Comparative Performance Evaluation of SCATS and Pre-timed Control Systems

By
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ABSTRACT

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. At the current level of funding, it would take 70 years to meet the capacity needs of the Oakland County roadways *(2)*. 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.

Through 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. SCAT 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.

In order to evaluate the performance of SCATS control system a research was conducted to determine the effectiveness of the SCATS signal system as compared to a pre-timed signal system in terms of traffic flow, delay, fuel consumption, emission and other selected measures of effectiveness. The research was conducted through a field experiment along a four-mile segment of M-59 between Pontiac Lake Road West to Pontiac Lake Road East consisting of seven signalized intersections. The M-59 corridor is located in Oakland County, Michigan. The data for the corridor was collected for the two signal system scenarios on a typical weekday and Friday for the noon (12 PM to 1 PM) and PM (4 PM to 6 PM) peak period, as well for a Saturday peak (9 AM to 11 AM). For the purpose of this study, M-59 corridor was converted from SCAT control system to Pre-Timed control system for eight weeks. When comparing the mean values for the various measures of effectiveness, the SCATS signal system, generally, had better performance indicators than the pre-timed signal system based upon the percent differences between the two systems. However, based upon the statistical analysis, the majority of the statistical tests indicated that there was no statistical difference between the two signal systems for any of the measures of effectiveness or peak periods analyzed.

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INTRODUCTION AND BACKGROUND

Metropolitan areas across the United States have been experiencing increased traffic congestion problems over the past several years due to increased travel demands and a lack of sufficient highway capacity. The total delay that drivers experienced has increased from 0.8 billion hours in 1982 to 4.2 billion hours in 2005 *(1)*. Factoring in the 2.9 billion gallons of fuel consumed due to congestion, leads to a total congestion cost of $78.2 billion dollars for drivers in 437 urban areas of the nation *(1)*. Operational treatments that have been implemented in 2005 saved drivers 292 million hours of travel delay and $5.4 billion of congestion costs.

In spite of the implementation of many demand management measures, congestion and its associated costs in 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.

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. At the current level of funding, it would take 70 years to meet the capacity needs of the Oakland County roadways *(2)*. 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.

Through 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. SCAT 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 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 among 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 was 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 measures of effectiveness (MOE's).

A literature review was performed to examine past research on the signal coordination and progression for corridors and networks. 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 as the ability to generalize the benefits may vary on corridor length, intersection spacing, traffic volumes or volume variation *(3)*. 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 *(4)*. 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 *(4)*. SCOOT has been utilized in Toronto, San Diego, Anaheim, London and Bangkok *(5)*. 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 *(4)*. The SCATS system has been utilized in Hong Kohn, Sydney, Melbourne and Oakland County, Michigan *(5)*.

Martin et. al. *(4,6)* 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 *(7)*. 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 *(3)*. 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.

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 *(8)*. 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.

Abdel-Rahim and Taylor *(9)* 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. However, 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 *(10)*.

Past research projects have evaluated signal systems through various measures of effectiveness. Park et. al. *(11)* 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 *(12)* 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. *(4,6)* to compare the delay, queue length and travel time between SCOOT and a fixed-time system with CORSIM. Wolshon and Taylor *(13)* utilized intersection delay for individual movements in order to analyze the implementation of the SCATS system in South Lyon, Michigan. Liu and Cheu *(7)* 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 *(14)*. Girianna and Benekohal *(15)* validated a two-way street network with ten signalized intersections utilizing total vehicles discharged and average link speed.

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, total delay, queue length, fuel consumption, emission data, number of stops and number of stopped vehicles.

METHODOLOGY AND STUDY DATA

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 traffic characteristics as compared to a pre-timed signal system. The evaluation of the SCATS system was conducted through a field experiment along a four-mile segment of M-59 between Pontiac Lake Road West to Pontiac Lake Road East consisting of seven signalized intersections, an average annual daily traffic of approximately 44,000 and a speed limit of 50 miles per hour.

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 June of 2007 while area schools were still in session. The following equation was used to calculate the number of runs required *(16,17)*:

Where,

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

= 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 *(16)*, 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" *(16)*. 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 as shown in Table 1. Based upon the preliminary travel time data, it was assumed that ten to fourteen travel time runs should satisfy the sample size requirements for travel time.

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

$\hat{\sigma}$

TABLE 1 Statistical Data Summary from Preliminary Travel Time 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

The data for the M-59 corridor was collected for the two signal system scenarios 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 peak (9AM to 11 AM). The travel time, travel speed, fuel consumption, emissions (hydrocarbon, carbon monoxide and nitrogen oxide), number of stops and total delay data was collected using computerized equipment available from JAMAR Technologies. The travel data collection method was based upon the 'Average Vehicle, Floating Car' method as outlined in the Institute of Transportation Engineers (ITE) Manual of Traffic Engineering Studies *(17)*. 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 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 by critical lane group, left turn or through movements, for each of the 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 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 travel runs were conducted only on days in which the weather conditions were clear and dry. Due to similarities in the results of the analysis for eastbound, westbound and the combined eastbound/westbound travel directions, only the combined eastbound/westbound travel data and statistical analysis results will be presented. The data collected by peak period for each of the two signal systems are presented in Table 2. Also presented in Table 2 is the percent difference between the mean values for each MOE with an indication of the system with better performance indicators, 'S' for the SCATS system and 'P' for the pre-timed system. The percent difference was calculated by dividing the difference of the pre-timed system mean and the SCATS system mean by the pre-timed system mean and then multiplying by 100.

