	N/A	19.43	239.39	N/A	N/A

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 10. Typical Weekday Nitrogen Oxide Emissions Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	NOx (gms)	NOx (gms)	NOx (gms)	NOx (gms)
Noon Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	13.83	15.45	10.37	8.49
2	13.34	11.65	11.41	10.84
3	11.41	11.48	12.22	11.92
4	13.25	13.98	13.10	14.20
5	15.10	12.28	9.37	10.31
6	12.44	13.10	10.72	12.28
7	11.73	15.06	11.04	9.80
8	10.17	14.49	14.21	12.99
9	14.19	16.78	11.43	11.62
10	11.33	12.64	14.74	13.03
11	10.34	10.03	8.56	8.39
12	11.59	12.72	12.83	13.20
13	N/A	N/A	15.34	12.69
14	N/A	N/A	14.25	13.74
15	N/A	N/A	N/A	10.12
PM Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	13.57	10.85	14.94	11.94
2	13.09	14.79	10.90	10.32
3	15.57	12.84	12.46	13.23
4	10.17	12.43	11.16	13.51
5	12.63	13.13	10.48	11.45
6	16.57	12.19	12.47	13.46
7	16.15	13.06	10.31	9.98
8	14.27	12.00	14.40	13.32
9	15.26	15.37	17.01	13.58
10	11.08	11.96	13.42	10.94
11	13.98	11.87	12.76	10.84
12	11.02	13.94	7.58	11.07
13	N/A	N/A	14.08	12.18
14	N/A	N/A	11.00	11.35
15	N/A	N/A	12.57	N/A

Table 11. Friday Hydrocarbon and Carbon Monoxide Emissions Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	20.99	266.85	16.69	218.54	19.02	217.08	13.74	171.83
2	19.39	216.47	17.37	219.83	21.33	284.23	18.86	252.00
3	18.47	216.31	14.30	165.80	21.58	278.61	22.89	302.11
4	22.09	285.62	20.25	255.74	17.06	217.96	21.15	274.88
5	20.38	263.56	23.08	306.38	19.10	250.42	18.11	227.97
6	19.04	231.29	20.59	233.67	N/A	N/A	N/A	N/A
7	20.29	252.31	19.54	262.03	N/A	N/A	N/A	N/A
8	21.66	295.22	21.37	275.01	N/A	N/A	N/A	N/A
9	22.43	303.97	22.00	286.84	N/A	N/A	N/A	N/A
10	20.10	267.23	19.71	252.44	N/A	N/A	N/A	N/A
11	20.70	269.38	20.02	258.33	N/A	N/A	N/A	N/A
12	19.20	237.66	22.47	297.38	N/A	N/A	N/A	N/A
13	N/A	N/A	19.13	246.07	N/A	N/A	N/A	N/A
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	19.89	250.14	18.28	231.05	17.54	235.45	16.03	202.21
2	22.03	293.55	20.96	252.04	21.05	260.85	19.34	223.59
3	18.25	233.40	19.90	227.98	17.11	209.27	23.74	253.80
4	17.89	236.14	21.97	253.64	19.38	243.25	26.66	240.54
5	23.38	268.95	22.16	275.03	19.04	231.31	25.27	258.76
6	24.43	288.42	23.09	268.26	22.43	272.03	22.47	278.90
7	20.04	224.06	17.79	233.20	21.26	268.17	19.42	235.27
8	21.60	242.01	23.09	288.84	17.60	213.41	20.14	238.89
9	19.39	225.09	17.59	220.01	22.18	293.38	21.37	257.07
10	21.10	241.08	22.33	279.96	19.19	256.57	19.99	229.46
11	N/A	N/A	22.39	245.56	16.77	240.59	18.31	242.10
12	N/A	N/A	19.46	239.08	21.73	305.61	20.73	234.87
13	N/A	N/A	N/A	N/A	15.05	201.87	24.81	296.63
14	N/A	N/A	N/A	N/A	21.59	289.79	20.30	258.05
15	N/A	N/A	N/A	N/A	20.06	262.40	23.17	294.43
16	N/A	N/A	N/A	N/A	17.77	249.66	25.83	283.98

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 12. Friday Nitrogen Oxide Emissions Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	NOx (gms)	NOx (gms)	NOx (gms)	NOx (gms)
Noon Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	13.10	10.45	11.99	7.98
2	12.03	10.33	13.13	11.84
3	10.70	8.23	14.35	15.70
4	13.81	13.31	10.44	13.78
5	12.42	15.35	12.73	10.77
6	11.23	13.04	N/A	N/A
7	12.61	13.22	N/A	N/A
8	13.97	13.92	N/A	N/A
9	14.54	14.97	N/A	N/A
10	12.57	13.00	N/A	N/A
11	13.06	13.01	N/A	N/A
12	11.64	15.11	N/A	N/A
13	N/A	12.53	N/A	N/A
PM Peak Period	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
1	12.81	11.16	10.44	10.03
2	14.63	12.60	14.05	11.59
3	10.79	11.39	10.48	14.39
4	11.32	13.61	12.38	14.16
5	15.96	13.72	11.25	15.45
6	16.64	14.60	15.63	14.68
7	11.63	10.25	14.34	11.87
8	14.36	14.75	10.69	12.30
9	12.40	10.60	13.74	13.56
10	12.43	13.99	12.12	12.25
11	N/A	14.38	10.61	11.14
12	N/A	11.26	14.24	12.58
13	N/A	N/A	9.66	15.75
14	N/A	N/A	14.31	12.62
15	N/A	N/A	13.11	15.03
16	N/A	N/A	11.20	16.66

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 13. Saturday Hydrocarbon and Carbon Monoxide Emissions Data

Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)	HC (gms)	CO (gms)
	Eastbound		Westbound		Eastbound		Westbound	
1	18.51	229.47	15.73	204.34	20.17	261.63	17.92	229.74
2	15.92	205.56	12.19	155.82	17.27	228.37	22.75	293.05
3	16.82	204.42	13.73	184.13	17.62	244.37	19.08	234.89
4	20.32	265.37	17.94	230.95	18.27	269.36	15.46	212.50
5	23.70	276.27	22.42	290.80	17.27	234.78	23.84	318.79
6	21.91	241.02	18.65	244.51	16.27	198.68	16.19	206.36
7	17.58	214.69	15.04	199.91	15.93	203.75	16.83	210.58
8	18.69	249.39	14.75	193.61	13.61	189.92	12.75	170.25
9	20.07	251.58	15.74	214.42	17.10	220.93	16.65	212.62
10	22.67	287.99	18.32	228.58	18.18	209.84	16.37	189.04
11	20.28	244.67	18.96	235.09	15.03	181.35	16.63	190.27

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 14. Saturday Nitrogen Oxide Emissions Data

Travel Time Run Number	MDOT Pre-timed System		SCATS System	
	NOx (gms)	NOx (gms)	NOx (gms)	NOx (gms)
	Eastbound	Westbound	Eastbound	Westbound
1	10.95	8.89	13.29	11.04
2	9.53	6.44	11.19	15.41
3	10.10	7.88	11.30	11.83
4	12.42	11.45	11.97	9.25
5	15.57	14.53	11.27	15.78
6	12.48	12.38	9.38	8.99
7	11.35	9.12	9.89	9.99
8	11.95	9.03	7.79	6.84
9	12.24	9.86	10.02	9.87
10	14.45	11.85	10.59	9.59
11	12.47	12.42	8.28	10.26

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Number of Stops and Total Delay

The number of stops and total delay for the M-59 corridor were collected for two signal systems scenarios (MDOT pre-timed and SCATS). The data was collected in a similar manner as that of the travel time and travel speed data described in the previous section. The number of stops and total delay data collected by signal system, peak period and direction of travel for the typical weekday is documented in Table 15, for Friday in Table 16 and for Saturday in Table 17.

Table 15. Typical Weekday Number of Stops and Total Delay Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	3	171	2	153	0	73	2	121
2	4	171	2	60	2	122	3	145
3	2	112	3	159	1	76	2	95
4	3	152	3	154	1	41	3	119
5	3	164	2	129	0	55	1	61
6	3	154	2	66	1	73	1	126
7	1	80	3	95	1	83	1	74
8	2	69	2	73	2	143	3	146
9	5	151	3	107	2	127	1	82
10	3	133	3	87	5	155	2	129
11	3	132	2	71	1	84	2	139
12	4	141	3	103	1	101	4	109
13	N/A	N/A	N/A	N/A	4	153	2	87
14	N/A	N/A	N/A	N/A	4	98	3	164
15	N/A	N/A	N/A	N/A	N/A	N/A	3	111
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	4	140	3	184	4	134	2	132
2	3	175	6	257	1	43	3	144
3	3	145	3	172	2	112	3	145
4	0	21	3	168	2	121	3	161
5	2	108	4	195	1	101	1	58
6	3	153	3	179	3	190	3	153

Table 15. Typical Weekday Number of Stops and Total Delay Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
PM Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
7	5	170	2	108	2	81	2	60
8	3	133	2	121	1	90	2	152
9	5	224	5	209	3	118	3	161
10	3	122	4	195	2	134	4	211
11	3	111	2	152	1	111	3	151
12	3	132	6	219	1	36	2	166
13	N/A	N/A	N/A	N/A	4	145	5	183
14	N/A	N/A	N/A	N/A	2	106	4	189
15	N/A	N/A	N/A	N/A	2	122	N/A	N/A

Table 16. Friday Number of Stops and Total Delay Data

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
Noon Peak Period	**Eastbound**		**Westbound**		**Eastbound**		**Westbound**	
1	2	159	2	60	3	141	0	43
2	3	170	2	115	3	160	1	97
3	2	170	2	75	2	120	3	110
4	2	170	2	115	1	90	2	127
5	4	163	4	141	2	66	2	132
6	3	173	4	180	N/A	N/A	N/A	N/A
7	3	151	2	63	N/A	N/A	N/A	N/A
8	2	124	3	132	N/A	N/A	N/A	N/A
9	2	140	3	111	N/A	N/A	N/A	N/A
10	2	125	3	94	N/A	N/A	N/A	N/A
11	3	136	3	107	N/A	N/A	N/A	N/A
12	4	151	3	119	N/A	N/A	N/A	N/A
13	N/A	N/A	3	87	N/A	N/A	N/A	N/A

Table 16. Friday Number of Stops and Total Delay Data (continued)

Peak Period and Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
PM Peak Period	Eastbound		Westbound		Eastbound		Westbound	
1	4	121	2	123	2	101	1	55
2	3	119	4	207	1	123	3	181
3	3	131	5	229	2	105	6	303
4	1	78	6	220	2	119	8	327
5	5	176	4	202	2	168	8	349
6	6	187	5	230	3	122	3	169
7	3	223	3	130	1	113	2	159
8	6	169	3	191	2	124	3	183
9	4	141	3	119	3	182	4	174
10	4	233	4	204	2	100	4	186
11	N/A	N/A	5	223	1	32	1	110
12	N/A	N/A	3	188	2	104	3	213
13	N/A	N/A	N/A	N/A	0	46	5	247
14	N/A	N/A	N/A	N/A	3	111	3	150
15	N/A	N/A	N/A	N/A	3	101	4	176
16	N/A	N/A	N/A	N/A	2	63	8	286

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Table 17. Saturday Number of Stops and Total Delay Data

Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
	Eastbound		Westbound		Eastbound		Westbound	
1	3	143	2	94	2	96	2	105
2	2	71	0	38	1	49	3	129
3	3	88	0	35	2	49	3	135
4	3	151	2	78	0	27	2	50
5	3	207	3	151	0	40	3	154

Table 17. Saturday Number of Stops and Total Delay Data (continued)

Travel Time Run Number	MDOT Pre-timed System				SCATS System			
	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)	No. of Stops	Total Delay (sec)
	Eastbound		Westbound		Eastbound		Westbound	
6	9	295	2	64	2	115	2	119
7	3	83	1	42	1	56	2	105
8	2	80	0	31	0	26	0	37
9	5	160	0	32	2	109	2	100
10	3	167	2	88	3	168	3	122
11	2	162	2	96	1	104	1	101

Note: Travel time runs were not equal for each direction and scenario based upon the travel conditions in the field. Periods which experienced fewer travel time runs are designated by N/A.

Number of Stopped Vehicles

The number of stopped vehicles data was collected for two signal systems scenarios (MDOT pre-timed and SCATS). The number of stopped vehicles was selected as a surrogate measure for intersection delay. Intersection delay is calculated by dividing the cumulative number of stopped vehicles collected in all specified intervals for a peak period by the volume for each critical lane group, such as through or left turn movements, and multiplying by the interval of the data collection period. In order to accurately collect the intersection delay, the volume of each critical lane group would be needed for each day of the data collection as traffic volumes along a roadway can vary substantially by day. Therefore, the number of stopped vehicles was utilized as a surrogate measure for intersection delay. The number of stopped vehicles was collected along M-59 on a typical weekday and Friday for the noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak periods, as well for a Saturday morning peak (9 AM to 11 AM). The number of stopped vehicles were collected by critical lane group, left turn or through movements, for each of the six intersections studied along the M-59 corridor. The interval selected for data collection was 15 seconds for through movements and 60 seconds for left turn movements. Therefore, the total number of stopped vehicles is the summation of the number of vehicles observed stopped during each interval observed.

The number of stopped vehicles collected by signal system, peak period and direction of travel for the MDOT pre-timed system data is documented in Table 18, and for the SCATS system data in Table 19.

Table 18. MDOT Pre-timed System Number of Stopped Vehicles Data

Intersection by Approach and Movement	Number of Stopped Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Pontiac Lake West Road					
EB Left Turn	70	66	98	173	52
EB Through	397	403	316	535	381
WB Left Turn	123	221	286	656	99
WB Through	105	420	192	231	143
NB Left Turn	5	15	6	24	8
NB Through	68	128	346	1141	21
SB Left Turn	0	5	6	1	5
SB Through	62	82	177	354	147
Williams Lake Road					
EB Left Turn	125	186	124	180	121
EB Through	886	1587	536	1418	672
WB Left Turn	33	26	12	40	17
WB Through	1249	1753	1230	1921	1009
NB Left Turn	164	417	310	575	231
NB Through	216	395	376	1274	398
SB Left Turn	115	80	116	77	41
SB Through	677	1808	519	1259	990
Oakland Boulevard					
EB Left Turn	157	119	260	186	22
EB Through	782	846	740	683	592
WB Left Turn	160	192	215	223	17
WB Through	516	1211	650	767	457
NB Left Turn	74	127	111	121	22
NB Through	220	190	143	196	91
SB Left Turn	118	157	164	170	21
SB Through	212	206	150	174	118

Table 18. MDOT Pre-timed System Number of Stopped Vehicles Data (continued)

Intersection by Approach and Movement	Number of Stopped Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Airport Road					
EB Left Turn	270	451	219	403	198
EB Through	1599	3087	1647	2045	1107
WB Left Turn	105	64	53	98	43
WB Through	904	3788	966	2157	720
NB Left Turn	286	370	520	700	117
NB Through	1177	4443	1346	4915	559
SB Left Turn	92	61	42	74	39
SB Through	961	1981	1039	2965	523
Crescent Lake Road					
EB Left Turn	162	489	304	504	127
EB Through	2920	1746	1289	456	743
WB Left Turn	117	122	62	238	44
WB Through	2255	5033	2234	9286	962
NB Left Turn	130	151	111	380	49
NB Through	457	134	500	959	270
SB Left Turn	71	93	73	127	40
SB Through	769	3137	955	1661	269
Pontiac Lake East Road					
EB Left Turn	96	98	88	162	37
EB Through	1254	1099	1498	926	1541
WB Left Turn	24	16	17	27	6
WB Through	2011	7936	3537	6383	840
NB Left Turn	306	287	395	576	335
NB Through	1106	1582	565	1736	470
SB Left Turn	96	210	98	108	68
SB Through	1516	4376	1632	3299	590

Table 19. SCATS System Number of Stopped Vehicles Data

Intersection by Approach and Movement	Number of Stopped Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Pontiac Lake West Road					
EB Left Turn	48	38	42	37	14
EB Through	441	411	877	584	459
WB Left Turn	3	1	9	3	0
WB Through	220	393	891	415	476
NB Left Turn	131	345	113	283	42
NB Through	14	139	376	99	13
SB Left Turn	4	6	2	11	2
SB Through	80	59	71	38	117
Williams Lake Road					
EB Left Turn	101	218	99	151	140
EB Through	1195	1357	1330	1596	1143
WB Left Turn	24	23	24	27	15
WB Through	1101	2101	1183	2290	1633
NB Left Turn	195	239	215	319	196
NB Through	497	1011	622	1095	730
SB Left Turn	93	128	94	107	113
SB Through	283	772	404	1162	1213
Oakland Boulevard					
EB Left Turn	57	49	52	71	13
EB Through	224	331	263	316	112
WB Left Turn	63	52	43	63	50
WB Through	144	92	156	206	91
NB Left Turn	6	121	16	24	10
NB Through	24	113	61	90	74
SB Left Turn	3	18	50	28	15
SB Through	354	436	92	114	148

Table 19. SCATS System Number of Stopped Vehicles Data (continued)

Intersection by Approach and Movement	Number of Stopped Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Airport Road					
EB Left Turn	455	384	351	468	179
EB Through	2053	1757	1334	1593	1001
WB Left Turn	81	98	82	120	40
WB Through	2177	3783	2590	4642	1367
NB Left Turn	340	792	251	571	132
NB Through	1049	2354	1217	1912	712
SB Left Turn	52	55	81	79	45
SB Through	1149	1463	954	2452	605
Crescent Lake Road					
EB Left Turn	176	396	209	521	170
EB Through	1705	1387	1575	1826	1004
WB Left Turn	164	115	129	154	63
WB Through	2165	4510	1816	5008	1258
NB Left Turn	152	200	161	184	65
NB Through	779	2208	789	2860	421
SB Left Turn	81	99	75	119	52
SB Through	987	1792	1624	5396	576
Pontiac Lake East Road					
EB Left Turn	80	102	120	121	62
EB Through	1509	2038	2443	2673	907
WB Left Turn	21	27	25	20	22
WB Through	2234	6073	2056	5269	1702
NB Left Turn	365	300	418	459	233
NB Through	806	982	1362	2433	834
SB Left Turn	68	184	94	183	56
SB Through	1461	3103	1479	4676	774

Queue Length

The maximum queue length for each approach's movement for each intersection along M-59 was collected for a typical weekday and Friday for the noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak periods, as well for a Saturday morning peak (9 AM to 11 AM). The queue length was collected every 15 seconds for each critical lane group, left turn and through movements, to determine the extent of the overflow of vehicles at the intersection. Any vehicle stopped or traveling less than five miles per hour was considered a part of the queue. Due to variation in traffic volumes during a peak period, at least a 60 minute time period was recorded for each approach.

The maximum queue length collected by signal system, peak period and direction of travel for the MDOT pre-timed system data is documented in Table 20, and for the SCATS system data in Table 21.

