Adaptive Control Software – LITE Before and After Traffic Analysis, State Highway 6 – City of Houston, Texas

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U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The *Adaptive Control Software - LITE Before and After Traffic Analysis Report* provides information on the traffic data collection study performed on State Highway 6 in the City of Houston, Texas. The study was conducted to fully assess the benefits of Adaptive Control Software Lite (ACS Lite). The ACS Lite software is a tool for optimization of traffic signal timing splits and offsets in a 'real time' mode of operation. The software monitors traffic volumes in real-time and issues commands, on a cycle-by-cycle basis, to the controller to adjust splits and offsets for optimum operations.

This report will be useful to the Federal Highway Administration (FHWA), Office of Operations Research and Development and to small and medium cities that have existing Closed Loop traffic signal systems that are neither obsolete nor state-of-the-art.

Toni Wilbur, Director
Office of Operations
Research and Development

Technical Report Documentation Page

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

1. INTRODUCTION

The Federal Highway Administration, Office of Operations Research and Development requested a 'Before' and 'After' traffic data collection study be performed on State Route 6 in the City of Houston, Texas to fully assess the benefits of Adaptive Control Software Lite (ACS Lite). The ACS Lite software is a tool for optimization of traffic signal timing splits and offsets in a 'real time' mode of operation. The software monitors traffic volumes in real-time and issues commands, on a cycle-by-cycle basis, to the controller to adjust splits and offsets for optimum operations.

Specifically, this study focused on the following:

- Collecting 'before' and 'after' traffic volume machine counts on State Route 6 (SR 6) between Clay Road to the south and West Little York Road to the north – eight intersections
- Performing 'before' and 'after' floating car travel time and delay studies along SR 6 – eight intersections
- Performing statistical analysis on 'before' and 'after' traffic volumes, speed and travel time and delay data

The results indicate that the total delay, number of stops and fuel consumption decreased during the 'after' study period in which the ACS Lite software was in effect along the SR 6 study corridor. The analysis shows that there would be an annual savings of approximately $578,000 due to these improvements.

2. OBJECTIVES

The objectives of this study are to collect and analyze 'before' and 'after' performance measures and assess the benefits of the ACS Lite software. Traffic data was collected before (November 14 – November 17, 2005) and after (January 9 – January 12, 2006) the ACS Lite software was implemented at all eight intersections along the SR 6 corridor. The data collected for this purpose included machine volume counts, travel time, speed and delay. Statistical analysis was performed on the 'before' and 'after' data for comparison. The speed data is evaluated for the statistical mean, median, standard deviation, range, and skew.

The ACS Lite is designed for retrofit to existing Closed Loop Systems without having to change controllers, communication media and other devices. The system is designed for small to medium cities where the existing systems are neither obsolete nor state-of-the-art. The ACS Lite was tested against the existing timing along SR 6, which was last retimed and optimized in 2002.

3. SITE DESCRIPTION

The study corridor of State Route 6 is located in the greater Houston, Texas metropolitan area. The study section of SR 6 is north of I-10 and west of State Route 8. There are eight traffic signals in this network, from Clay Road to the south to West Little York Road to the north. The total length of this study section is approximately 3.5 kilometers (2.1 miles). An area map of the corridor is shown in figure 1.