TABLE 2 Signal System Data Summary

MOE	**MOE Mean Value by System for Combined EB/WB**	**Peak Period**				
		Weekday Noon	**Weekday PM**	**Friday Noon**	**Friday PM**	**Saturday**
Travel Time (sec)	Pre-timed System	399.00	442.67	413.80	453.81	393.64
	SCATS System	392.41	413.10	394.20	438.66	376.05
	Percent Difference	1.65% (S)	6.68% (S)	4.74% (S)	3.34% (S)	4.47% (S)
Travel Speed (mph)	Pre-timed System	35.24	32.51	34.52	31.23	37.11
	SCATS System	36.52	34.77	36.26	33.07	38.26
	Percent Difference	3.60% (S)	6.95% (S)	5.04% (S	5.89% (S)	3.10% (S)
Fuel Consumption (gallons)	Pre-timed System	0.2180	0.2269	0.2220	0.2256	0.2131
	SCATS System	0.2115	0.2154	0.2139	0.2209	0.2060
	Percent Difference	2.98% (S)	5.07% (S)	3.65% (S)	2.08% (S)	3.33% (S)
Hydrocarbon Emissions (grams)	Pre-timed System	19.94	20.96	20.05	20.77	18.18
	SCATS System	18.82	19.38	19.28	20.54	17.33
	Percent Difference	5.62% (S)	7.54% (S)	3.84% (S)	1.11% (S)	4.68% (S)
Carbon Monoxide Emissions (grams)	Pre-timed System	247.77	262.91	255.36	250.80	229.66
	SCATS System	242.33	243.46	247.71	251.94	223.23
	Percent Difference	2.20% (S)	7.40% (S)	3.00% (S)	0.45% (P)	2.80% (S)
Nitrogen Oxide Emissions (grams)	Pre-timed System	12.85	13.24	12.73	12.97	11.24
	SCATS System	11.83	12.16	12.27	12.88	10.63
	Percent Difference	7.94% (S)	8.16% (S)	3.61% (S)	0.69% (S)	5.43% (S)
Number of Stops	Pre-timed System	2.75	3.33	2.72	3.91	2.36
	SCATS System	2.00	2.45	1.90	3.03	1.68
	Percent Difference	27.27% (S)	26.43% (S)	30.15% (S)	22.51% (S)	28.81% (S)
Total Travel Delay (sec)	Pre-timed System	120.29	158.04	129.24	174.73	107.09
	SCATS System	106.62	127.93	108.60	155.69	90.73
	Percent Difference	11.36% (S)	19.05% (S)	15.97% (S)	10.90% (S)	15.28% (S)
Number of Stopped Vehicles	Pre-timed System	680.00	1289.96	690.54	1237.42	414.58
	SCATS System	685.04	1072.33	737.46	1173.92	496.71
	Percent Difference	0.74% (P)	16.87% (S)	6.79% (P)	5.13% (S)	19.81% (P)
Maximum Queue Length (vehicles)	Pre-timed System	16.50	23.23	15.83	21.00	12.58
	SCATS System	15.29	19.17	16.83	20.67	17.38
	Percent Difference	7.33% (S)	17.48% (S)	6.32% (P)	1.57% (S)	38.16% (S)

As depicted in Table 2, the SCATS signal system had better performance indicators than the pre-timed signal system based upon the percent differences between the two systems. The exceptions being during the Friday PM peak period, the pre-timed system had fewer carbon monoxide emissions, during the Friday noon peak period and Saturday peak period, the pre-timed system had fewer vehicles stopped at the intersections along the M-59 corridor and during the Friday noon peak period, the pre-timed system had a shorter queue length along the M-59 corridor. In terms of travel speed, each of the peak periods exhibited speeds significantly below the posted speed of 50 miles per hour. However, as expected, the PM peak period speeds were lower than those during the noon peak or Saturday peak when traffic volumes are 25 to 35 percent lower.

RESULTS AND 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.

All of the data, except for the number of stopped vehicles and maximum queue length, was analyzed for adherence to the assumption of normality for use in the Student’s t-test for determining if the difference in the means were 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 data indicated that the data was not normally distributed and therefore the Student’s t-test could not be utilized while maintaining adequate power and robustness of the test which assures the results of the analysis. An analysis of variance (ANOVA) test, at a 95 percent level of confidence, was conducted on the data to determine if the difference in the means between the SCATS and the MDOT pre-timed system were 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 each of the measures of effectiveness for the SCATS system as compared to the MDOT pre-timed system were statistically significantly different for the eastbound travel, the westbound travel and the combined travel (eastbound and westbound). 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.