Table 20. MDOT Pre-timed System Maximum Queue Length Data

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Pontiac Lake West Road					
EB Left Turn	5	5	6	11	3
EB Through	26	25	15	22	13
WB Left Turn	9	12	9	18	6
WB Through	7	14	16	14	8
NB Left Turn	2	2	2	2	1
NB Through	6	4	10	22	2
SB Left Turn	0	1	6	1	1
SB Through	3	2	9	8	5
Williams Lake Road					
EB Left Turn	8	9	7	7	7
EB Through	20	32	14	32	18
WB Left Turn	3	2	3	3	3
WB Through	22	32	38	28	18
NB Left Turn	10	19	15	26	12
NB Through	8	12	23	22	8
SB Left Turn	5	6	8	5	3
SB Through	14	29	10	35	16

Table 20. MDOT Pre-timed System Maximum Queue Length Data (continued)

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Oakland Boulevard					
EB Left Turn	9	4	5	5	3
EB Through	29	33	26	26	27
WB Left Turn	5	4	4	5	4
WB Through	22	35	20	27	20
NB Left Turn	2	3	4	4	3
NB Through	6	5	5	7	3
SB Left Turn	4	5	4	4	4
SB Through	8	6	4	5	12
Airport Road					
EB Left Turn	14	16	14	15	9
EB Through	28	48	31	36	25
WB Left Turn	10	4	5	8	4
WB Through	18	52	19	28	28
NB Left Turn	20	16	20	23	6
NB Through	14	31	16	37	10
SB Left Turn	5	5	3	6	6
SB Through	17	31	15	123	12
Crescent Lake Road					
EB Left Turn	9	17	14	22	10
EB Through	39	29	20	11	20
WB Left Turn	7	11	5	11	3
WB Through	39	67	40	92	28
NB Left Turn	8	11	7	16	6
NB Through	13	5	8	14	8
SB Left Turn	5	7	6	8	4
SB Through	17	30	14	22	7

Table 20. MDOT Pre-timed System Maximum Queue Length Data (continued)

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Pontiac Lake East Road					
EB Left Turn	9	5	4	7	6
EB Through	21	33	26	23	20
WB Left Turn	2	2	4	4	1
WB Through	35	67	35	49	18
NB Left Turn	15	14	16	25	17
NB Through	16	20	11	21	10
SB Left Turn	7	11	7	8	5
SB Through	18	32	20	29	13

Table 21. SCATS System Maximum Queue Length Data

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Pontiac Lake West Road					
EB Left Turn	4	3	3	3	2
EB Through	19	13	18	15	12
WB Left Turn	1	1	1	1	0
WB Through	12	20	20	18	21
NB Left Turn	8	14	7	13	4
NB Through	3	4	12	3	1
SB Left Turn	1	1	1	8	2
SB Through	5	8	2	2	5

Table 21. SCATS System Maximum Queue Length Data (continued)

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Williams Lake Road					
EB Left Turn	6	16	6	17	7
EB Through	26	38	36	34	19
WB Left Turn	3	2	4	2	2
WB Through	21	31	21	33	30
NB Left Turn	11	17	18	24	10
NB Through	12	17	16	22	14
SB Left Turn	9	9	8	11	8
SB Through	8	14	11	18	13
Oakland Boulevard					
EB Left Turn	3	4	5	5	2
EB Through	10	16	12	15	10
WB Left Turn	4	4	3	5	30
WB Through	12	11	11	14	12
NB Left Turn	2	2	3	3	2
NB Through	1	4	3	4	3
SB Left Turn	1	3	10	3	2
SB Through	7	7	4	4	3
Airport Road					
EB Left Turn	21	22	28	29	8
EB Through	30	32	27	35	25
WB Left Turn	7	6	5	7	4
WB Through	34	48	39	51	26
NB Left Turn	14	24	12	27	10
NB Through	14	30	19	22	11
SB Left Turn	4	4	7	5	2
SB Through	19	23	19	38	15

Table 21. SCATS System Maximum Queue Length Data (continued)

Intersection by Approach and Movement	Maximum Queue Length in Vehicles During Peak Period				
	Weekday Noon Peak Period	Weekday PM Peak Period	Friday Noon Peak Period	Friday PM Peak Period	Saturday Peak Period
Crescent Lake Road					
EB Left Turn	12	14	13	21	10
EB Through	32	34	25	30	20
WB Left Turn	9	7	9	9	6
WB Through	31	42	27	44	29
NB Left Turn	8	10	9	9	5
NB Through	13	32	14	33	9
SB Left Turn	9	7	9	5	4
SB Through	14	21	27	41	13
Pontiac Lake East Road					
EB Left Turn	6	7	8	7	5
EB Through	33	41	36	35	23
WB Left Turn	2	2	4	2	4
WB Through	29	46	43	64	110
NB Left Turn	16	15	18	19	16
NB Through	13	14	19	28	15
SB Left Turn	8	11	6	13	4
SB Through	21	36	20	44	16

TRAFFIC OPERATIONAL DATA STATISTICAL ANALYSIS

The statistical significance of the effectiveness of the two signal systems (SCATS and the MDOT pre-timed system) were examined to determine whether the changes observed in the measures of effectiveness were attributable to the signal system or chance.

The dependant variable for the statistical tests was the measure of effectiveness while the independent variable was the type of signal system. The dependant variables were considered continuous data or data assuming a range of numerical values. The independent variable was considered discrete and categorical data described by the data belonging to only one group; SCATS or the MDOT pre-timed system.

Statistical tests were conducted to determine the effectiveness of the signal systems for each dependant variable. Due to the assumptions associated with the various statistical tests, the normality of the data and the homogeneity of the variances were examined for each dependant variable.

The statistical analysis is detailed in the following sections, respectively, for each measure of effectiveness including the following:

- Travel time for the corridor
- Travel speed for the corridor
- Travel time total delay for the corridor
- Fuel consumption
- Hydrocarbon, carbon monoxide and nitrogen oxide emissions
- Number of stops along the corridor
- Number of vehicles stopped at the intersections for the corridor and side streets
- Maximum queue length at the intersections for the corridor and side streets

Travel Time Analysis

The travel time data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The mean travel times for each direction of travel as well as for the overall travel are shown graphically in Figures 2 through 4.

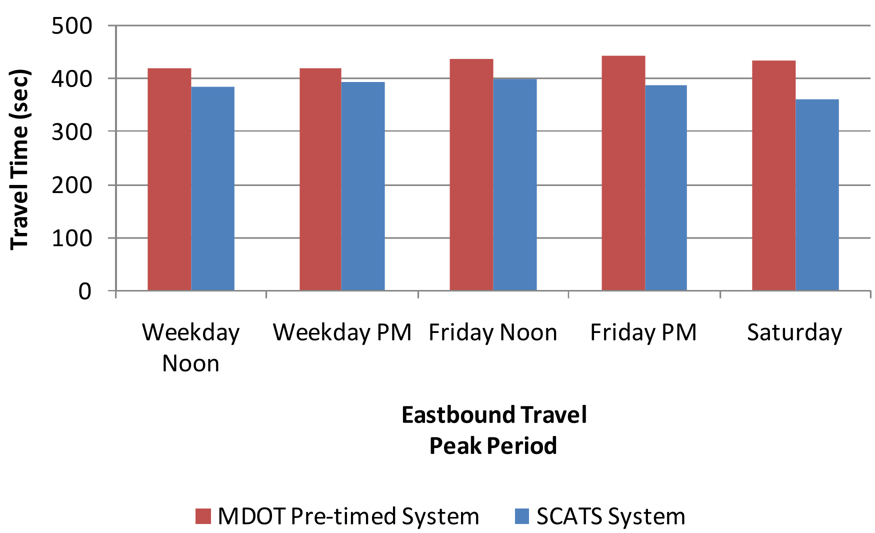

Figure 2. Eastbound Mean Travel Time By Peak Period

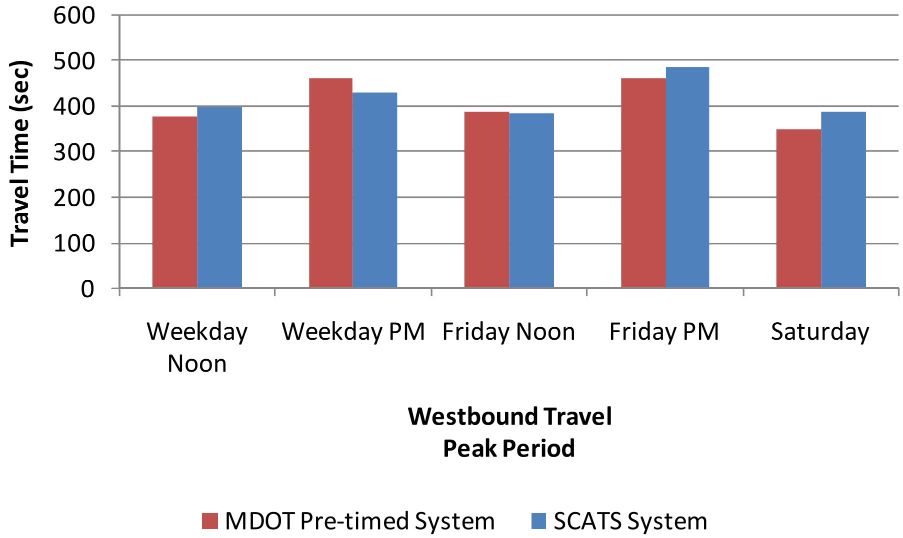

Figure 3. Westbound Mean Travel Time By Peak Period

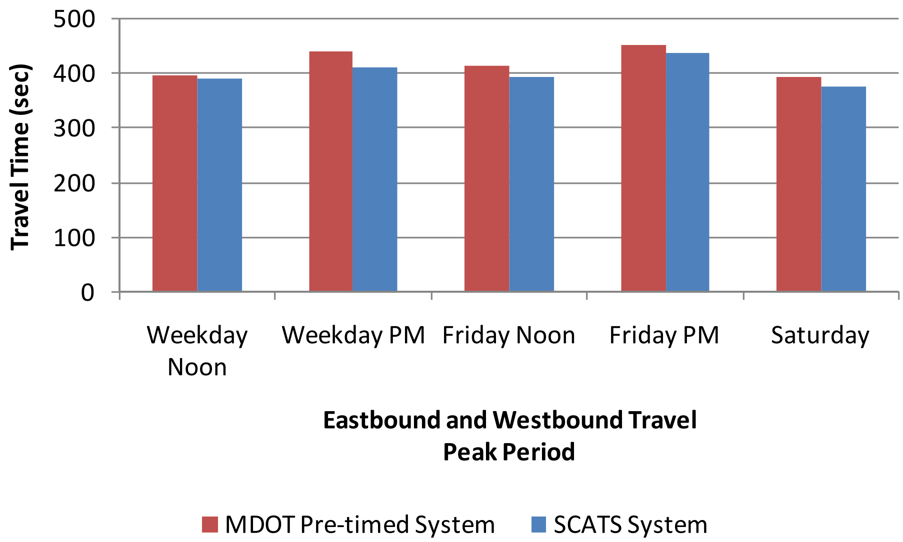

Figure 4. Overall Mean Travel Time By Peak Period

Statistical data calculated, including the mean travel time, standard deviation, are shown in Table 22. A negative value for the percent difference in mean travel time indicates that the travel time in the MDOT pre-timed system was faster than that in the SCATS system. A positive value for the percent difference in mean travel time indicates that the travel time in the SCATS system was faster than that in the MDOT pre-timed system.

Table 22. Travel Time Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Mean Travel Time
	Mean Travel Time (sec)	Standard Deviation	Mean Travel Time (sec)	Standard Deviation	
Weekday Noon Peak					
Eastbound	420.25	36.62	385.5	36.21	8.27%
Westbound	377.75	53.40	398.87	30.05	-5.59%
Total	399.00	49.76	392.41	33.27	1.65%
Weekday PM Peak					
Eastbound	421.92	48.70	395.67	38.07	6.22%
Westbound	463.42	41.70	431.79	42.88	6.83%
Total	442.67	49.15	413.10	43.77	6.68%
Friday Noon Peak					
Eastbound	438.75	17.15	402.00	37.62	8.38%
Westbound	390.77	32.94	386.4	36.05	1.12%
Total	413.80	35.72	394.20	35.70	4.74%
Friday PM Peak					
Eastbound	444.80	49.31	388.56	42.48	12.64%
Westbound	462.67	47.85	488.75	79.47	-5.64%
Total	453.81	49.27	438.66	80.74	3.34%
Saturday Peak					
Eastbound	435.64	66.63	362.27	45.69	16.84%
Westbound	351.64	37.29	389.82	34.87	-10.86%
Total	393.64	68.00	376.05	42.09	4.47

The travel time data was analyzed for adherence to the assumption of normality for use in the Student's t-test for determining if the difference in mean travel time is significant. As the number of tests performed upon one data set reduces the power and robustness of each test, the analysis for normality was conducted by reviewing the histogram and a normal probability plot for each data set. A review of the travel time data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis.

An analysis of variance (ANOVA) test can also be conducted on the travel time data to determine if the difference in the mean travel times between the SCATS and the MDOT pre-timed system are significantly different. One advantage the ANOVA has over the Student's t-test is the ability to compare several means simultaneously without reducing the power and the robustness of the test.

The assumptions for the ANOVA are similar to those of the Student's t-test; however, the ANOVA is considered a very robust test even with the violation of normality.

The ANOVA was used to determine if the travel time for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound travel time by peak period
- Westbound travel time by peak period
- Total travel time (combined eastbound and westbound travel times) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the travel time data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the mean travel time between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 23.

Table 23. Travel Time Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-34.75	14.33	-91.61	22.11	SCATS=Pre-timed (0.642)
Eastbound Weekday PM Peak	-26.25	17.15	-95.33	42.83	SCATS= Pre-timed (0.985)
Eastbound Friday Noon Peak	-36.75	17.54	-141.55	68.05	SCATS= Pre-timed (0.784)
Eastbound Friday PM Peak	-56.24	18.87	-134.12	21.64	SCATS= Pre-timed (0.335)
Eastbound Saturday Peak	-73.36	24.36	-173.40	26.67	SCATS= Pre-timed (0.319)
Westbound Weekday Noon Peak	21.12	17.26	-50.53	92.76	SCATS= Pre-timed (0.998)
Westbound Weekday PM Peak	-31.63	16.62	-97.49	34.23	SCATS= Pre-timed (0.910)
Westbound Friday Noon Peak	-4.37	18.53	-99.49	90.75	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	26.08	24.20	-69.20	121.37	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	38.18	15.39	-24.04	100.40	SCATS= Pre-timed (0.608)
Total Weekday Noon Peak	-6.59	11.89	-46.46	33.28	SCATS= Pre-timed (1.000)
Total Weekday PM Peak	-29.56	12.91	-72.44	13.32	SCATS= Pre-timed (0.414)
Total Friday Noon Peak	-19.60	13.36	-67.98	28.78	SCATS= Pre-timed (0.887)
Total Friday PM Peak	-15.15	17.87	-74.27	43.96	SCATS= Pre-timed (0.997)
Total Saturday Peak	-17.59	17.05	-75.13	39.95	SCATS= Pre-timed (0.988)

Travel Speed Analysis

The travel speed data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The mean travel speeds for each direction of travel as well as for the overall travel are shown graphically in Figures 5 through 7.

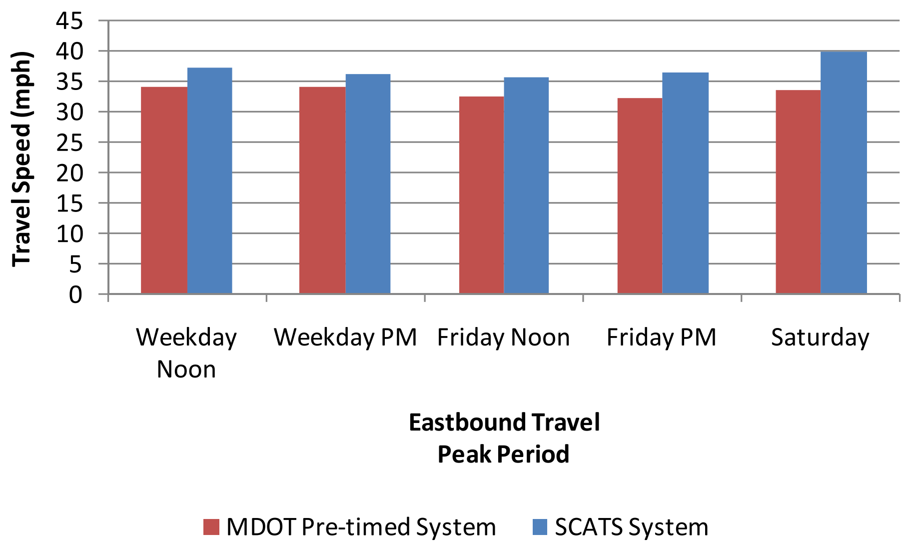

Figure 5. Eastbound Mean Travel Speed By Peak Period

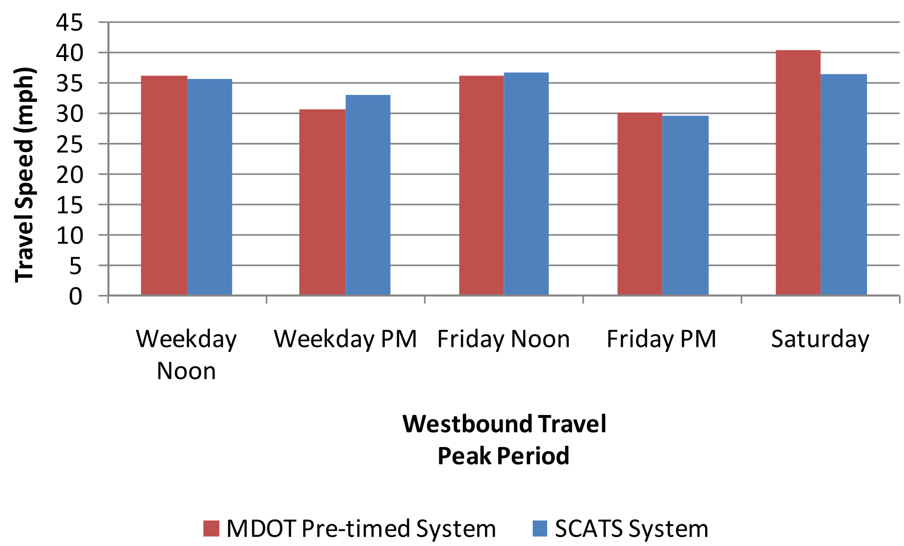

Figure 6. Westbound Mean Travel Speed By Peak Period

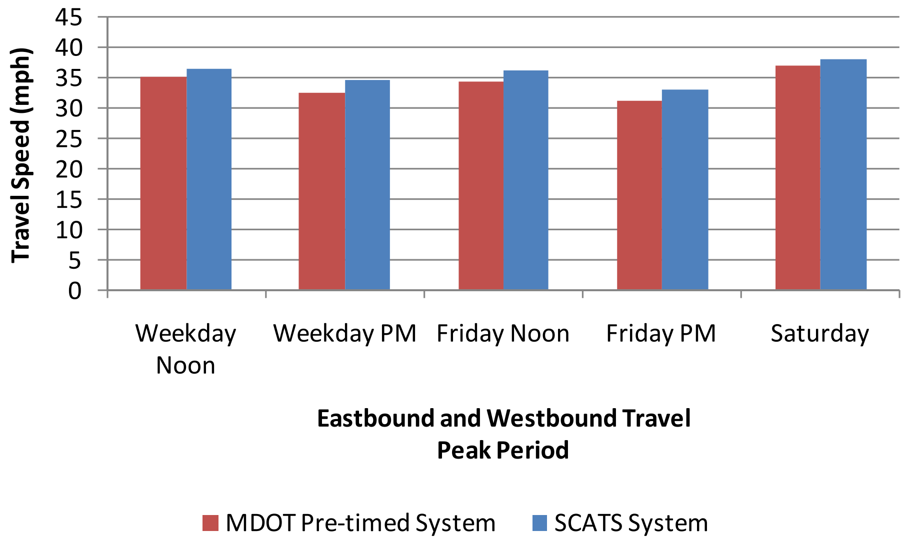

Figure 7. Overall Mean Travel Speed By Peak Period

Statistical data calculated, including the mean travel speed, standard deviation, and the percent difference in mean travel speed, are shown in Table 24. A positive value for the percent difference in mean travel speed indicates that the travel speed in the MDOT pre-timed system was faster than that in the SCATS system. A negative value for the percent difference in mean travel speed indicates that the travel speed in the SCATS system was faster than that in the MDOT pre-timed system.

Table 24. Travel Speed Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Mean Travel Speed
	Mean Travel Speed (sec)	Standard Deviation	Mean Travel Speed (sec)	Standard Deviation	
Weekday Noon Peak					
Eastbound	34.19	3.33	37.34	3.44	-9.21%
Westbound	36.29	3.27	35.75	2.77	1.49%
Total	35.24	3.40	36.52	3.16	-3.63%
Weekday PM Peak					
Eastbound	34.25	4.51	36.31	3.63	-6.01%
Westbound	30.78	2.84	33.12	3.75	-7.60%
Total	32.51	4.09	34.77	3.97	-6.95%

Table 24. Travel Speed Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Mean Travel Speed
	Mean Travel Speed (sec)	Standard Deviation	Mean Travel Speed (sec)	Standard Deviation	
Friday Noon Peak					
Eastbound	32.56	1.29	35.70	3.37	-9.64%
Westbound	36.34	2.99	36.82	3.82	-1.32%
Total	34.52	2.99	36.26	3.45	-5.04%
Friday PM Peak					
Eastbound	32.49	3.62	36.48	3.64	-12.28%
Westbound	30.18	2.89	29.67	4.92	1.69%
Total	31.23	3.37	33.07	5.48	-5.89%
Saturday Peak					
Eastbound	33.70	4.78	39.89	3.49	-18.37%
Westbound	40.53	4.06	36.64	3.56	9.60%
Total	37.11	5.56	38.26	4.44	-3.10%

A review of the travel speed data indicates that the data was not normally distributed and therefore the Student's t-test cannot be conducted while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the travel speeds for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound travel speed by peak period
- Westbound travel speed by peak period
- Total travel speed (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the travel speed data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the mean travel speed between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 25.

Table 25. Travel Speed Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	3.15	1.33	-2.12	8.42	SCATS= Pre-timed (0.675)
Eastbound Weekday PM Peak	2.06	1.60	-4.38	8.51	SCATS= Pre-timed (0.998)
Eastbound Friday Noon Peak	3.14	1.55	-6.37	12.65	SCATS= Pre-timed (0.811)
Eastbound Friday PM Peak	3.99	1.46	-1.95	9.92	SCATS= Pre-timed (0.462)
Eastbound Saturday Peak	6.19	2.04	-2.05	14.43	SCATS= Pre-timed (0.300)
Westbound Weekday Noon Peak	-0.54	1.18	-5.27	4.20	SCATS= Pre-timed (1.000)
Westbound Weekday PM Peak	2.35	1.29	-2.78	7.47	SCATS= Pre-timed (0.937)
Westbound Friday Noon Peak	0.48	1.90	-9.71	10.67	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	-0.51	1.49	-6.36	5.35	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	-3.89	1.62	-10.48	2.70	SCATS= Pre-timed (0.662)

Table 25. Travel Speed Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Total Weekday Noon Peak	1.27	0.91	-1.73	4.29	SCATS= Pre-timed (0.919)
Total Weekday PM Peak	2.26	1.11	-1.43	5.95	SCATS= Pre-timed (0.584)
Total Friday Noon Peak	1.74	1.24	-2.85	6.32	SCATS= Pre-timed (0.911)
Total Friday PM Peak	1.84	1.21	-2.15	5.83	SCATS= Pre-timed (0.874)
Total Saturday Peak	1.15	1.52	-3.93	6.23	SCATS= Pre-timed (0.999)

Fuel Consumption Analysis

The gallons of fuel consumed along the corridor was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The average gallons of fuel consumed for each direction of travel as well as for the overall travel are shown graphically in Figures 8 through 10.