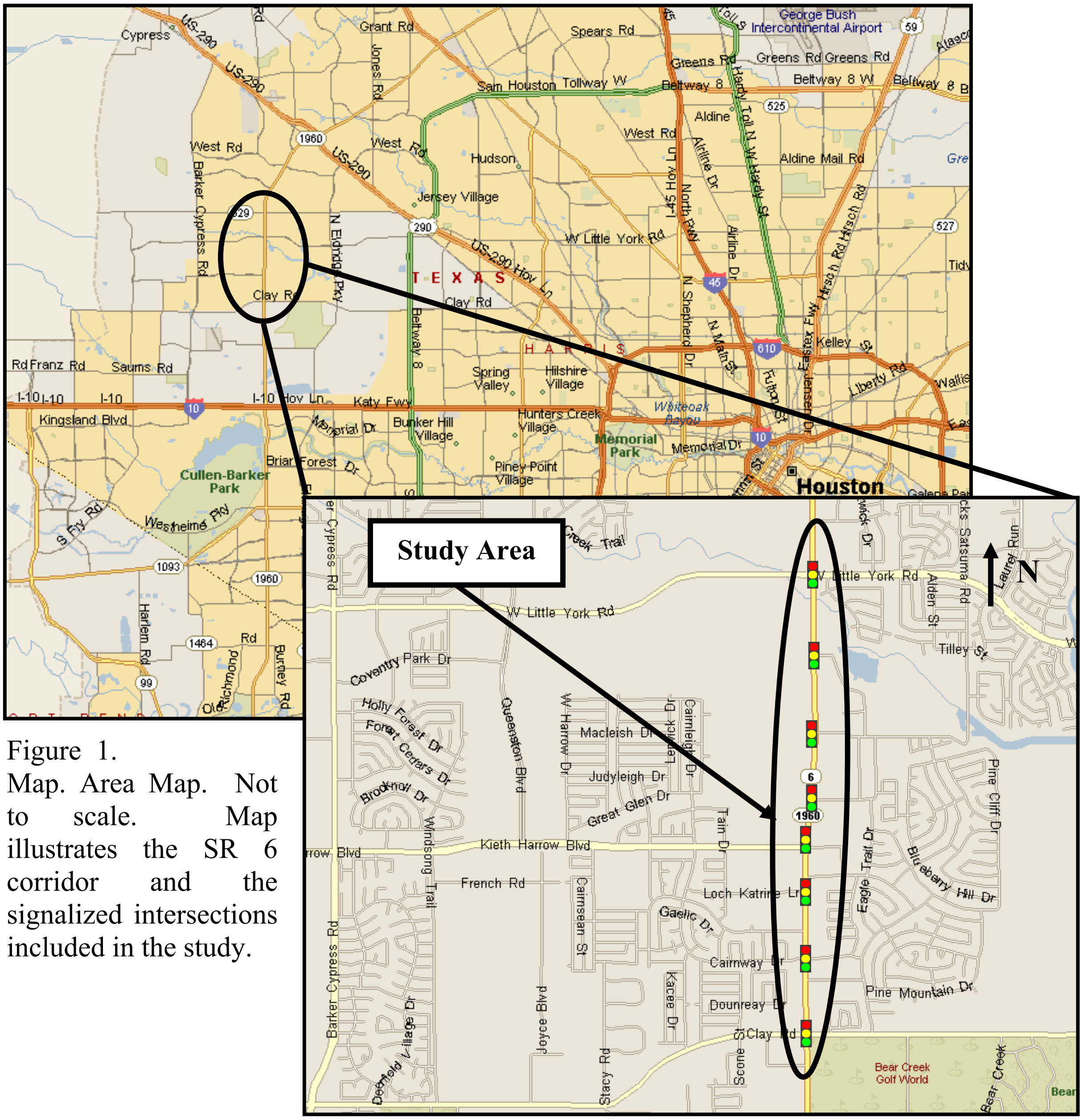

Figure 1. Map. Area Map. Not to scale. Map illustrates the SR 6 corridor and the signalized intersections included in the study.

Photographs of the study corridor are included in appendix A. The lane configurations, NEMA phasing and link distances for the study corridor are shown on the condition diagram also included in appendix A.

4. DATA COLLECTION METHODOLOGY

The following traffic data was collected before and after the activation of the ACS Lite software:

- Traffic volume machine (pneumatic tube) counts at the following locations:
    - NB and SB SR 6, north of West Little York Road
    - SB SR 6, north of Kieth-Harrow Boulevard
    - NB SR 6, south of Kieth-Harrow Boulevard
    - NB and SB SR 6, south of Clay Road
- Floating car travel time and delay runs along SR 6

The pneumatic tube locations were selected to collect traffic data entering and exiting the network, as well as at the critical intersection of Kieth-Harrow Boulevard.