The number of stopped vehicles and the maximum queue length data was analyzed using the paired t-test due to the matched characteristics of the data collected. The data was collected for each intersection’s critical lane group for the same period under each signal system. The paired t-tests were conducted for the M-59 corridor and the minor roadways separately for each peak period.

The peak periods for the analysis included the weekday noon, weekday PM, Friday noon, Friday PM and Saturday. The null hypotheses stated that there was no difference in the measure of effectiveness between the SCATS and the MDOT pre-timed systems.

Based upon the statistical analysis, the null hypotheses were accepted for all of the comparisons between the SCATS and the MDOT pre-timed system, except for the fuel consumption during the weekday PM peak period (combined travel). The acceptance of the null hypothesis for the majority of the statistical tests indicates there was no statistical difference between the two signal systems for any of the MOE's or peak periods analyzed. In terms of the fuel consumption analysis during the weekday PM peak period; 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. When compared separately, the eastbound and westbound fuel consumption data analysis does not produce a significant result. 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 combined travel (eastbound/westbound) results of the post hoc tests are shown in Table 3.

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
- Maximum queue length at each intersection for M-59

TABLE 3 Results of Statistical Testing

MOE	**MOE Mean Value by System for Combined EB/WB**	**Peak Period**				
		Weekday Noon	**Weekday PM**	**Friday Noon**	**Friday PM**	**Saturday**
Travel Time (sec)	Mean Difference	-6.59	-29.56	-19.60	-15.15	-17.59
	Standard Error	11.89	12.91	13.36	17.87	17.05
	p-Value	1.00	0.414	0.887	0.997	0.988
	Test Result	SCATS = Pre-timed				
Travel Speed (mph)	Mean Difference	1.27	2.26	1.74	1.84	1.15
	Standard Error	0.91	1.11	1.24	1.21	1.52
	p-Value	0.919	0.584	0.911	0.874	0.999
	Test Result	SCATS = Pre-timed				
Fuel Consumption	Mean Difference	-0.006	-0.11	-0.008	-0.005	-0.007
	Standard Error	0.004	0.003	0.005	0.004	0.005
	p-Value	0.850	0.019	0.873	0.959	0.930
	Test Result	SCATS = Pre-timed	Reject Null; SCATS ≠ Pre-timed	SCATS = Pre-timed		
Hydrocarbon Emissions	Mean Difference	-1.12	-1.58	-0.766	-0.232	-0.852
	Standard Error	0.584	0.579	0.926	0.666	0.843
	p-Value	0.660	0.187	0.996	1.000	0.990
	Test Result	SCATS = Pre-timed				
Carbon Monoxide Emissions	Mean Difference	-5.44	-19.46	-7.65	1.15	-6.43
	Standard Error	11.07	6.99	14.12	6.96	10.63
	p-Value	1.000	0.169	1.000	1.000	1.000
	Test Result	SCATS = Pre-timed				
Nitrogen Oxide Emissions	Mean Difference	-1.01	-1.08	-0.456	-0.083	-0.615
	Standard Error	0.508	0.495	0.770	0.510	0.662
	p-Value	0.607	0.483	1.000	1.000	0.994
	Test Result	SCATS = Pre-timed				
Number of Stops	Mean Difference	-0.75	-0.89	-0.82	-0.88	-0.68
	Standard Error	0.29	0.35	0.35	0.46	0.47
	p-Value	0.251	0.266	0.414	0.651	0.901
	Test Result	SCATS = Pre-timed				
Total Travel Delay	Mean Difference	-13.67	-30.11	-20.64	-19.04	-16.34
	Standard Error	9.83	12.96	13.21	17.09	16.70
	p-Value	0.924	0.393	0.848	0.981	0.992
	Test Result	SCATS = Pre-timed				
Number of Stopped Vehicles	Mean Difference	-5.04	217.63	-46.92	63.50	-82.13
	Standard Error	85.97	113.96	121.28	240.42	69.65
	p-Value	0.954	0.069	0.702	0.794	0.250
	Test Result	SCATS = Pre-timed				
Maximum Queue Length (vehicles)	Mean Difference	1.21	4.08	-1.00	0.33	-4.79
	Standard Error	1.52	2.06	1.96	2.89	4.11
	p-Value	0.435	0.060	0.616	0.909	0.256
	Test Result	SCATS = Pre-timed				

The statistical significance of the effectiveness of the two signal systems were tested to determine whether the changed 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.

Although only one statistically significant result was found among the various MOE's test for various peak periods, the performance of the SCATS system was found to be superior for several of the performance measures for each of the peak periods. In terms of the fuel consumption analysis during the weekday PM peak period where the significant result was 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. When compared separately, the eastbound and westbound fuel consumption data analysis does not produce a significant result.

Even though the results of the statistical analysis did not prove to be significant at a level of confidence at 95 percent, the data indicated that the SCATS system outperformed the pre-timed system in terms of having better performance indicators.

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