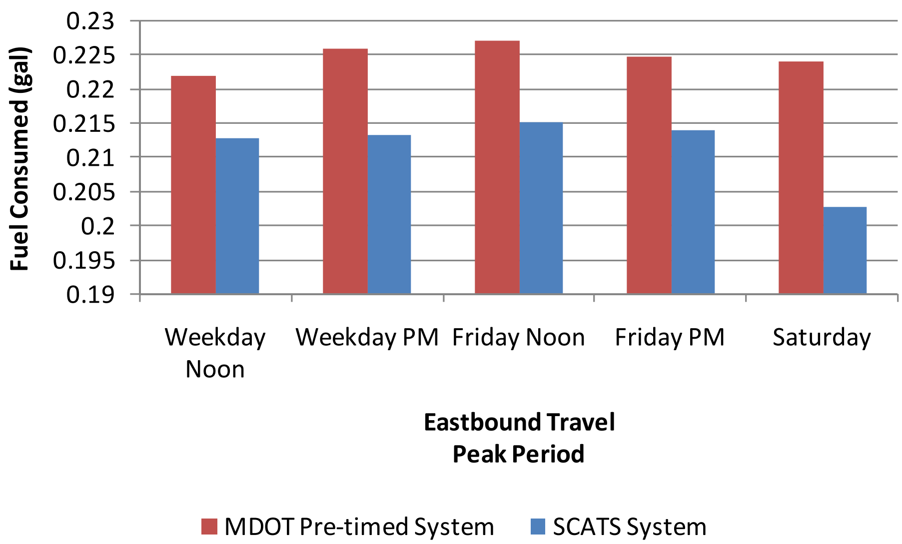

Figure 8. Eastbound Fuel Consumption By Peak Period

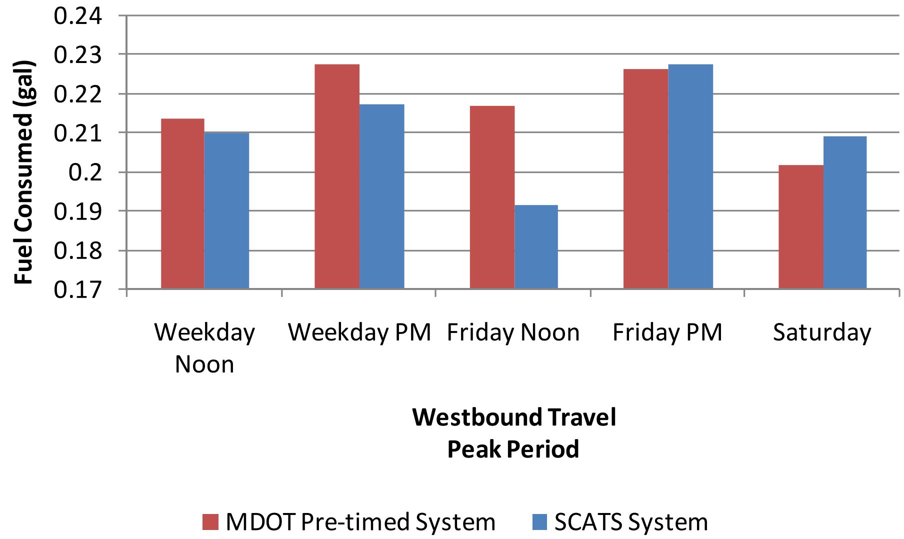

Figure 9. Westbound Fuel Consumption By Peak Period

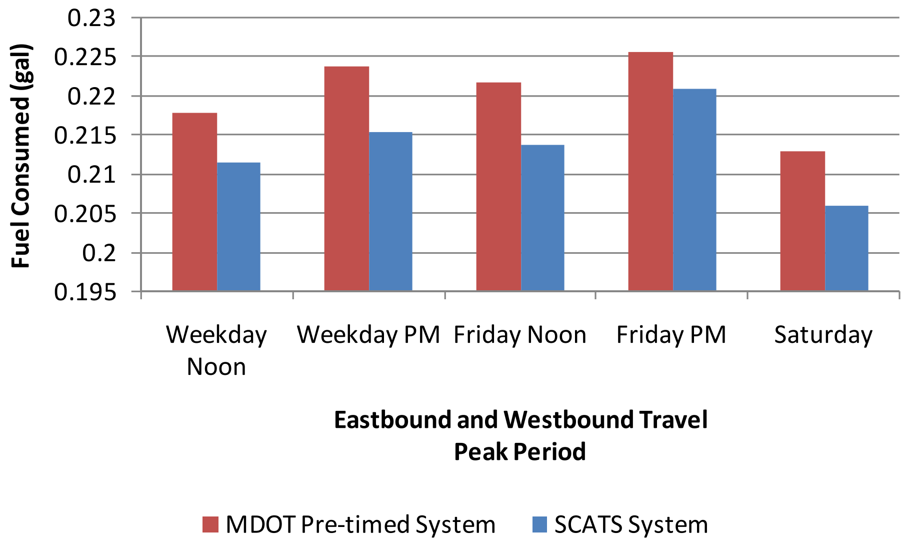

Figure 10. Overall Fuel Consumption By Peak Period

Statistical data calculated, including the average fuel consumption, standard deviation, and the percent difference in average fuel consumed, are shown in Table 26. A negative value for the percent difference in the average fuel consumed indicates that the fuel consumed in the MDOT pre-timed system was lower than that in the SCATS system. A positive value for the percent difference in the average fuel consumed indicates that fuel consumed in the SCATS system was lower than that in the MDOT pre-timed system.

Table 26. Fuel Consumption Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Average Fuel Consumed
	Average Fuel Consumed	Standard Deviation	Average Fuel Consumed	Standard Deviation	
Weekday Noon Peak					
Eastbound	0.2220	0.0040	0.2129	0.0158	4.10%
Westbound	0.2139	0.0215	0.2103	0.0109	1.68%
Total	0.2180	0.0157	0.2115	0.1329	2.98%
Weekday PM Peak					
Eastbound	0.2260	0.1239	0.2134	0.0142	5.58%
Westbound	0.2278	0.0089	0.2175	0.0093	4.52%
Total	0.2269	0.0106	0.2154	0.0121	5.07%
Friday Noon Peak					
Eastbound	0.2271	0.0103	0.2152	0.0145	5.24%
Westbound	0.2172	0.0137	0.2126	0.0167	2.12%
Total	0.2220	0.0130	0.2139	0.0148	3.65%
Friday PM Peak					
Eastbound	0.2249	0.0108	0.2140	0.0153	4.85%
Westbound	0.2263	0.0080	0.2279	0.0184	-0.71%
Total	0.2256	0.0092	0.2209	0.0181	2.08%
Saturday Peak					
Eastbound	0.2242	0.0149	0.2028	0.01037	9.55%
Westbound	0.2020	0.1684	0.2093	0.0179	-3.61%
Total	0.2131	0.0193	0.2060	0.0146	3.33%

A review of the fuel consumption data indicates that the data was not normally distributed and therefore the Student's t-test cannot be conducted while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the fuel consumed under the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound fuel consumed by peak period
- Westbound fuel consumed by peak period
- Total fuel consumed (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the fuel consumption data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the average fuel consumed between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for all of the directional comparisons between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the directional peak periods analyzed. However, when the eastbound and westbound fuel consumed data is combined for the weekday PM peak period, a significant result is found. This significance is due to the differences between the eastbound and westbound data and not due to the difference in the SCATS versus the MDOT pre-timed signal systems. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 27.

Table 27. Fuel Consumption Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-0.009	0.004	-0.027	0.009	SCATS= Pre-timed (0.831)
Eastbound Weekday PM Peak	-0.125	0.005	-0.033	0.008	SCATS= Pre-timed (0.630)
Eastbound Friday Noon Peak	-0.119	0.007	-0.051	0.027	SCATS= Pre-timed (0.934)

Table 27. Fuel Consumption Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Friday PM Peak	-0.011	0.005	-0.313	0.010	SCATS= Pre-timed (0.821)
Eastbound Saturday Peak	-0.021	0.005	-0.044	0.001	SCATS= Pre-timed (0.074)
Westbound Weekday Noon Peak	-0.003	0.007	-0.032	0.025	SCATS= Pre-timed (1.000)
Westbound Weekday PM Peak	-0.010	0.004	-0.024	0.004	SCATS= Pre-timed (0.377)
Westbound Friday Noon Peak	-0.005	0.008	-0.049	0.040	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	0.002	0.005	-0.189	0.022	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	0.007	0.007	-0.227	0.037	SCATS= Pre-timed (1.000)
Total Weekday Noon Peak	-0.006	0.004	-0.198	0.007	SCATS= Pre-timed (0.850)
Total Weekday PM Peak	-0.011	0.003	-0.022	-0.001	**Reject Null**; SCATS≠Pre-timed (0.019)
Total Friday Noon Peak	-0.008	0.005	-0.028	0.012	SCATS= Pre-timed (0.873)
Total Friday PM Peak	-0.005	0.004	-0.017	0.008	SCATS= Pre-timed (0.959)
Total Saturday Peak	-0.007	0.005	-0.243	0.010	SCATS= Pre-timed (0.930)

Hydrocarbon Emissions Analysis

The grams of hydrocarbon emissions along the corridor data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The average grams of hydrocarbons emitted for each direction of travel as well as for the overall travel are shown graphically in Figures 11 through 13.

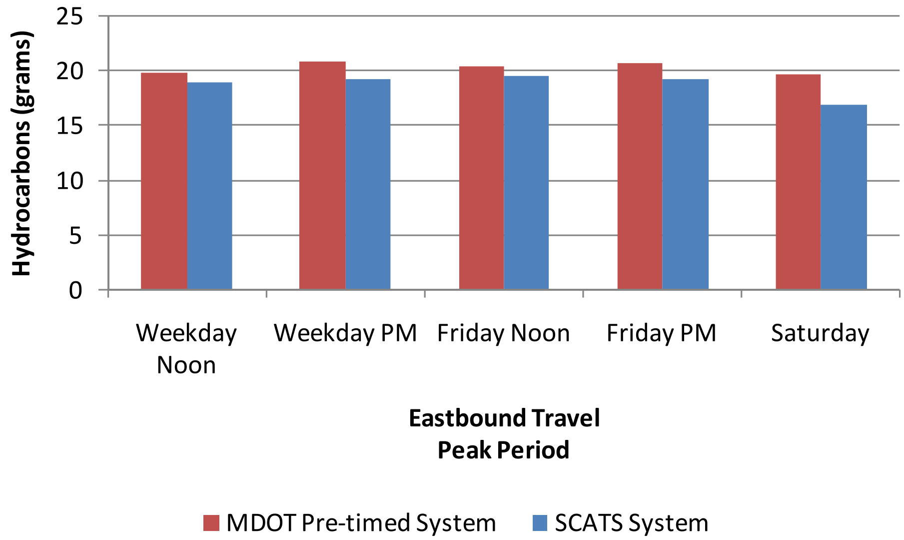

Figure 11. Eastbound Emission of Hydrocarbons By Peak Period

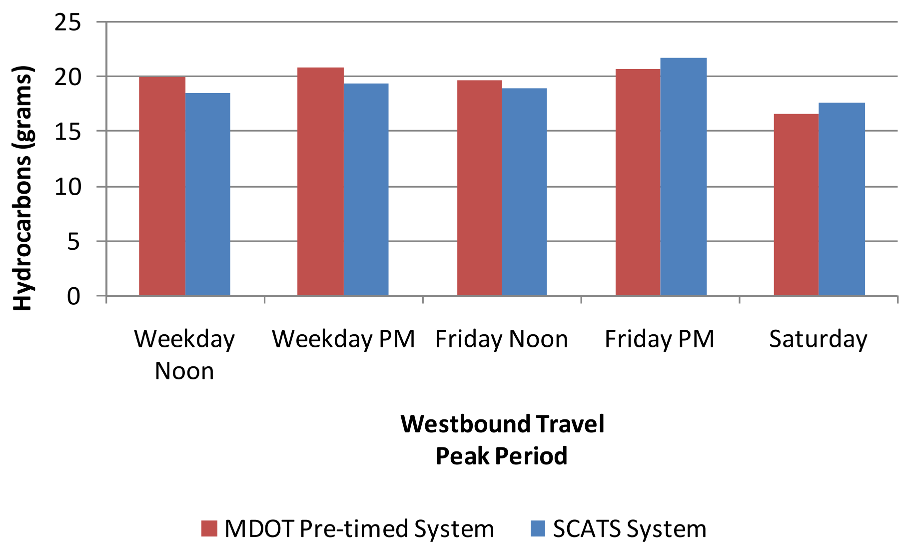

Figure 12. Westbound Emission of Hydrocarbons By Peak Period

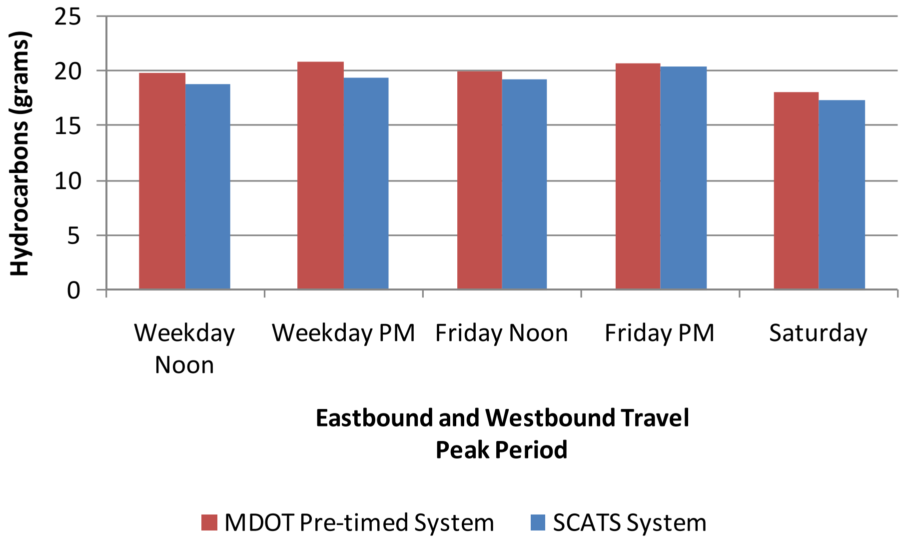

Figure 13. Overall Emission of Hydrocarbons By Peak Period

Statistical data calculated, including the average grams of hydrocarbon emissions, standard deviation, and the percent difference, are shown in Table 28. A negative value for the percent difference in the average grams of hydrocarbon emissions indicates that the hydrocarbons emitted in the MDOT pre-timed system was lower than that in the SCATS system. A positive value for the percent difference in the average grams of hydrocarbon emissions indicates that the hydrocarbons emitted in the SCATS system was lower than that in the MDOT pre-timed system.

Table 28. Hydrocarbon Emissions Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in HC Emissions
	HC Emissions (grams)	Standard Deviation	HC Emissions (grams)	Standard Deviation	
Weekday Noon Peak					
Eastbound	19.85	1.78	19.07	2.44	3.93%
Westbound	20.03	2.37	18.58	1.98	7.24%
Total	19.94	2.05	18.82	2.19	5.62%
Weekday PM Peak					
Eastbound	20.97	2.49	19.34	2.64	7.77%
Westbound	20.96	1.61	19.42	1.58	7.35%
Total	20.96	2.04	19.38	2.15	7.54%

Table 28. Hydrocarbon Emissions Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in HC Emissions
	HC Emissions (grams)	Standard Deviation	HC Emissions (grams)	Standard Deviation	
Friday Noon Peak					
Eastbound	20.40	1.25	19.61	1.87	3.87%
Westbound	19.73	2.46	18.95	3.47	3.95%
Total	20.05	1.96	19.28	2.65	3.84%
Friday PM Peak					
Eastbound	20.80	2.12	19.36	2.23	6.92%
Westbound	20.75	2.06	21.72	2.99	-4.67%
Total	20.77	20.4	20.54	2.86	1.11%
Saturday Peak					
Eastbound	19.68	2.45	16.97	1.75	13.77%
Westbound	16.68	2.89	17.68	3.19	-6.00%
Total	18.18	3.03	17.33	2.54	4.68%

A review of the hydrocarbon emissions data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the hydrocarbon emissions for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound hydrocarbons emitted by peak period
- Westbound hydrocarbons emitted by peak period
- Total hydrocarbons emitted (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the number of stops data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the average grams of hydrocarbon emitted between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 29.

Table 29. Hydrocarbon Emissions Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-0.774	0.832	-4.07	2.52	SCATS= Pre-timed (1.000)
Eastbound Weekday PM Peak	-1.63	0.990	-5.54	2.28	SCATS= Pre-timed (0.973)
Eastbound Friday Noon Peak	-0.777	0.910	-5.81	4.26	SCATS= Pre-timed (1.000)
Eastbound Friday PM Peak	-1.44	0.871	-4.96	2.08	SCATS= Pre-timed (0.968)
Eastbound Saturday Peak	-2.70	0.908	-6.42	1.01	SCATS= Pre-timed (0.333)
Westbound Weekday Noon Peak	-1.45	0.854	-4.86	1.98	SCATS= Pre-timed (0.963)

Table 29. Hydrocarbon Emissions Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Westbound Weekday PM Peak	-1.54	0.628	-4.02	0.95	SCATS= Pre-timed (0.626)
Westbound Friday Noon Peak	-0.782	1.70	-10.13	8.56	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	0.973	0.955	-2.78	4.72	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	1.00	1.30	-4.25	6.25	SCATS= Pre-timed (1.000)
Total Weekday Noon Peak	-1.12	0.584	-3.05	0.815	SCATS= Pre-timed (0.660)
Total Weekday PM Peak	-1.58	0.579	-3.50	0.332	SCATS= Pre-timed (0.187)
Total Friday Noon Peak	-0.766	0.926	-4.24	2.71	SCATS= Pre-timed (0.996)
Total Friday PM Peak	-0.232	0.666	-2.43	1.97	SCATS= Pre-timed (1.000)
Total Saturday Peak	-0.852	0.843	-3.67	1.97	SCATS= Pre-timed (0.990)

Carbon Monoxide Stops Analysis

The grams of carbon monoxide emissions along the corridor data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The average grams of carbon monoxide emitted for each direction of travel as well as for the overall travel are shown graphically in Figures 14 through 16.