4.1. Traffic Volumes

Traffic volumes were collected using Jamar Technologies Traxpro™ machines and pneumatic tubes. The locations of the counts were selected in coordination with the Texas Department of Transportation. The volume counts were collected for a minimum of a 72-hour weekday period within the 'before' and 'after' study periods. The data was collected in 15-minute increments. These volumes were used to assess any changes in traffic patterns during the before and after study periods. The volume counts are included in appendix B.

Figure 2. Photo. Volume tubes on SR 6. The pneumatic tubes were placed across SR 6 to collect traffic volumes in the study corridor.

4.2. Travel Time Runs

Speed and travel time data was collected utilizing Global Positioning System Time Reference Receiver devices (GPS TRR) (see figure 3). The GPS TRR units were installed in two test vehicles. Time-stamped coordinates were collected in 0.10-second increments. This information was then downloaded and reduced to derive travel time and speeds. Travel time runs were performed using the "floating car" methodology. In this method, a test vehicle is driven at an average speed through the arterial, allowing vehicular speed to be dictated by the platoon speed, not the posted speed limit. Travel time measurements begin when the test vehicle passes the stop line at the first intersection, and end when the vehicle passes the stop line at the last intersection in the section of arterial being evaluated.

Figure 3. Photo. In-Vehicle GPS System for data collection. The Global Positioning System Time Reference Receiver and handheld palm pilot were used to collect travel time data.

Northbound and southbound travel time studies were performed for the SR 6 corridor. The northern and southern limits of the study area are the traffic signals at West Little York Road and Clay Road, respectively. Travel time studies were performed on Monday through Thursday (November 14, 2005 – November 17, 2005 and January 9, 2006 – January 12, 2006) for the before and after study periods, respectively. A minimum of 25 runs was collected in each direction between the hours of 7 AM to 9 AM and 4 PM to 6 PM. In addition, several manual travel time runs were collected to validate the GPS data. Detailed travel time data is included in appendix C.

The data in this report is aggregated for total travel time, travel time delay, and stopped delay time by link, and by approach and by peak period. Stopped delay is the time a vehicle is stopped while waiting to pass an intersection. It is assumed that stopped delay is 5 seconds of continuous travel below 8 kilometers per hour.

Travel time delay is defined as the difference between the actual time for a vehicle to pass the intersection and the time for the vehicle to pass the intersection at the driver's desired speed. Figure 4 illustrates these delay concepts.

The speed limit in the study corridor is 72 kilometers per hour (45 miles per hour).