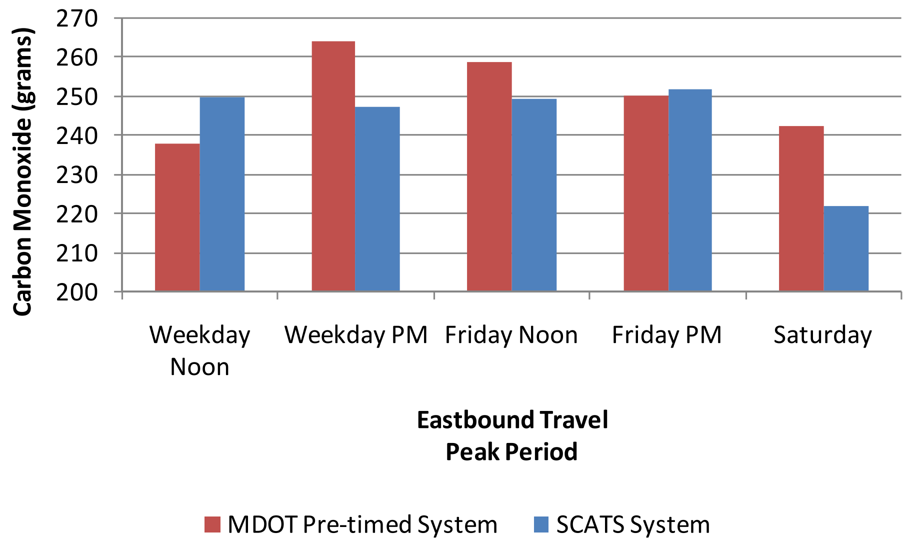

Figure 14. Eastbound Emission of Carbon Monoxide By Peak Period

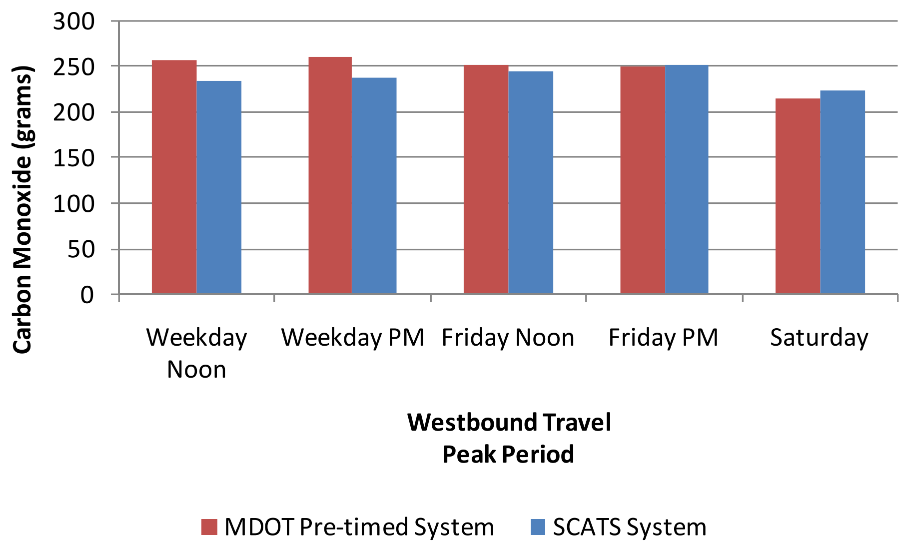

Figure 15. Westbound Emission of Carbon Monoxide By Peak Period

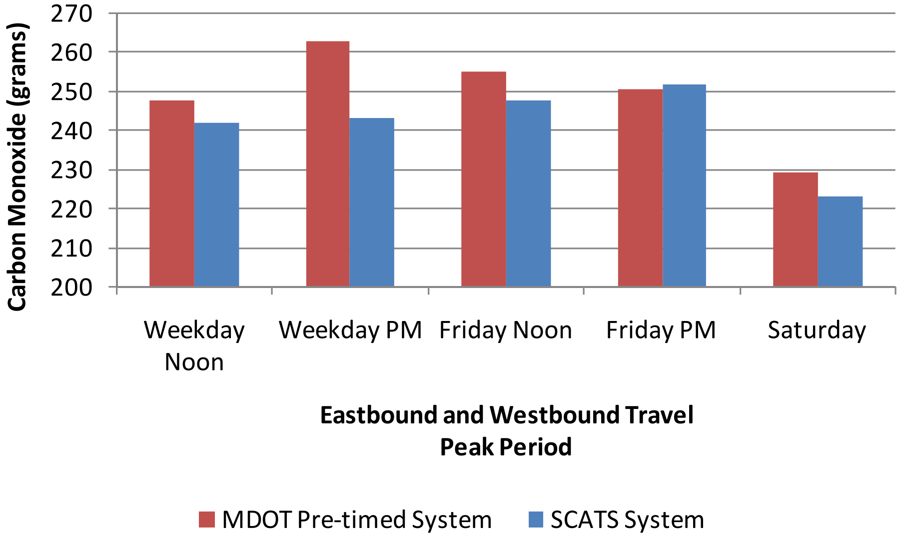

Figure 16. Overall Emission of Carbon Monoxide By Peak Period

Statistical data calculated, including the average grams of carbon monoxide emissions, standard deviation, and the percent difference, are shown in Table 30. A positive value for the percent difference in the average grams of carbon monoxide emissions indicates that the carbon monoxide emitted in the MDOT pre-timed system was lower than that in the SCATS system. A negative value for the percent difference in the average grams of carbon monoxide emissions indicates that the carbon monoxide emitted in the SCATS system was lower than that in the MDOT pre-timed system.

Table 30. Carbon Monoxide Emissions Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in CO Emissions
	CO Emissions (grams)	Standard Deviation	CO Emissions (grams)	Standard Deviation	
Weekday Noon Peak					
Eastbound	237.99	59.25	249.87	31.85	-4.99%
Westbound	257.54	30.58	235.28	25.93	8.64%
Total	247.77	47.18	242.33	29.37	2.20%
Weekday PM Peak					
Eastbound	264.21	27.31	247.66	32.84	6.26%
Westbound	261.62	19.55	238.95	20.90	8.67%
Total	262.91	23.27	243.46	27.60	7.40%

Table 30. Carbon Monoxide Emissions Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in CO Emissions
	CO Emissions (grams)	Standard Deviation	CO Emissions (grams)	Standard Deviation	
Friday Noon Peak					
Eastbound	258.82	29.92	249.66	32.02	3.54%
Westbound	252.16	37.49	245.76	49.61	2.54%
Total	255.36	33.13	247.71	39.42	3.00%
Friday PM Peak					
Eastbound	250.28	25.02	252.10	30.14	-0.73%
Westbound	251.22	22.42	251.78	26.35	-0.22%
Total	250.80	23.06	251.94	27.85	-0.45%
Saturday Peak					
Eastbound	242.77	27.62	222.09	28.68	8.52%
Westbound	216.56	36.62	224.37	44.62	-3.61%
Total	229.66	33.87	223.23	36.62	2.80%

A review of the carbon monoxide emissions data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the carbon monoxide emissions for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound carbon monoxide emitted by peak period
- Westbound carbon monoxide emitted by peak period
- Total carbon monoxide emitted (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the number of stops data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the average grams of carbon monoxide emitted between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 31.

Table 31. Carbon Monoxide Emissions Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	11.88	19.11	-67.57	91.32	SCATS= Pre-timed (1.000)
Eastbound Weekday PM Peak	-16.55	11.58	-62.16	29.07	SCATS= Pre-timed (0.993)
Eastbound Friday Noon Peak	-9.16	16.57	-93.63	75.03	SCATS= Pre-timed (1.000)
Eastbound Friday PM Peak	1.82	10.93	-41.84	45.48	SCATS= Pre-timed (1.000)
Eastbound Saturday Peak	-20.68	12.00	-69.19	27.83	SCATS= Pre-timed (0.955)
Westbound Weekday Noon Peak	-22.26	11.08	-66.59	22.06	SCATS= Pre-timed (0.867)

Table 31. Carbon Monoxide Emissions Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Westbound Weekday PM Peak	-22.67	7.94	-54.10	8.77	SCATS= Pre-timed (0.380)
Westbound Friday Noon Peak	-6.40	24.50	-139.12	126.32	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	0.564	9.24	-35.74	36.86	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	7.81	17.21	-62.16	77.79	SCATS= Pre-timed (1.000)
Total Weekday Noon Peak	-5.44	11.07	-42.67	31.78	SCATS= Pre-timed (1.00)
Total Weekday PM Peak	-19.46	6.99	-42.57	3.65	SCATS= Pre-timed (0.169)
Total Friday Noon Peak	-7.65	14.12	-59.87	44.57	SCATS= Pre-timed (1.000)
Total Friday PM Peak	1.15	6.96	-21.88	24.18	SCATS= Pre-timed (1.000)
Total Saturday Peak	-6.43	10.63	-41.95	29.09	SCATS= Pre-timed (1.000)

Nitrogen Oxides Emissions Analysis

The grams of nitrogen oxide emissions along the corridor data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The average grams of nitrogen oxide emitted for each direction of travel as well as for the overall travel are shown graphically in Figures 17 through 19.

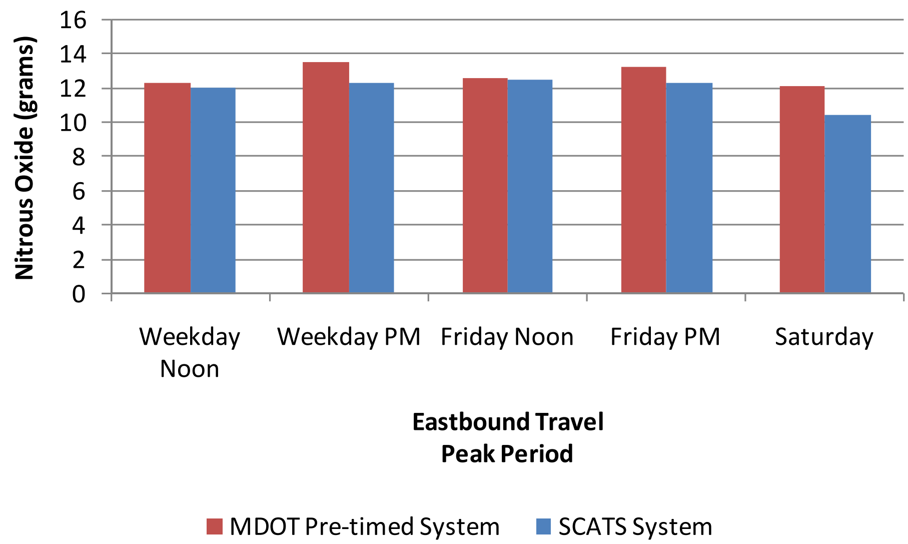

Figure 17. Eastbound Emission of Nitrogen Oxide By Peak Period

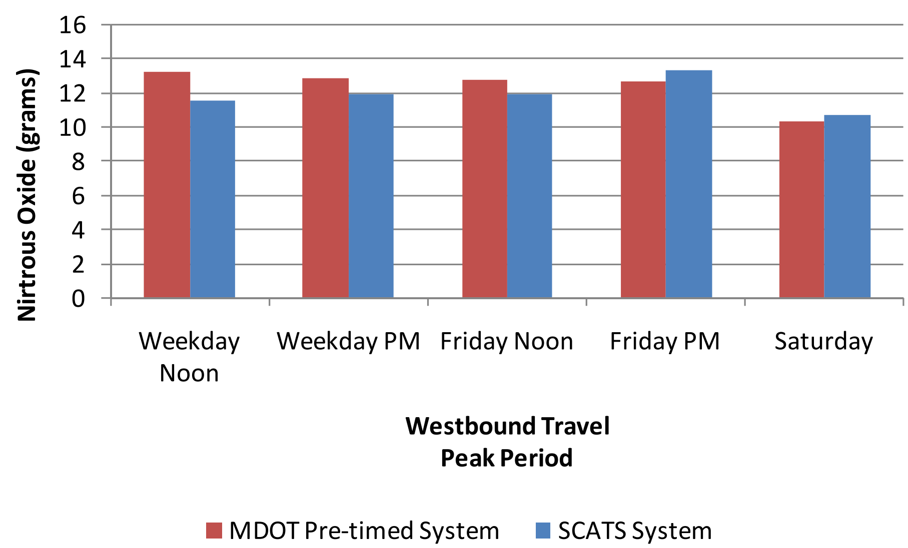

Figure 18. Westbound Emission of Nitrogen Oxide By Peak Period

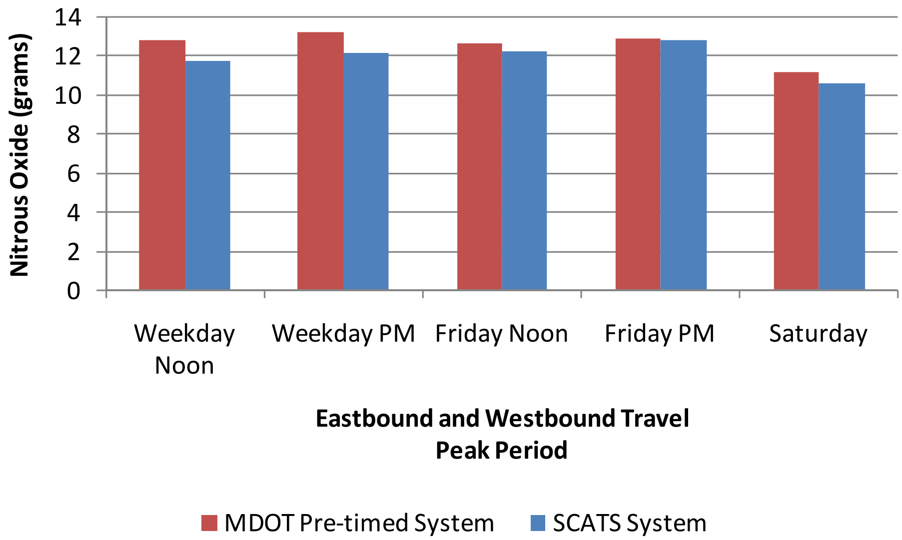

Figure 19. Overall Emission of Nitrogen Oxide By Peak Period

Statistical data calculated, including the average grams of nitrogen oxide emissions, standard deviation, and the percent difference, are shown in Table 32. A negative value for the percent difference in the average grams of nitrogen oxide emissions indicates that the nitrogen oxide emitted in the MDOT pre-timed system was lower than that in the SCATS system. A positive value for the percent difference in the average grams of nitrogen oxide emissions indicates that the nitrogen oxide emitted in the SCATS system was lower than that in the MDOT pre-timed system.

Table 32. Nitrogen Oxide Emissions Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in NOx Emissions
	NOx Emissions (grams)	Standard Deviation	NOx Emissions (grams)	Standard Deviation	
Weekday Noon Peak					
Eastbound	12.39	1.55	12.11	2.06	2.26%
Westbound	13.31	1.91	11.57	1.84	13.07%
Total	12.85	1.77	11.83	1.93	7.94%
Weekday PM Peak					
Eastbound	13.61	2.10	12.37	2.28	9.11%
Westbound	12.87	1.30	11.94	1.27	7.23%
Total	13.24	1.75	12.16	1.84	8.16%

Table 32. Nitrogen Oxide Emissions Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in NOx Emissions
	NOx Emissions (grams)	Standard Deviation	NOx Emissions (grams)	Standard Deviation	
Friday Noon Peak					
Eastbound	12.64	1.14	12.53	1.45	0.87%
Westbound	12.81	2.06	12.01	2.94	6.25%
Total	12.73	1.65	12.27	2.20	3.61%
Friday PM Peak					
Eastbound	13.30	2.00	12.39	1.83	6.84%
Westbound	12.69	1.67	13.38	1.86	-5.44%
Total	12.97	1.81	12.88	1.89	0.69%
Saturday Peak					
Eastbound	12.14	1.75	10.45	1.61	13.92%
Westbound	10.35	2.37	10.80	2.68	-4.35%
Total	11.24	2.23	10.63	2.16	5.43%

A review of the nitrogen oxide emissions data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the nitrogen oxide emissions for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound nitrogen oxide emitted by peak period
- Westbound nitrogen oxide emitted by peak period
- Total nitrogen oxide emitted (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the number of stops data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the average grams of nitrogen oxide emitted between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 33.

Table 33. Nitrogen Oxide Emissions Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-0.280	0.710	-3.09	2.53	SCATS= Pre-timed (1.000)
Eastbound Weekday PM Peak	-1.24	0.845	-4.57	2.09	SCATS= Pre-timed (0.991)
Eastbound Friday Noon Peak	-0.11	0.726	-3.96	3.74	SCATS= Pre-timed (1.000)
Eastbound Friday PM Peak	-1.22	0.760	-4.10	2.29	SCATS= Pre-timed (0.976)
Eastbound Saturday Peak	-1.69	0.715	-4.57	1.21	SCATS= Pre-timed (0.682)
Westbound Weekday Noon Peak	-1.73	0.728	-4.62	1.16	SCATS= Pre-timed (0.672)

Table 33. Nitrogen Oxide Emissions Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Westbound Weekday PM Peak	-0.928	0.506	-2.94	1.08	SCATS= Pre-timed (0.931)
Westbound Friday Noon Peak	-0.791	1.43	-8.71	7.12	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	0.686	0.670	-1.96	3.33	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	0.454	1.08	-3.91	4.82	SCATS= Pre-timed (1.000)
Total Weekday Noon Peak	-1.01	0.508	-2.70	0.669	SCATS= Pre-timed (0.607)
Total Weekday PM Peak	-1.08	0.495	-2.72	0.559	SCATS= Pre-timed (0.483)
Total Friday Noon Peak	-0.456	0.770	-3.34	2.43	SCATS= Pre-timed (1.000)
Total Friday PM Peak	-0.083	0.510	-1.78	1.61	SCATS= Pre-timed (1.000)
Total Saturday Peak	-0.615	0.662	-4.34	-0.329	SCATS= Pre-timed (0.994)

Number of Corridor Stops Analysis

The number of stops along the corridor data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The average number of stops for each direction of travel as well as for the overall travel is shown graphically in Figures 20 through 22.

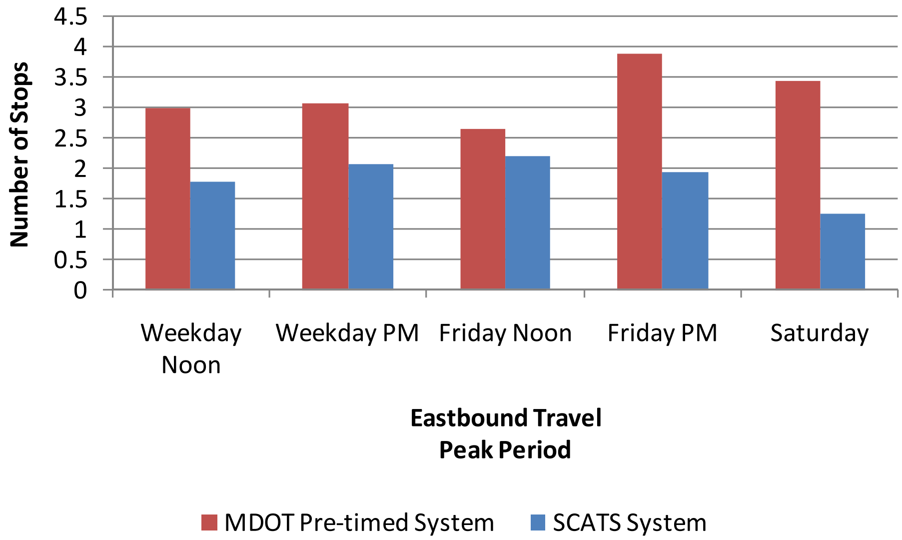

Figure 20. Eastbound Mean Number of Stops By Peak Period

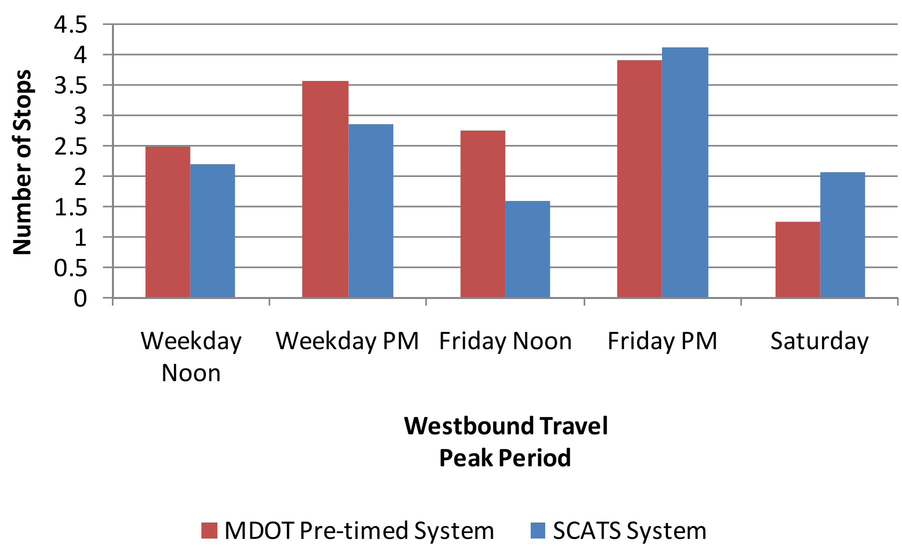

Figure 21. Westbound Mean Number of Stops By Peak Period

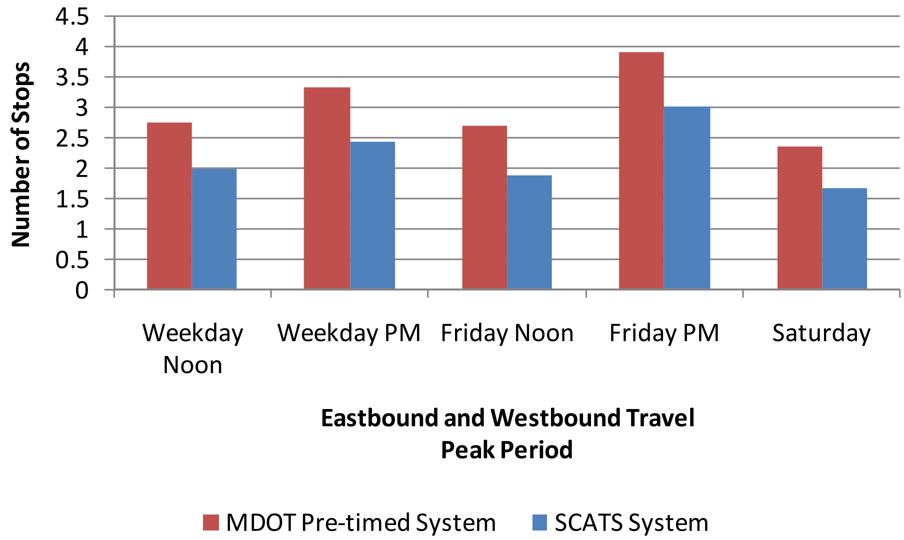

Figure 22. Overall Mean Number of Stops By Peak Period

Statistical data calculated, including the average number of stops, standard deviation, and the percent difference in average number of stops, are shown in Table 34. A negative value for the percent difference in the average number of stops indicates that the number of stops in the MDOT pre-timed system was lower than that in the SCATS system. A positive value for the percent difference in the average number of stops indicates that the number of stops in the SCATS system was lower than that in the MDOT pre-timed system.

Table 34. Number of Stops Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Average Number of Stops
	Average No. of Stops	Standard Deviation	Average No. of Stops	Standard Deviation	
Weekday Noon Peak					
Eastbound	3.00	1.04	1.78	1.53	40.67%
Westbound	2.50	0.52	2.20	0.94	12.00%
Total	2.75	0.85	2.00	1.25	27.27%
Weekday PM Peak					
Eastbound	3.08	1.31	2.07	1.03	32.79%
Westbound	3.58	1.44	2.86	1.03	20.11%
Total	3.33	1.37	2.45	1.09	26.43%

Table 34. Number of Stops Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Average Number of Stops
	Average No. of Stops	Standard Deviation	Average No. of Stops	Standard Deviation	
Friday Noon Peak					
Eastbound	2.67	0.78	2.20	0.84	17.60%
Westbound	2.77	0.73	1.60	1.14	42.24%
Total	2.72	0.74	1.90	0.99	30.15%
Friday PM Peak					
Eastbound	3.90	1.52	1.94	0.85	50.26%
Westbound	3.92	1.16	4.13	2.31	-5.36%
Total	3.91	1.31	3.03	2.04	22.51%
Saturday Peak					
Eastbound	3.45	2.02	1.27	1.01	63.19%
Westbound	1.27	1.10	2.09	0.94	-64.57%
Total	2.36	1.94	1.68	1.04	28.81%

A review of the number of stops data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the number of stops for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound number of stops by peak period
- Westbound number of stops by peak period
- Total number of stops (combined eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the number of stops data for the SCATS and the MDOT pre-timed system was as follows:

> H_o (null hypothesis): There was no difference between the average number of stops between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 35.

Table 35. Number of Stops Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-1.21	0.51	-3.23	0.80	SCATS= Pre-timed (0.662)
Eastbound Weekday PM Peak	-1.02	0.46	-2.88	0.85	SCATS= Pre-timed (0.775)
Eastbound Friday Noon Peak	-0.47	0.44	-2.67	1.74	SCATS= Pre-timed (0.999)
Eastbound Friday PM Peak	-1.96	0.53	-4.25	0.33	SCATS= Pre-timed (0.129)
Eastbound Saturday Peak	-2.18	0.68	-5.06	0.69	SCATS= Pre-timed (0.254)
Westbound Weekday Noon Peak	-0.30	0.29	-1.44	0.84	SCATS= Pre-timed (1.000)
Westbound Weekday PM Peak	-0.73	0.50	-2.75	1.30	SCATS= Pre-timed (0.990)
Westbound Friday Noon Peak	-1.17	0.55	-4.27	1.93	SCATS= Pre-timed (0.772)
Westbound Friday PM Peak	0.21	0.67	-2.44	2.86	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	0.82	0.44	-0.96	2.59	SCATS= Pre-timed (0.916)

Table 35. Number of Stops Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Total Weekday Noon Peak	-0.75	0.29	-1.71	0.21	SCATS= Pre-timed (0.251)
Total Weekday PM Peak	-0.89	0.35	-2.04	0.27	SCATS= Pre-timed (0.266)
Total Friday Noon Peak	-0.82	0.35	-2.12	0.48	SCATS= Pre-timed (0.414)
Total Friday PM Peak	-0.88	0.46	-2.38	0.63	SCATS= Pre-timed (0.651)
Total Saturday Peak	-0.68	0.47	-2.28	0.91	SCATS= Pre-timed (0.901)

Total Delay Analysis

The travel time total delay data was categorized by eastbound and westbound travel in addition to overall travel (eastbound and westbound combined) for each of the two signal systems; SCATS and the MDOT pre-timed system. The mean total delay for each direction of travel as well as for the overall travel are shown graphically in Figures 23 through 25.

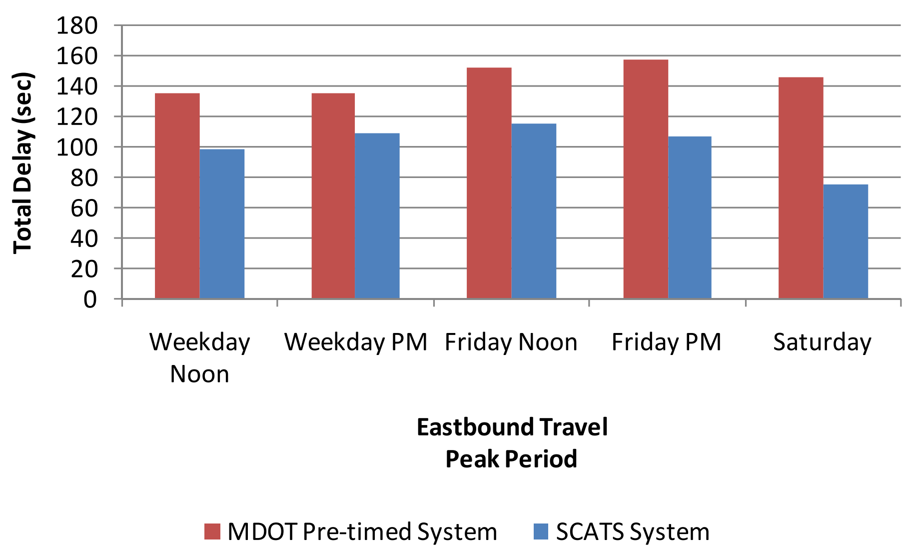

Figure 23. Eastbound Mean Total Delay By Peak Period

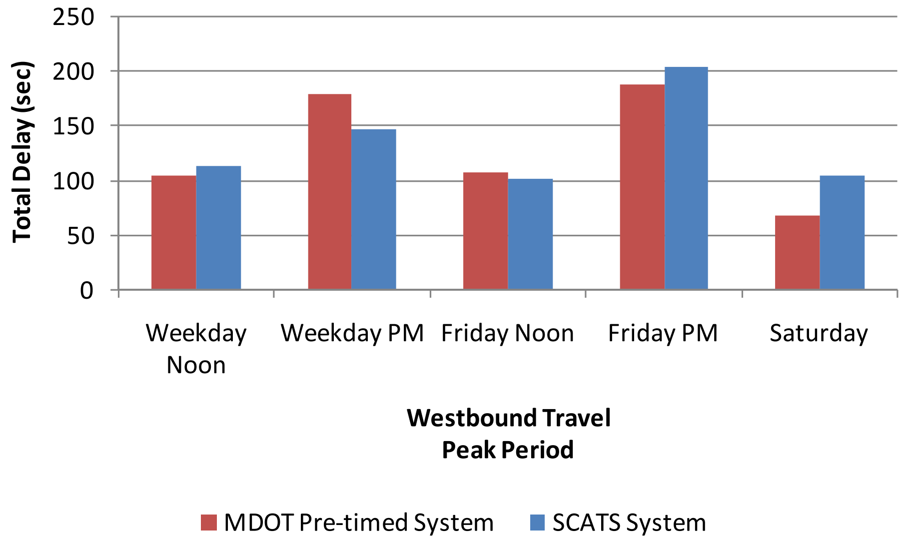

Figure 24. Westbound Mean Total Delay By Peak Period

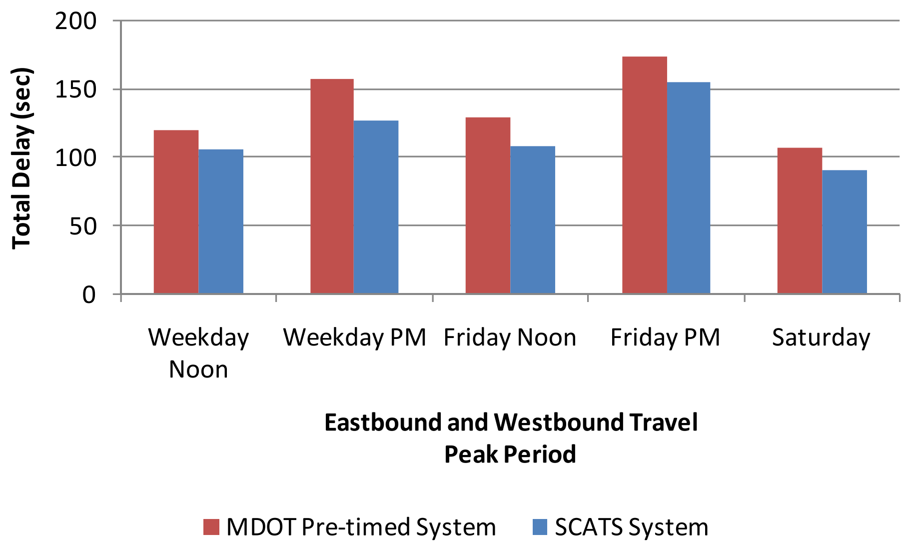

Figure 25. Overall Mean Total Delay By Peak Period

Statistical data calculated, including the mean total delay, standard deviation, and the percent difference in mean total delay, are shown in Table 36. A negative value for the percent difference in mean total delay indicates that the delay in the MDOT pre-timed system was lower than that in the SCATS system. A positive value for the percent difference in mean total delay indicates that the delay in the SCATS system was lower than that in the MDOT pre-timed system.

Table 36. Total Travel Delay Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Mean Total Delay
	Mean Total Delay (sec)	Standard Deviation	Mean Total Delay (sec)	Standard Deviation	
Weekday Noon Peak					
Eastbound	135.83	33.43	98.86	36.13	27.22%
Westbound	104.75	36.12	113.87	29.41	-8.71%
Total	120.29	37.56	106.62	33.12	11.36%
Weekday PM Peak					
Eastbound	136.17	48.30	109.60	38.18	19.51%
Westbound	179.92	40.92	147.57	42.71	17.98%
Total	158.04	49.15	127.93	44.14	19.05%
Friday Noon Peak					
Eastbound	152.67	17.82	115.40	37.92	24.41%
Westbound	107.62	33.08	101.80	35.69	5.41%
Total	129.24	34.93	108.60	35.44	15.97%
Friday PM Peak					
Eastbound	157.80	48.81	107.13	38.06	32.11%
Westbound	188.83	41.40	204.25	79.49	-8.17%
Total	174.73	46.57	155.69	78.70	10.90%
Saturday Peak					
Eastbound	146.09	66.46	76.27	45.07	47.79%
Westbound	68.09	37.68	105.18	34.72	-54.47%
Total	107.09	66.12	90.73	41.95	15.28%

A review of the travel delay data indicates that the data was not normally distributed and therefore the Student's t-test cannot be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. The ANOVA was used to determine if the total delay for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Eastbound total travel delay by peak period
- Westbound total travel delay by peak period
- Total travel delay combined (eastbound and westbound travel speed) by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the total travel delay data for the SCATS and the MDOT pre-timed system was as follows:

H_o (null hypothesis): There was no difference between the mean travel delay between the SCATS and MDOT pre-timed systems for a specified peak period.

For all the comparisons, the variances were found to be different resulting in the reporting of the Welch's modified F-statistic. Due to the unequal sample sizes for each comparison and the non-homogeneous variances, the Games-Howell post-hoc test was conducted.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. This indicates there was no statistical difference between the two signal systems for any of the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the post hoc results are shown in Table 37.

Table 37. Travel Delay Statistical Post hoc Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Eastbound Weekday Noon	-36.98	13.65	-91.01	17.05	SCATS= Pre-timed (0.464)
Eastbound Weekday PM Peak	-26.57	17.08	-95.27	42.13	SCATS= Pre-timed (0.982)
Eastbound Friday Noon Peak	-37.27	17.72	-142.64	68.11	SCATS= Pre-timed (0.782)
Eastbound Friday PM Peak	-50.68	18.13	-185.34	-8.91	SCATS= Pre-timed (0.433)
Eastbound Saturday Peak	-69.82	24.21	-169.34	29.70	SCATS= Pre-timed (0.381)
Westbound Weekday Noon Peak	9.12	12.90	-42.66	60.89	SCATS= Pre-timed (1.000)

Table 37. Travel Delay Statistical Post hoc Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Westbound Weekday PM Peak	-32.35	16.42	-97.41	32.72	SCATS= Pre-timed (0.885)
Westbound Friday Noon Peak	-5.82	18.41	-99.93	88.30	SCATS= Pre-timed (1.000)
Westbound Friday PM Peak	15.42	23.19	-76.47	107.31	SCATS= Pre-timed (1.000)
Westbound Saturday Peak	37.09	15.45	-25.37	99.55	SCATS= Pre-timed (0.656)
Total Weekday Noon Peak	-13.67	9.83	-46.32	18.98	SCATS= Pre-timed (0.924)
Total Weekday PM Peak	-30.11	12.96	-73.13	12.91	SCATS= Pre-timed (0.393)
Total Friday Noon Peak	-20.64	13.21	-68.57	27.29	SCATS= Pre-timed (0.848)
Total Friday PM Peak	-19.04	17.09	-75.57	37.49	SCATS= Pre-timed (0.981)
Total Saturday Peak	-16.34	16.70	-72.65	39.93	SCATS= Pre-timed (0.992)

Number of Stopped Vehicles Analysis

The number of vehicles stopping at the study intersections data was categorized by those vehicles stopping along the main roadway (M-59) and those along the minor roadways for each of the two signal systems; SCATS and the MDOT pre-timed system. The number of vehicles stopping at the study intersections for M-59, the minor roadways and the total number of stopped vehicles are shown graphically in Figures 26 through 28.

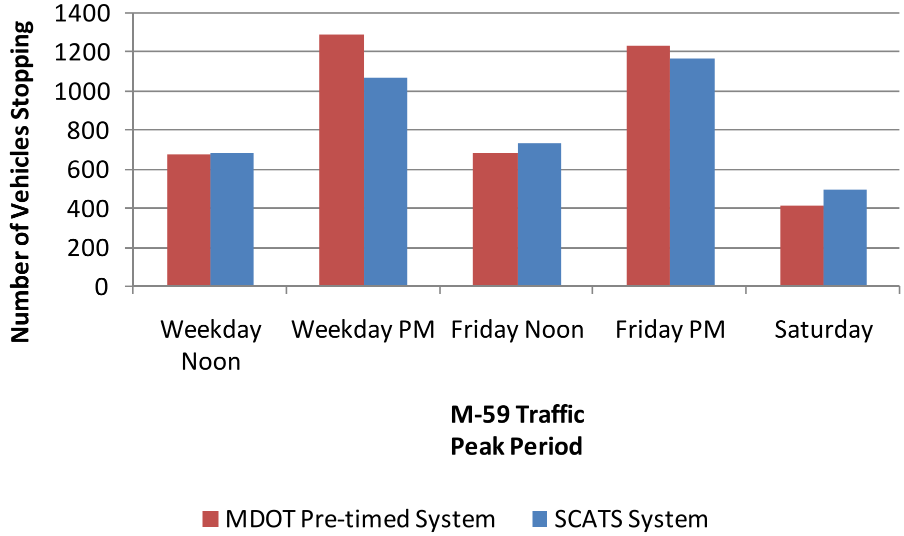

Figure 26. M-59 Number of Stopped Vehicles By Peak Period

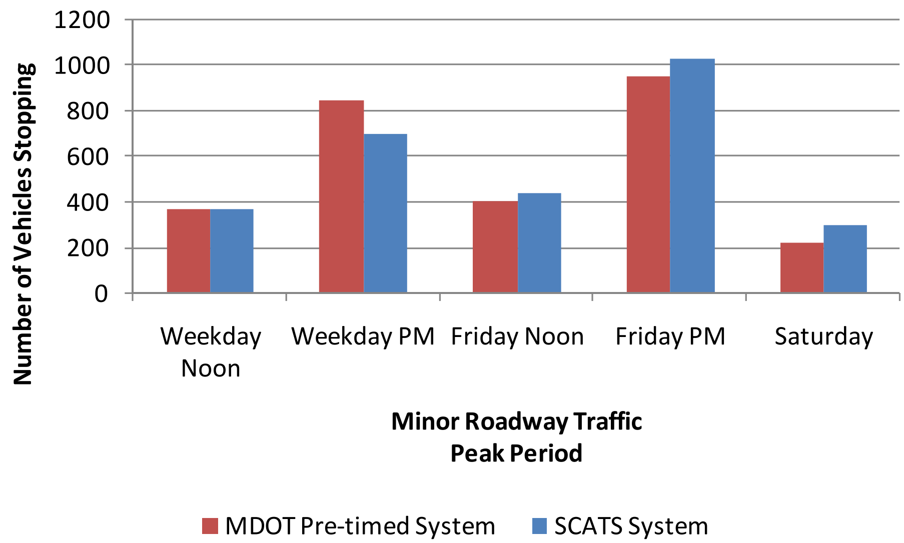

Figure 27. Minor Roadways Number of Stopped Vehicles By Peak Period

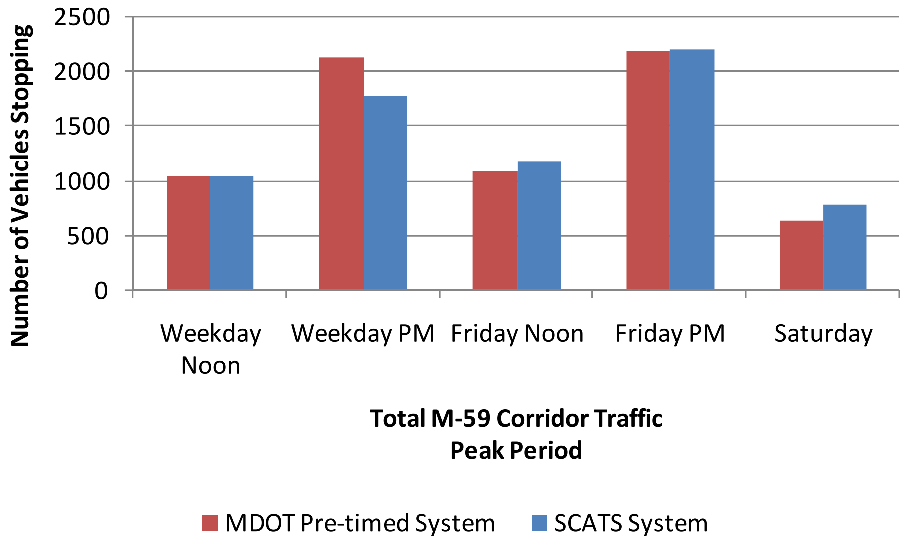

Figure 28. Total Number of Stopped Vehicles By Peak Period

Statistical data calculated, including the average number of stopped vehicles by roadway type, standard deviation, and the percent difference in average number of stopped vehicles, are shown in Table 38. A negative value for the percent difference in the number of stopped vehicles indicates that the MDOT pre-timed system had fewer stopped vehicles than the SCATS system. A positive value for the percent difference in the number of stopped vehicles indicates that the SCATS system had fewer stopped vehicles than the MDOT pre-timed system.

Table 38. Number of Stopped Vehicles Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Number of Stopped Vehicles
	Mean Number of Stopped Vehicles	Standard Deviation	Mean Number of Stopped Vehicles	Standard Deviation	
Weekday Noon Peak					
M-59	680.00	810.70	685.04	828.99	-0.74%
Minor Roadways	370.75	429.99	373.88	429.37	-0.84%
Weekday PM Peak					
M-59	1289.96	1925.05	1072.33	1617.69	16.87%
Minor Roadways	851.46	1348.47	704.96	867.01	17.21%
Friday Noon Peak					
M-59	690.54	856.96	737.46	845.87	-6.79%
Minor Roadways	404.17	433.62	442.54	513.19	-9.49%

Table 38. Number of Stopped Vehicles Statistical Data (continued)

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Number of Stopped Vehicles
	Mean Number of Stopped Vehicles	Standard Deviation	Mean Number of Stopped Vehicles	Standard Deviation	
Friday PM Peak					
M-59	1237.42	2170.03	1173.92	1659.73	5.13%
Minor Roadways	952.75	1230.46	1028.92	1514.31	-7.99%
Saturday Peak					
M-59	414.58	440.35	496.71	581.76	-19.81%
Minor Roadways	225.92	251.10	299.08	343.41	-32.38%

The number of stopped vehicle data was analyzed for adherence to the assumption of normality for use in the paired t-test for determining if the difference in the average number of stopped vehicles was significant. The paired t-test was selected for the number of stopped vehicle data due to the matched characteristics of the data collection. For the number of stopped vehicle data, data was collected for each intersection's critical lane group for the same period under each signal system. A review of the data indicates that the data was not normally distributed and therefore the paired t-test should not be conducted due to the lack of the test's ability to maintain adequate power and robustness of the test, which assures the results of the analysis.

A non-parametric test can be conducted when the assumption of normality is violated in the paired t-test, such as the Wilcoxon Signed Rank Test. Due to confusion regarding non-parametric tests outside of the academia, both the paired t-test and the Wilcoxon Signed Rank test were conducted to provide further justification for the non-parametric results. The tests was used to determine if the average number of stops for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Number of stopped vehicles along M-59 by peak period
- Number of stopped vehicles along the minor roadways by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the number of stopped vehicle data for the SCATS and the MDOT pre-timed system was as follows:

H_o (null hypothesis): There was no difference between the average number of stopped vehicles between the SCATS and MDOT pre-timed systems for a specified peak period.

Based upon the statistical analysis, the null hypothesis was not accepted for each comparison between the SCATS and the MDOT pre-timed system. For the paired t-test, the comparison of the SCATS system to the MDOT pre-timed system for the minor roadways during the Saturday peak period were found to be statistically different. The MDOT pre-timed system had fewer vehicles stopping along the minor roadways than the SCATS system. The Wilcoxon Signed Rank test found similar results for the Saturday peak period. In addition, the Wilcoxon Signed Rank test found statistically different results in the comparison of the M-59 traffic during the weekday PM peak period. The SCATS system has fewer vehicles stopping along M-59 during the weekday PM peak period. For the remaining of the comparisons, there was no statistical difference between the two signal systems for the remaining peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the paired t-test results are shown in Table 39 while the results of the Wilcoxon Signed Rank test results are shown in Table 40.

Table 39. Number of Stopped Vehicles Paired t-test Statistical Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
M-59 Traffic Weekday Noon	-5.04	85.97	-182.89	172.80	SCATS= Pre-timed (0.954)
M-59 Traffic Weekday PM Peak	217.63	113.96	-18.12	453.37	SCATS= Pre-timed (0.069)
M-59 Traffic Friday Noon Peak	-46.92	121.28	-297.80	203.97	SCATS= Pre-timed (0.702)
M-59 Traffic Friday PM Peak	63.50	240.42	-433.84	560.84	SCATS= Pre-timed (0.794)
M-59 Traffic Saturday Peak	-82.13	69.65	-226.20	61.95	SCATS= Pre-timed (0.250)

Table 39. Number of Stopped Vehicles Paired t-test Statistical Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Minor Roadways Weekday Noon Peak	-3.13	33.95	-73.36	67.11	SCATS= Pre-timed (0.927)
Minor Roadways Weekday PM Peak	146.50	159.62	-183.70	476.70	SCATS= Pre-timed (0.368)
Minor Roadways Friday Noon Peak	-38.38	50.26	-142.34	65.59	SCATS= Pre-timed (0.453)
Minor Roadways Friday PM Peak	-76.17	235.32	-562.97	410.63	SCATS= Pre-timed (0.749)
Minor Roadways Saturday Peak	-73.17	25.75	-126.44	-19.89	**Reject Null**; SCATS≠ Pre-timed (0.009)

Table 40. Number of Stopped Vehicles Wilcoxon Signed Rank Statistical Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Negative Ranks (SCATS< Pre-timed)	Positive Ranks (SCATS> Pre-timed)	Z-Calculated	Test Result (p-value)
M-59 Traffic Weekday Noon	14	10	-0.057	SCATS= Pre-timed (0.954)
M-59 Traffic Weekday PM Peak	17	7	-2.286	**Reject Null**; SCATS≠ Pre-timed (0.022)
M-59 Traffic Friday Noon Peak	12	12	0.000	SCATS= Pre-timed (1.000)
M-59 Traffic Friday PM Peak	14	10	-0.543	SCATS= Pre-timed (0.587)
M-59 Traffic Saturday Peak	10	14	-1.172	SCATS= Pre-timed (0.241)

Table 40. Number of Stopped Vehicles Wilcoxon Signed Rank Statistical Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Negative Ranks (SCATS< Pre-timed)	Positive Ranks (SCATS> Pre-timed)	Z-Calculated	Test Result (p-value)
Minor Roadways Weekday Noon Peak	11	13	-0.086	SCATS= Pre-timed (0.932)
Minor Roadways Weekday PM Peak	13	11	-0.829	SCATS= Pre-timed (0.407)
Minor Roadways Friday Noon Peak	14	10	-0.543	SCATS= Pre-timed (0.587)
Minor Roadways Friday PM Peak	15	9	-0.971	SCATS=Ag Pre-timed ed (0.331)
Minor Roadways Saturday Peak	9	15	-2.229	**Reject Null**; SCATS≠ Pre-timed (0.026)

Maximum Queue Length Analysis

The maximum queue length in vehicles at the study intersections data was categorized by those vehicles queued at signals along the main roadway (M-59) and those along the minor roadways for each of the two signal systems; SCATS and the MDOT pre-timed system. The maximum queue length in vehicles at the study intersections for M-59 and the minor roadways are shown graphically in Figures 29 through 30.

Statistical data calculated, including the mean queue length by roadway type, standard deviation, and the percent difference in mean queue length, are shown in Table 41. A negative value for the percent difference in the mean queue length indicates that the MDOT pre-timed system had shorter queues than the SCATS system. A positive value for the percent difference in the mean queue length indicates that the SCATS system had shorter queues than the MDOT pre-timed system.

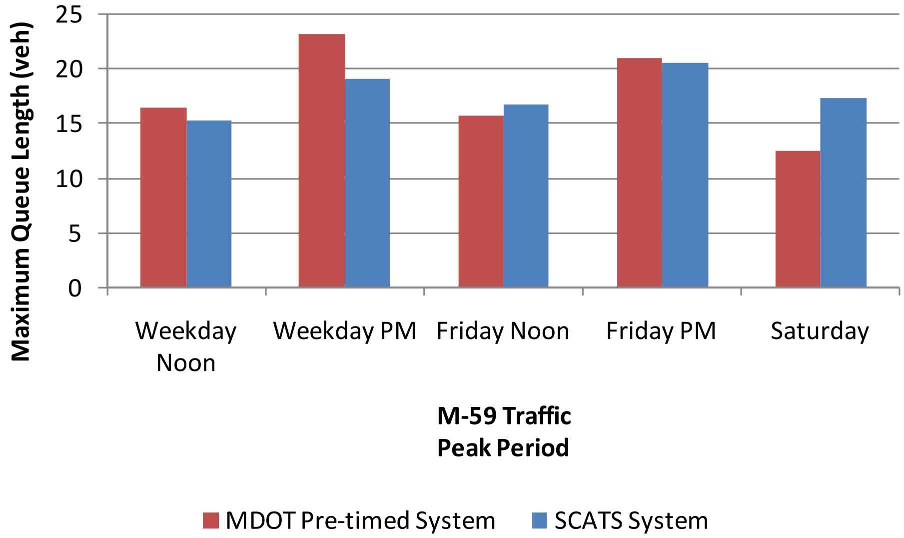

Figure 29. M-59 Maximum Queue Length By Peak Period

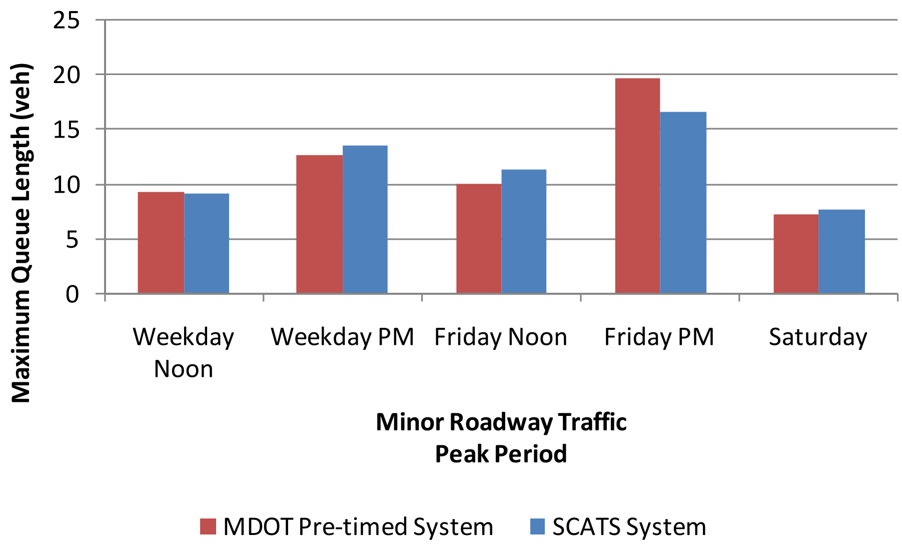

Figure 30. Minor Roadways Maximum Queue Length By Peak Period

Table 41. Maximum Queue Length Statistical Data

Day, Peak Period and Direction of Travel	MDOT Pre-timed System		SCATS System		Percent Difference in Mean Queue Length
	Mean Queue Length	Standard Deviation	Mean Queue Length	Standard Deviation	
Weekday Noon Peak					
M-59	16.50	11.44	15.29	11.55	7.33%
Minor Roadways	9.29	5.87	9.21	5.66	0.86%
Weekday PM Peak					
M-59	23.23	19.92	19.17	15.74	17.48%
Minor Roadways	12.79	10.66	13.63	9.84	-6.57%
Friday Noon Peak					
M-59	15.83	11.60	16.83	13.04	-6.32%
Minor Roadways	10.13	5.94	11.42	6.89	-12.73%
Friday PM Peak					
M-59	21.00	19.13	20.67	17.15	1.57%
Minor Roadways	19.71	24.48	16.63	13.15	15.63%
Saturday Peak					
M-59	12.58	9.08	17.38	22.10	-38.16%
Minor Roadways	7.25	4.59	7.79	5.27	-7.45%

The maximum queue length data was analyzed for adherence to the assumption of normality for use in the paired t-test for determining if the difference in the mean maximum queue length was significant. The paired t-test was selected for the maximum queue length due to the matched characteristics of the data collection where data was collected for each intersection's critical lane group for the same period under each signal system. A review of the data indicates that the data was not normally distributed and therefore the paired t-test should not be conducted due to the lack of the test's ability to maintain adequate power and robustness of the test, which assures the results of the analysis.

A non-parametric test can be conducted when the assumption of normality is violated in the paired t-test, such as the Wilcoxon Signed Rank Test. Due to confusion regarding non-parametric tests outside of the academia, both the paired t-test and the Wilcoxon Signed Rank test were conducted to provide further justification for the non-parametric results. The tests were used to determine if the mean maximum queue length for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the following comparisons:

- Maximum queue length along M-59 by peak period
- Maximum queue length along the minor roadways by peak period

The peak periods for the analysis include the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypothesis for the queue length data for the SCATS and the MDOT pre-timed system was as follows:

H_o (null hypothesis): There was no difference between the average maximum queue length between the SCATS and MDOT pre-timed systems for a specified peak period.

Based upon the statistical analysis, the null hypothesis was accepted for each comparison between the SCATS and the MDOT pre-timed system. Therefore, there was no statistical difference between the two signal systems for the peak periods analyzed. A significant result indicating differences between the two systems would be represented by a p-value less than 0.05, representing a level of confidence of 95 percent. The results of the paired t-test results are shown in Table 42 while the results of the Wilcoxon Signed Rank test results are shown in Table 43.

Table 42. Queue Length Paired t-test Statistical Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
M-59 Traffic Weekday Noon	1.21	1.52	-1.94	4.35	SCATS= Pre-timed (0.435)
M-59 Traffic Weekday PM Peak	4.08	2.06	-0.19	8.35	SCATS= Pre-timed (0.060)
M-59 Traffic Friday Noon Peak	-1.00	1.96	-5.06	3.06	SCATS= Pre-timed (0.616)
M-59 Traffic Friday PM Peak	0.33	2.89	-5.64	6.31	SCATS= Pre-timed (0.909)
M-59 Traffic Saturday Peak	-4.79	4.11	-13.30	3.71	SCATS= Pre-timed (0.256)

Table 42. Queue Length Paired t-test Statistical Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Mean Difference	Standard Error of the Difference	95% Lower Bound Confidence Interval	95% Upper Bound Confidence Interval	Test Result (p-value)
Minor Roadways Weekday Noon Peak	0.08	0.659	-1.28	1.48	SCATS= Pre-timed (0.900)
Minor Roadways Weekday PM Peak	-0.83	1.61	-4.16	2.50	SCATS= Pre-timed (0.609)
Minor Roadways Friday Noon Peak	-1.29	1.00	-3.37	0.78	SCATS= Pre-timed (0.210)
Minor Roadways Friday PM Peak	3.08	4.10	-5.39	11.56	SCATS= Pre-timed (0.459)
Minor Roadways Saturday Peak	-0.54	0.71	-2.02	0.93	SCATS= Pre-timed (0.455)

Table 43. Queue Length Wilcoxon Signed Rank Statistical Analysis Results

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Negative Ranks (SCATS< Pre-timed)	Positive Ranks (SCATS> Pre-timed)	Tie Ranks (SCATS= Pre-timed)	Z-Calculated	Test Result (p-value)
M-59 Traffic Weekday Noon	14	8	2	-0.992	SCATS= Pre-timed (0.321)
M-59 Traffic Weekday PM Peak	12	8	4	-1.345	SCATS= Pre-timed (0.179)
M-59 Traffic Friday Noon Peak	10	11	3	-0.522	SCATS= Pre-timed (0.601)
M-59 Traffic Friday PM Peak	12	9	3	-0.191	SCATS= Pre-timed (0.848)
M-59 Traffic Saturday Peak	10	9	5	-0.609	SCATS= Pre-timed (0.542)
Minor Roadways Weekday Noon Peak	9	11	4	-0.038	SCATS= Pre-timed (0.970)
Minor Roadways Weekday PM Peak	11	9	4	-0.113	SCATS= Pre-timed (0.910)

Table 43. Queue Length Wilcoxon Signed Rank Statistical Analysis Results (continued)

Comparison Category of SCATS vs. MDOT Pre-timed Systems	Negative Ranks (SCATS< Pre-timed)	Positive Ranks (SCATS> Pre-timed)	Tie Ranks (SCATS= Pre-timed)	Z-Calculated	Test Result (p-value)
Minor Roadways Friday Noon Peak	7	14	3	-1.323	SCATS= Pre-timed (0.186)
Minor Roadways Friday PM Peak	14	9	1	-0.198	SCATS= Pre-timed (0.843)
Minor Roadways Saturday Peak	10	11	3	-0.875	SCATS= Pre-timed (0.381)

CONCLUSIONS

Beginning in 1992, Oakland County began converting their pre-timed coordinated traffic signal systems to SCATS (Sydney Coordinated Adaptive Traffic System). SCATS uses anticipatory and adaptive techniques to increase the efficiency of the road network by minimizing the overall number of vehicular stops and delay experienced by motorists. The primary purpose of the SCATS system is to maximize the throughput of a roadway by controlling queue formation. The SCATS system has the ability to change the signal phasing, timing strategies and the signal coordination within a network to alleviate congestion by automatically adjusting the signal parameters according to real time traffic demand.

There had not been any comprehensive studies conducted in the past that evaluated the performance of the SCATS system in terms of delay, flow, queue length, fuel consumption, emissions and other characteristics.

The objective of this research was to assess the effectiveness of the SCATS signal system on the reduction of traffic congestion in terms of delay, queue length and other characteristics as compared to a pre-timed signal system.

Traffic operational data was collected for the SCATS signal system and an MDOT pre-timed signal system. The traffic operational data included the following:

- Travel time
- Travel speed
- Fuel consumption
- Hydrocarbon emissions
- Carbon monoxide emissions
- Nitrogen oxide emissions
- Number of stops along the corridor
- Total travel delay
- Number of stopped vehicles at each intersection for M-59 and the minor intersecting roadways
- Maximum queue length at each intersection for M-59 and the minor intersecting roadways

The statistical significance of the effectiveness of the two signal systems were tested to determine whether the changes observed in the measures of effectiveness were attributable to the signal system or chance. Several hypotheses were presented and tested for significance at a 95 percent level of confidence or alpha equal to 0.05. A summary of the findings are as follows:

- The performance of the SCATS system was found to be superior for several of the performance measures for each of the peak periods generally for the eastbound travel direction. At 95 percent confidence level, it was not significant.
- A statistical difference was found between the two signal systems based upon the number of stopped vehicles for the minor roadways during the Saturday peak period. The number of stopped vehicles under the MDOT pre-timed signal system operation was fewer than under the SCATS signal system operation. For the remaining peak period comparisons for the minor roadways, there were not any statistical differences found between the two signal systems based upon the number of stopped vehicles.
- A statistical difference was found between the two signal systems based upon the number of stopped vehicles for M-59 during the weekday PM peak period. The number of stopped vehicles under the SCATS signal system operation was fewer than under the MDOT pre-timed signal system operation. For the remaining peak period comparisons for M-59, there were not any statistical differences found between the two signal systems based upon the number of stopped vehicles.

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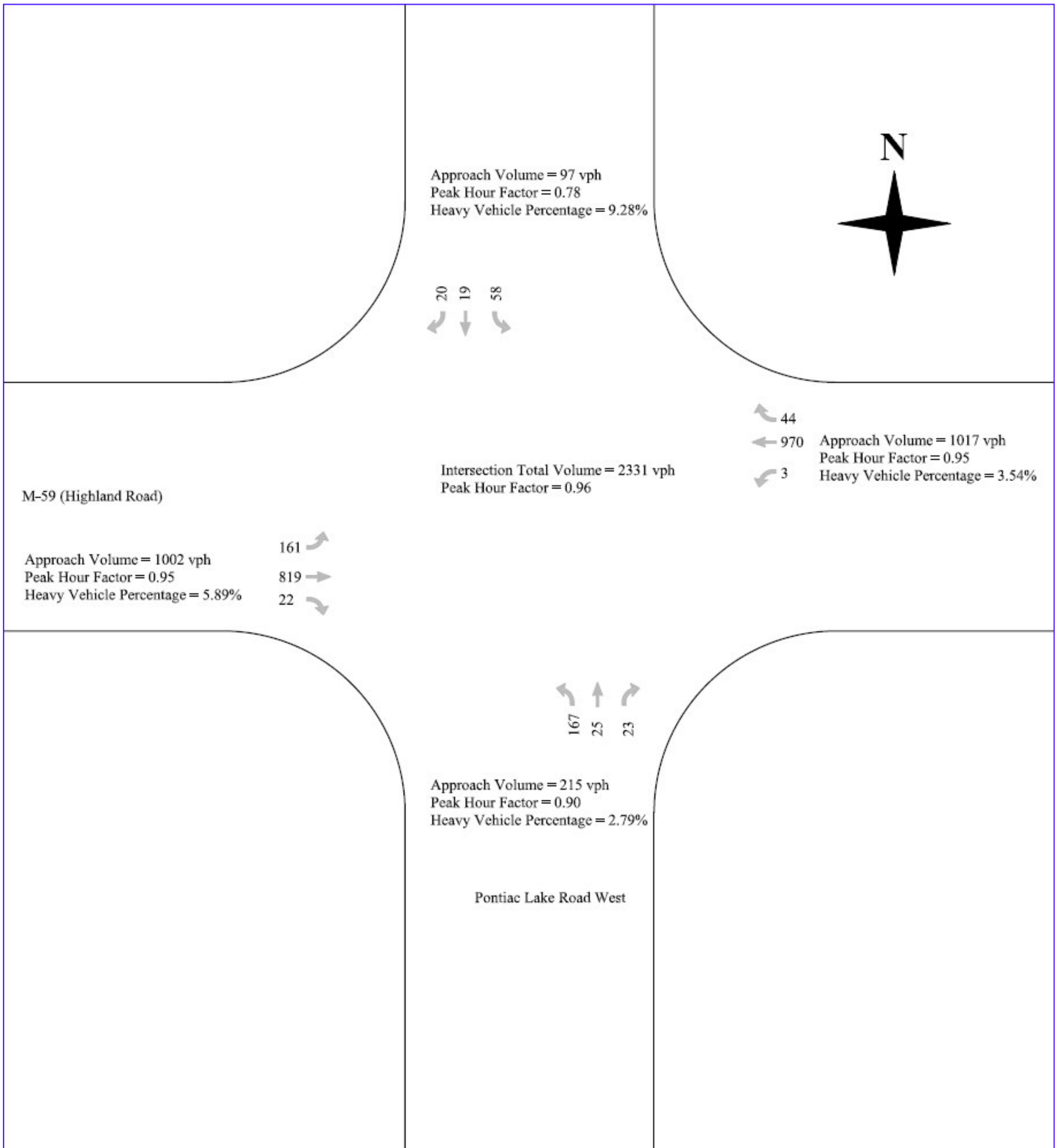
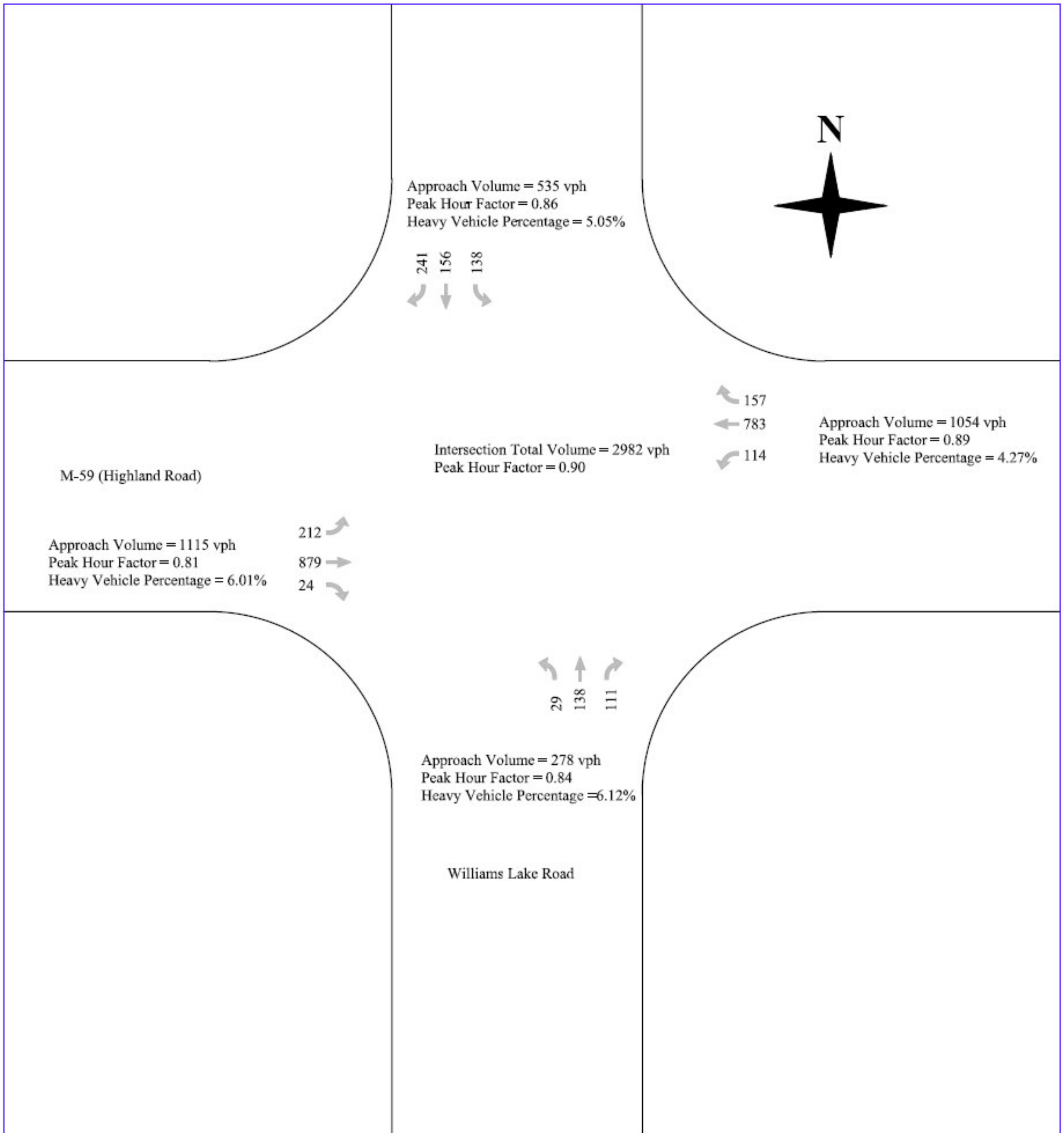
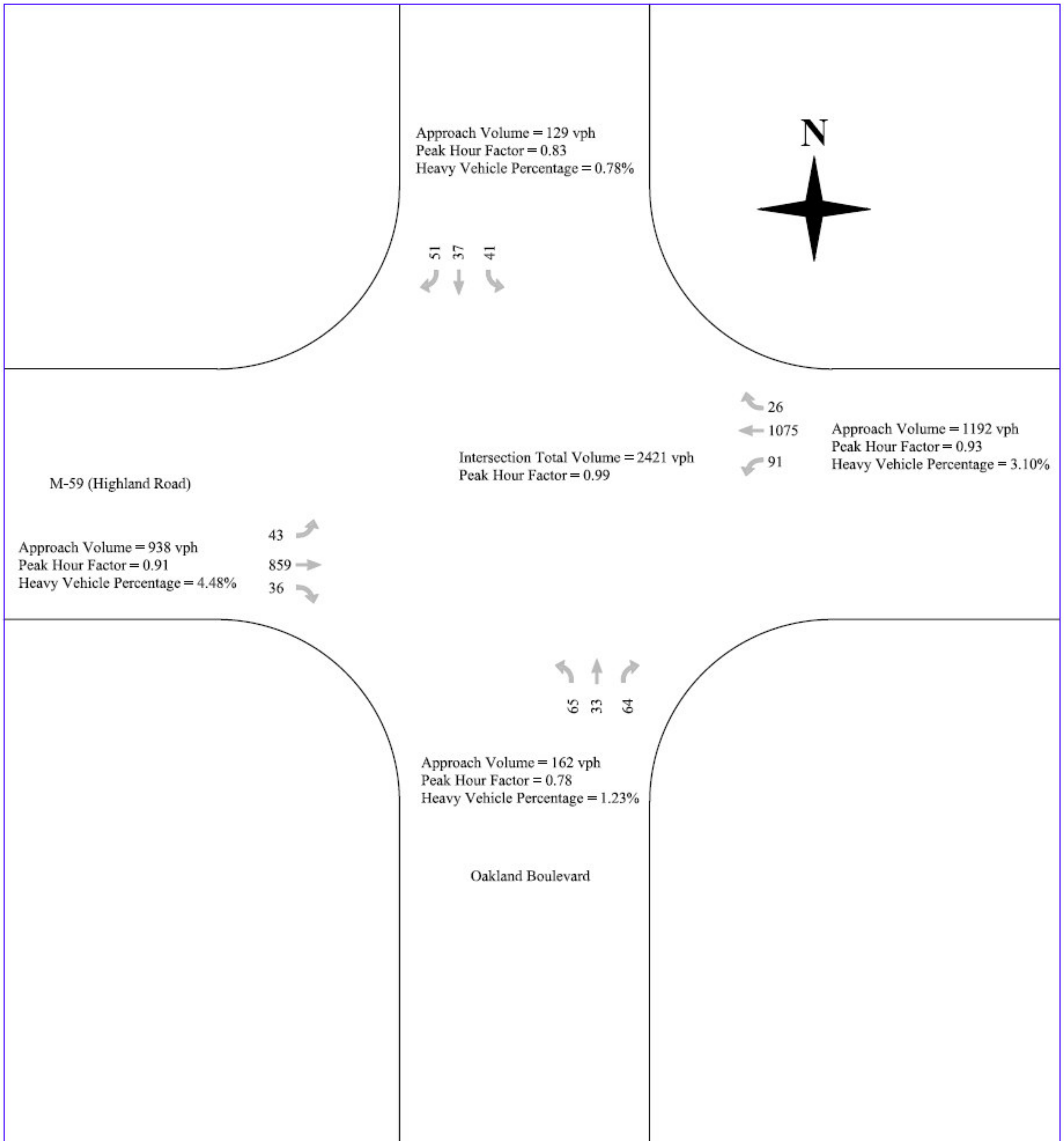
APPENDIX A



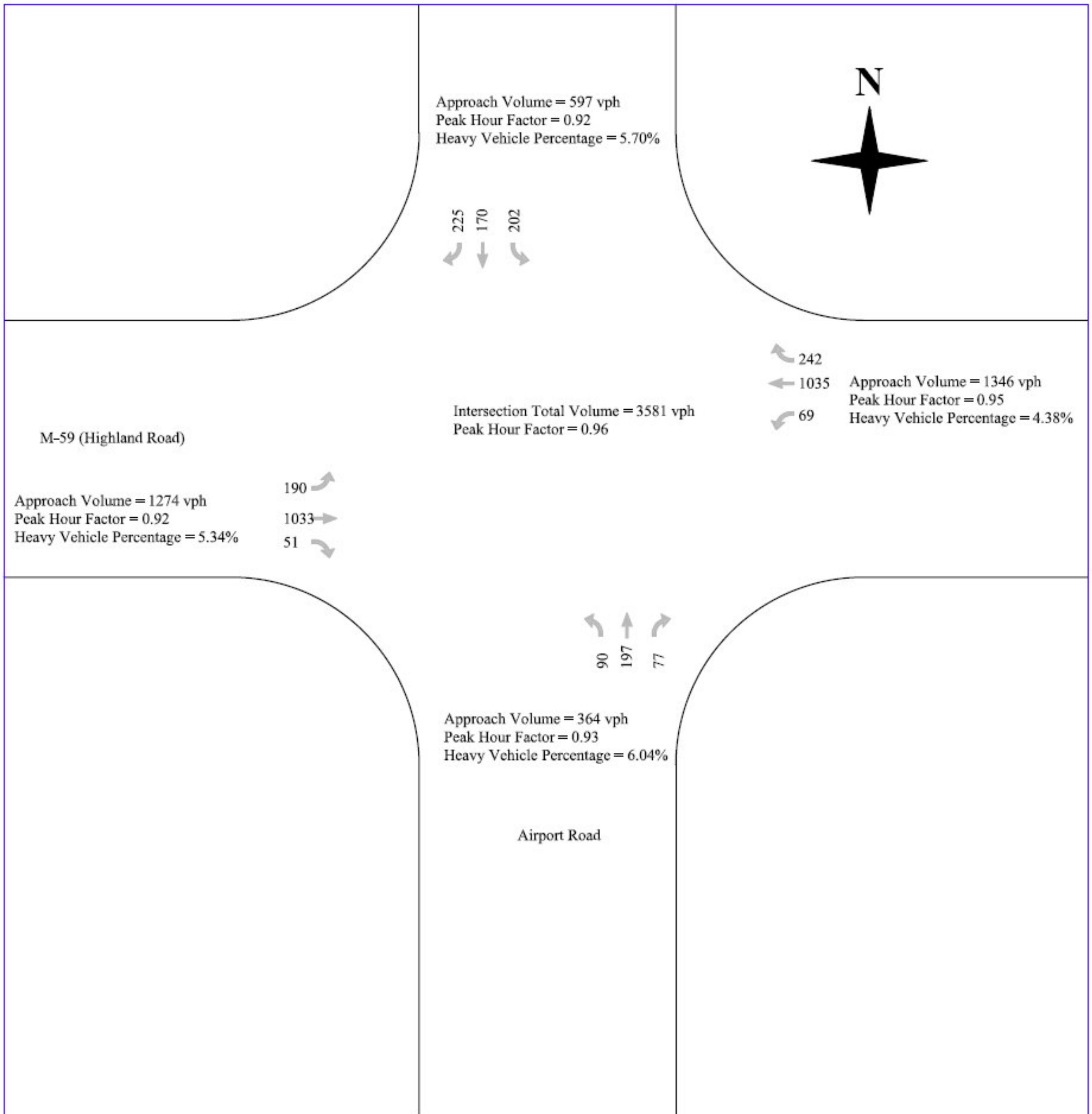
Volume Diagram
M-59 and Pontiac Lake Road West
Noon Peak Hour Volume Diagram



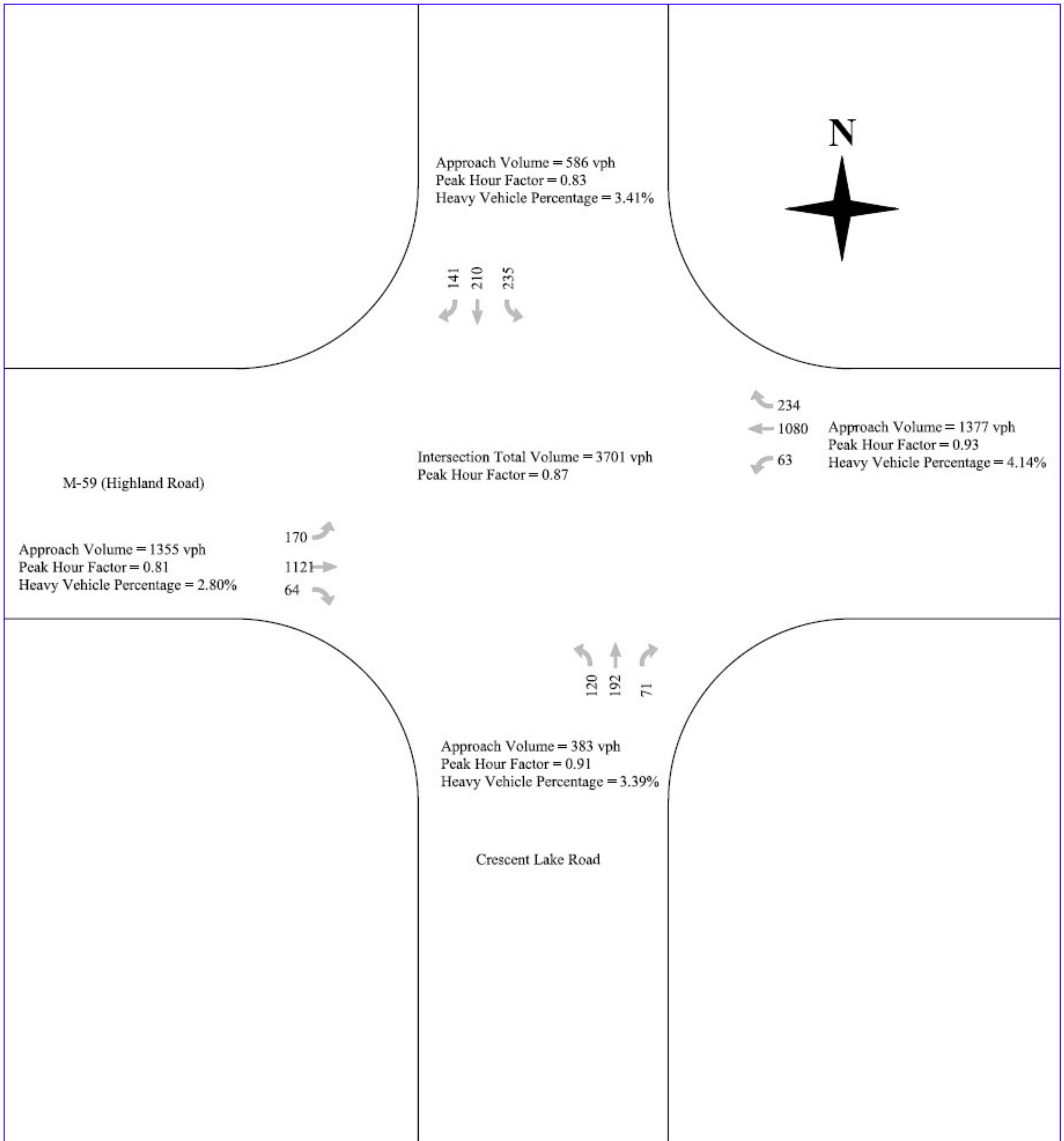
Volume Diagram
M-59 and Williams Lake Road
Noon Peak Hour Volume Diagram



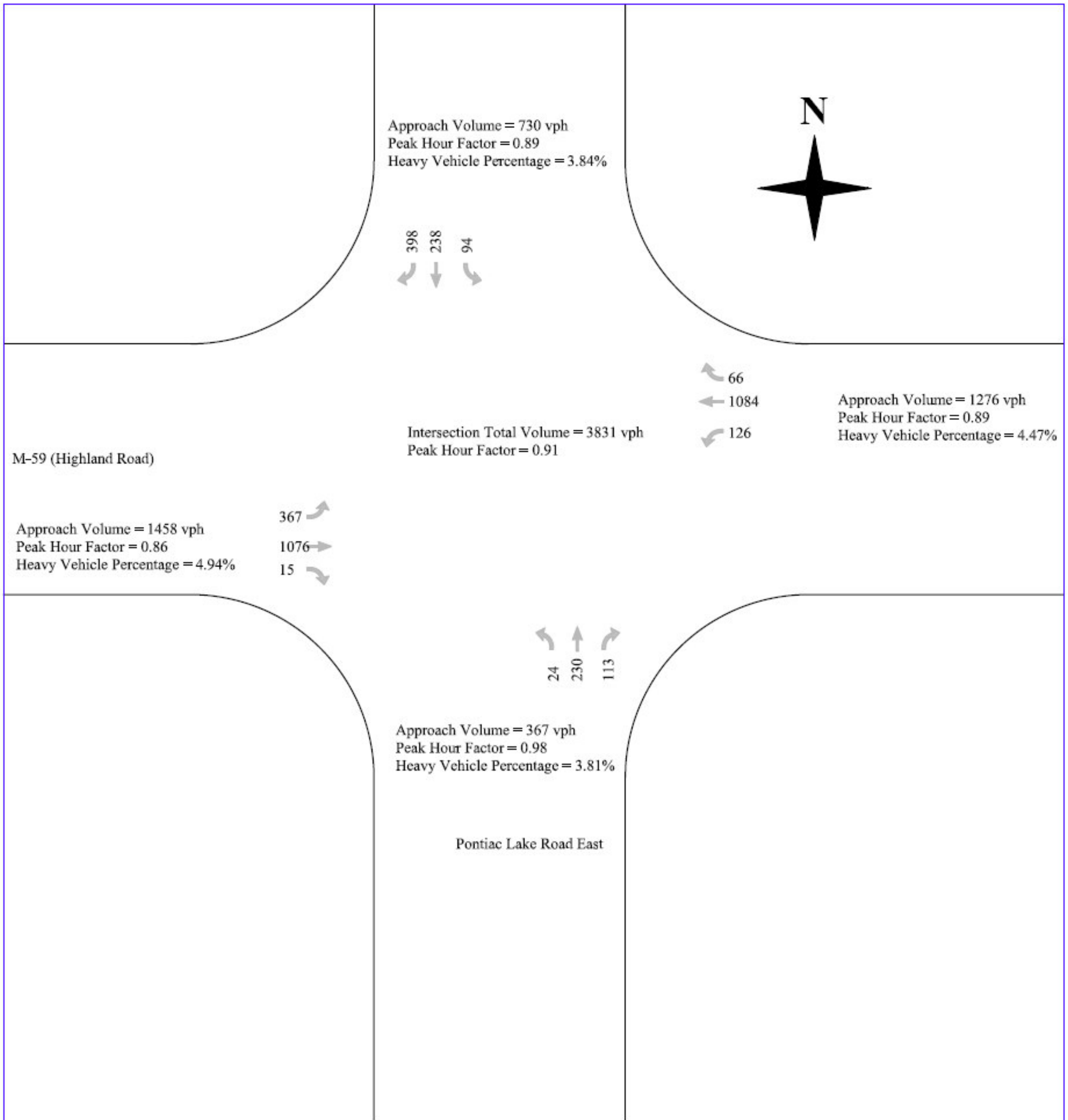
Volume Diagram
M-59 and Oakland Boulevard
Noon Peak Hour Volume Diagram



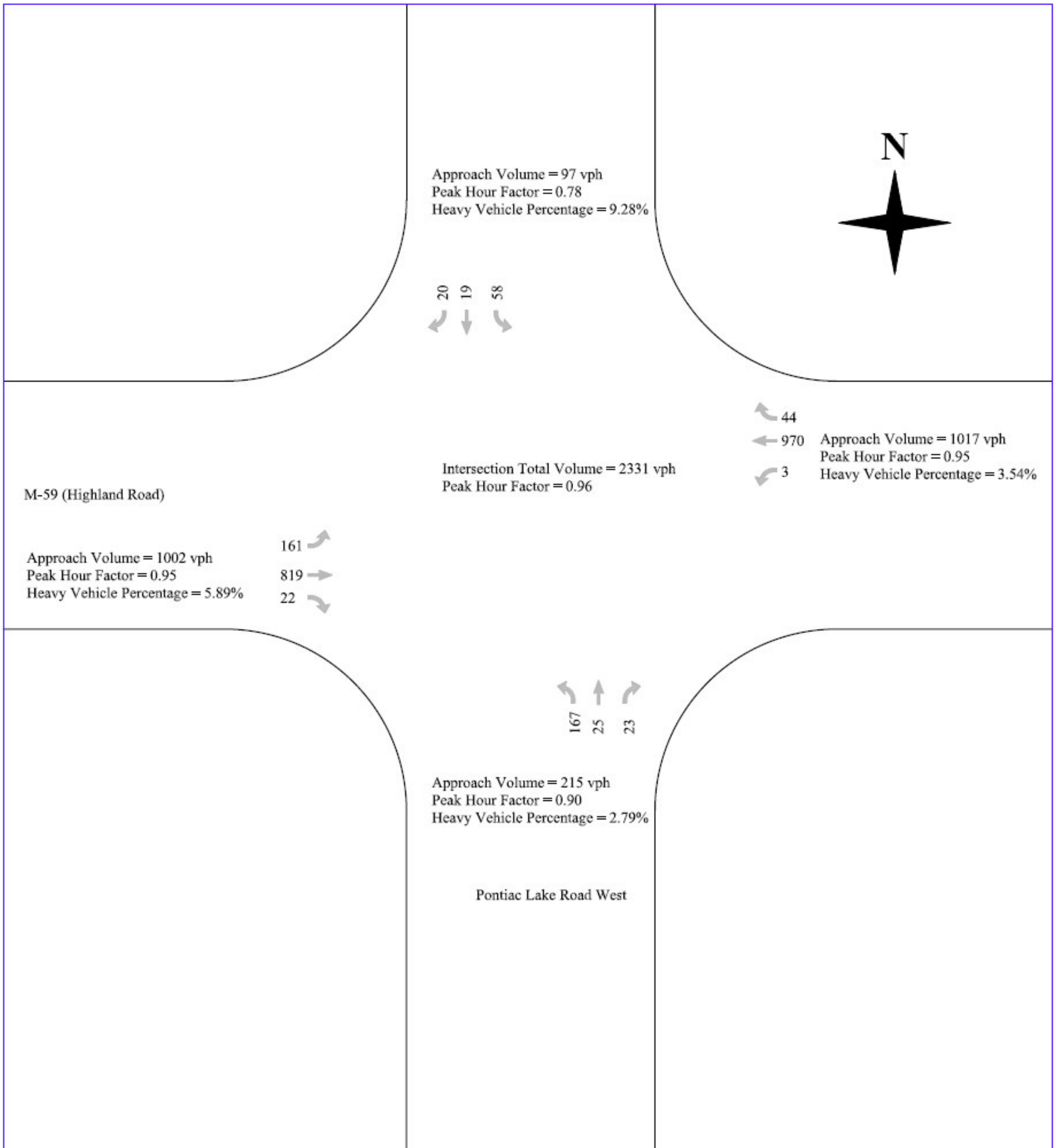
Volume Diagram
M-59 and Airport Road
Noon Peak Hour Volume Diagram



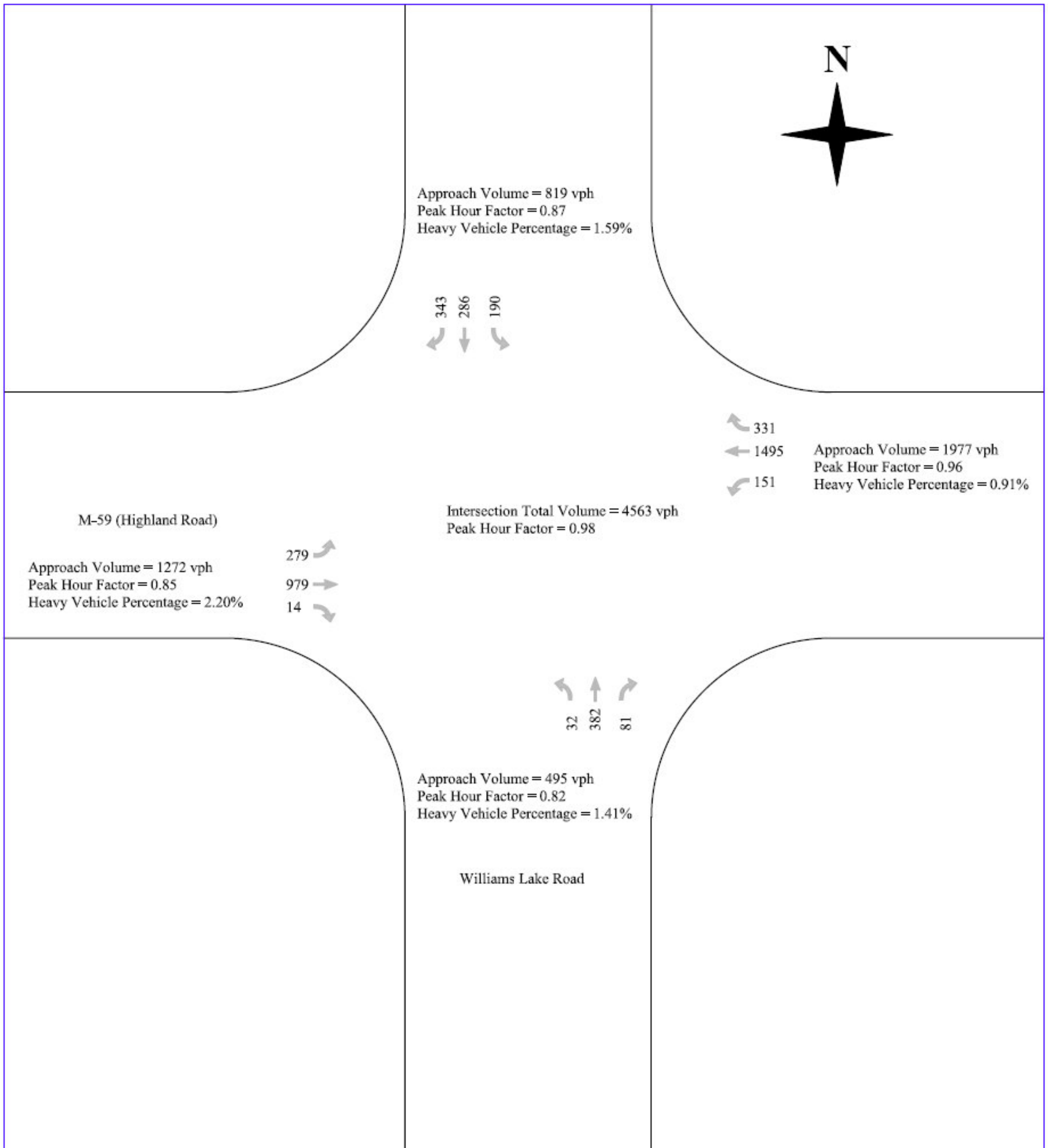
Volume Diagram
M-59 and Crescent Lake Road
Noon Peak Hour Volume Diagram



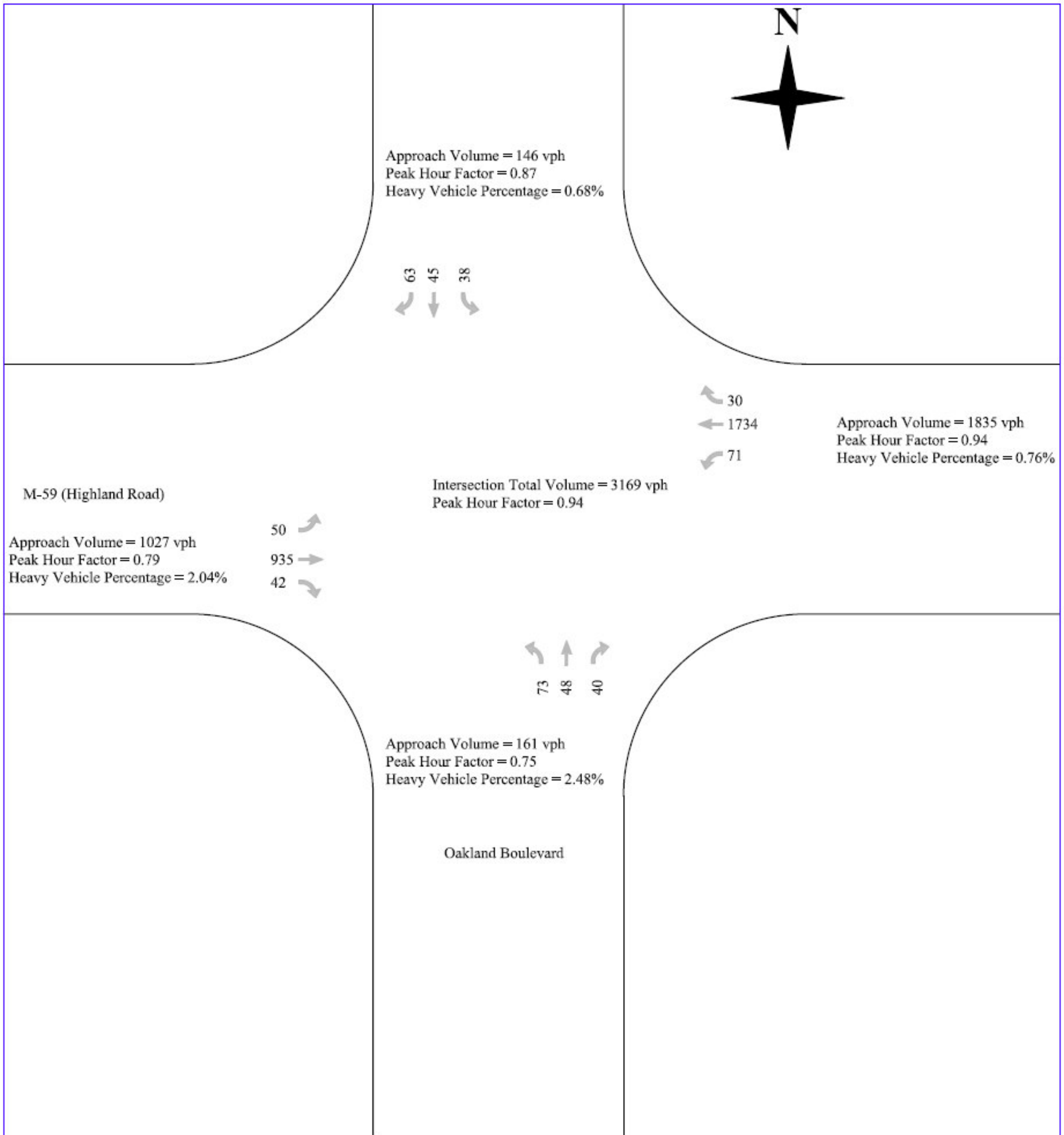
Volume Diagram
M-59 and Pontiac Lake Road East
Noon Peak Hour Volume Diagram



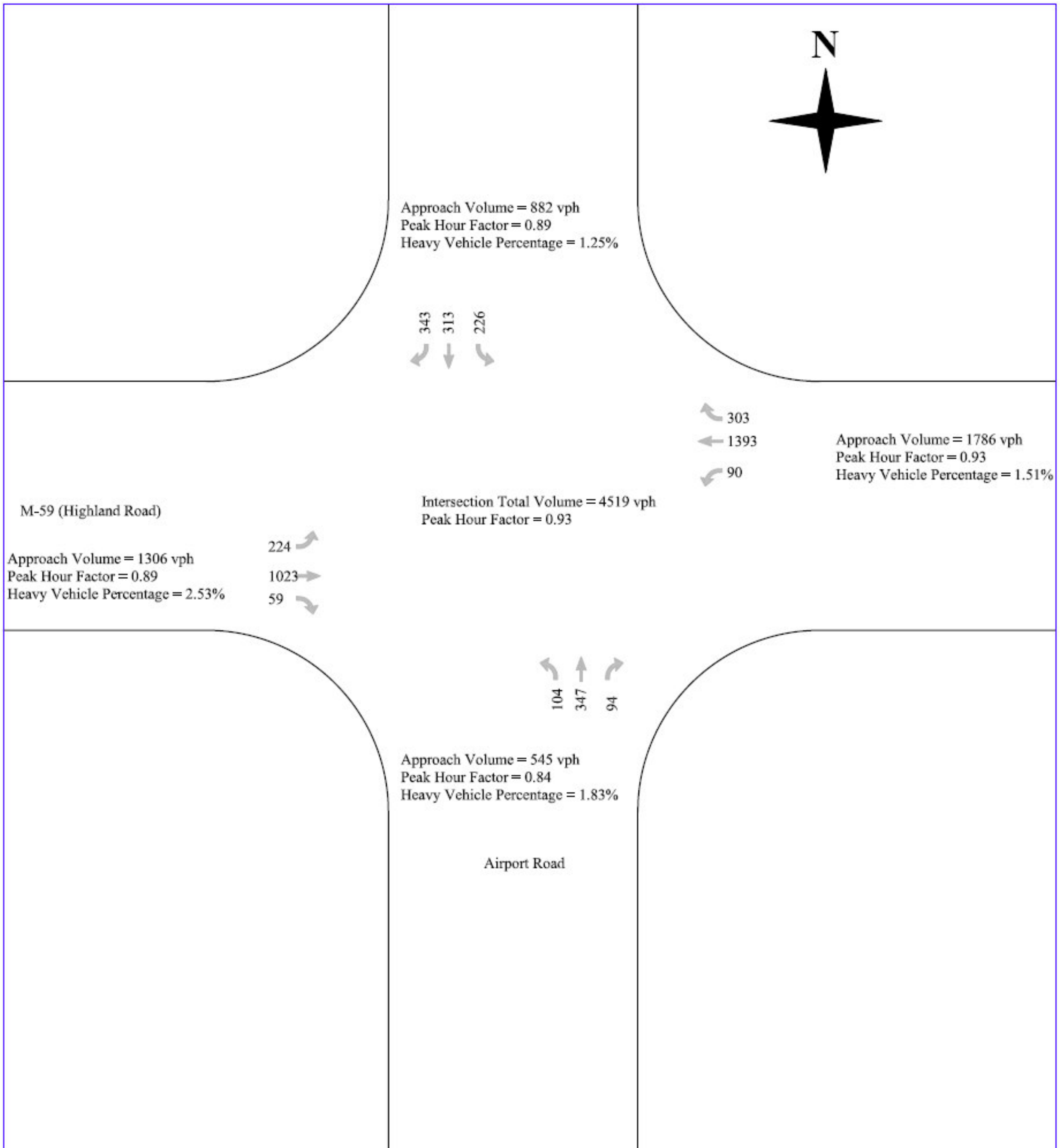
Volume Diagram
M-59 and Pontiac Lake Road West
PM Peak Hour Volume Diagram



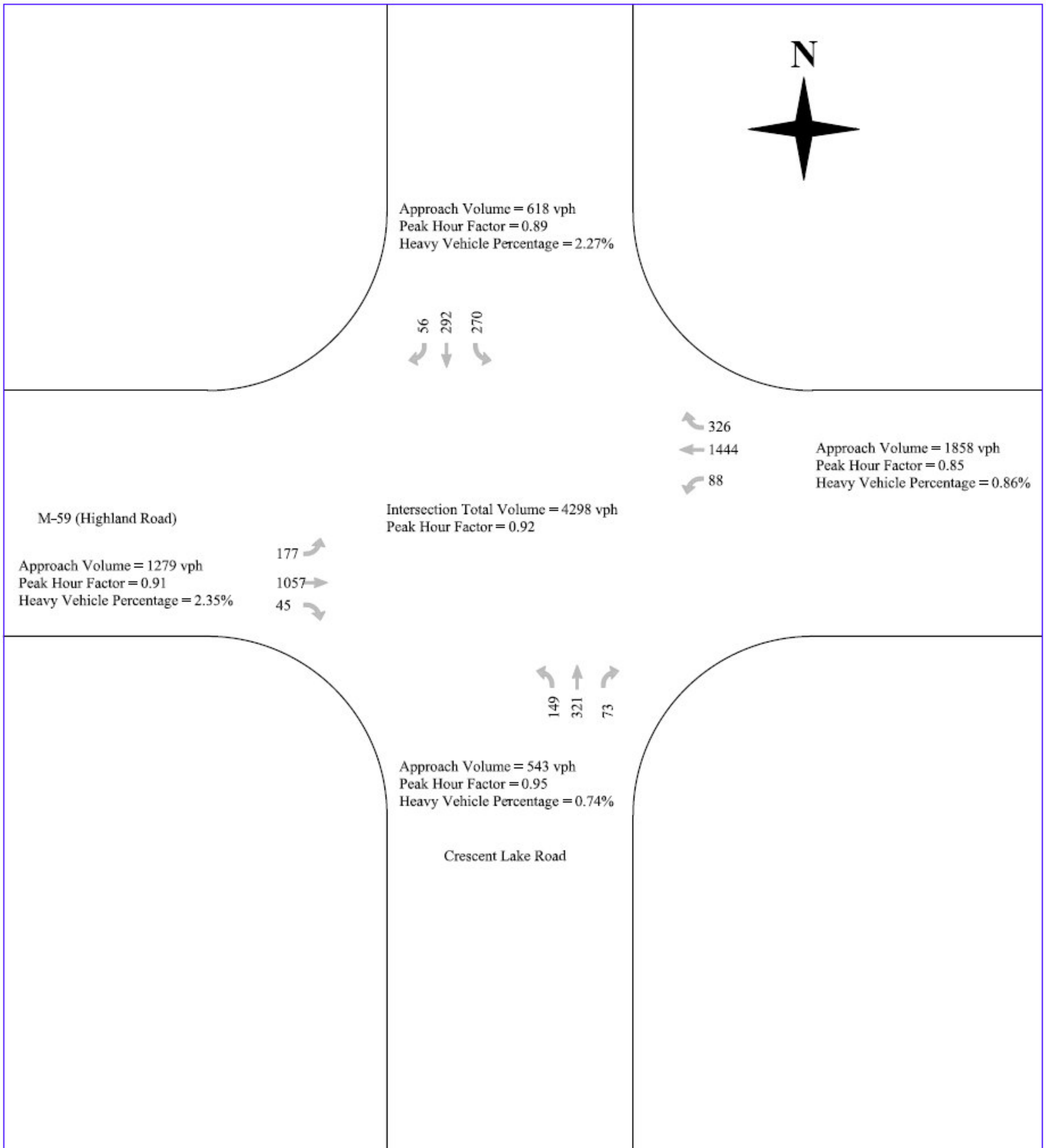
Volume Diagram
M-59 and Williams Lake Road
PM Peak Hour Volume Diagram



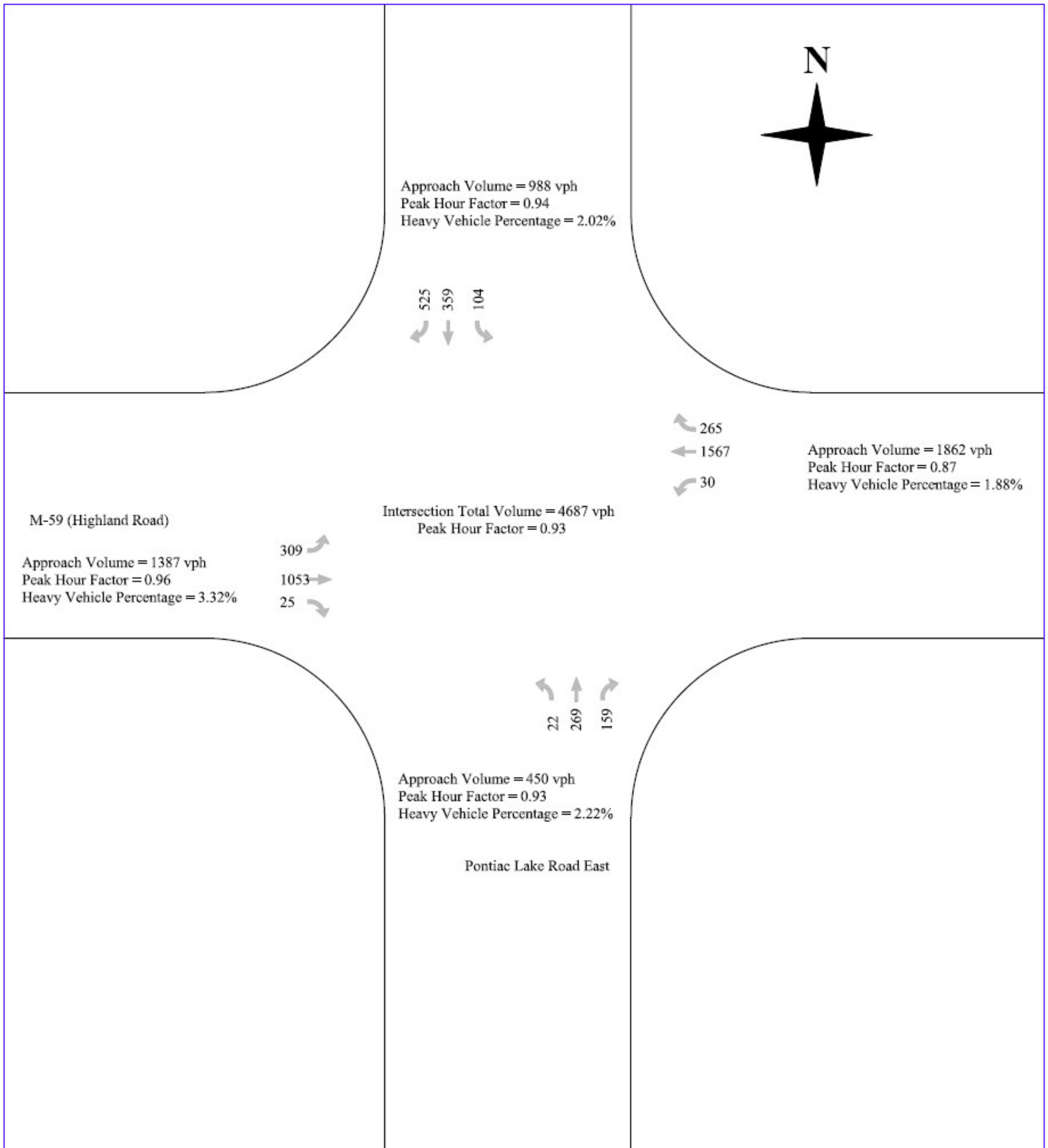
Volume Diagram
M-59 and Oakland Boulevard
PM Peak Hour Volume Diagram



Volume Diagram
M-59 and Airport Road
PM Peak Hour Volume Diagram



Volume Diagram
M-59 and Crescent Lake Road
PM Peak Hour Volume Diagram



Volume Diagram
M-59 and Pontiac Lake Road East
PM Peak Hour Volume Diagram