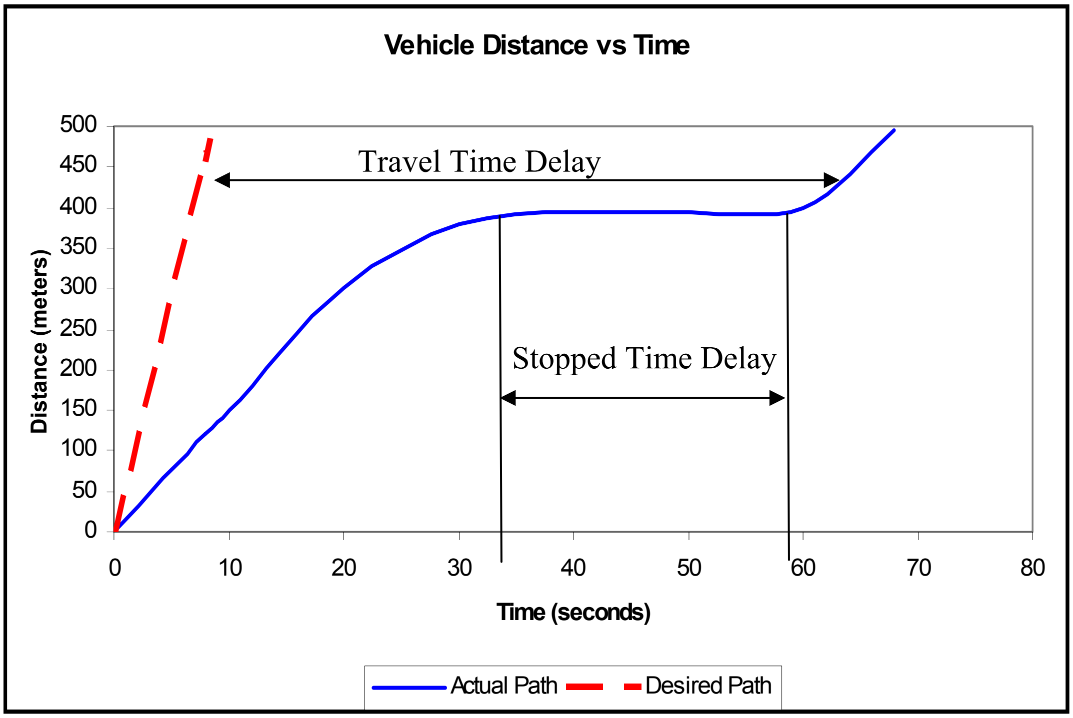

Figure 4. Graph. Illustration of stopped and travel time delay. The distance versus time graph illustrates the concepts of the travel time delay, which is shown as the difference in time between the free flow travel time and the actual travel time, and the stopped time delay, which is shown as the duration of travel below 8 kilometers per hour (5 miles per hour).

5. DATA COLLECTION

5.1 Before Data

'Before' data collection was performed during the week of November 14, 2005. Traffic volumes were collected beginning the evening of Sunday, November 13th through the evening of Thursday, November 17th. Traffic volumes were averaged across all days and an average peak hour volume is determined at each volume location.

A minimum of 25 travel time and delay runs was performed for each direction in each time period. Any runs containing erroneous data or where abnormal events occurred (accidents, etc.) were discarded. All of the runs for the separate peak periods are combined over the three days of data collection.

5.2 After Data

'After' data collection was performed during the week of January 9, 2006. Traffic volumes were collected beginning the evening of Sunday, January 8th through Thursday, January 12th. Table 1 summarizes the peak hour volumes for the 'before' and 'after' periods at each location.

Table 2 summarizes the travel time, number of stops, stopped delay and travel time delay for the northbound and southbound AM and PM peak periods. Detailed 'before' and 'after' travel time data is included in appendix C.

Table 1. 'Before' and 'after' peak hour volumes - AM (PM)

Machine Location	NB (vehicles)		SB (vehicles)	
	Before	After	Before	After
NB and SB SR 6 (North of West Little York Road)	1973 (2645)	1923 (2896)	2103 (2211)	2096 (2254)
SB SR 6 (North of Kieth-Harrow Boulevard)	---	---	2283 (2198)	2100 (1940)
NB SR 6 (South of Kieth-Harrow Boulevard)	1570 (2585)	1505 (2765)	---	---
NB and SB SR 6 (South of Clay Road)	1179 (2212)	1149 (2413)	2116 (1343)	2128 (1239)

Table 2. Travel time results – before (after)

MOE	NB AM	NB PM	SB AM	SB PM
Number of Runs	35 (40)	32 (35)	35 (41)	32 (37)
Travel Time (s)	252.7 (197.9)	310.8 (256.5)	225.8 (208.8)	221.2 (211.3)
Number of Stops	2.2 (1.0)	3.0 (2.2)	1.4 (1.1)	0.8 (0.7)
Stopped Delay (s)	44.1 (19.2)	69.2 (39.5)	29.6 (25.2)	24.3 (18.9)
Travel Time Delay (s)	75.9 (32.8)	128.1 (83.0)	51.6 (41.8)	43.9 (38.9)

6. COMPARISON ANALYSIS

The performance measures used for analysis are speed, travel time, number of stops, stopped delay and travel time delay.

The 'before' and 'after' volumes are compared to assess the similarity of the study conditions during the travel times. Overall, the network volume experienced a very marginal change, less than 0.1-percent, between the 'before' and 'after' studies. Figures 5a and 5b illustrate the difference in volume by machine count location for the AM and PM peak periods, respectively.

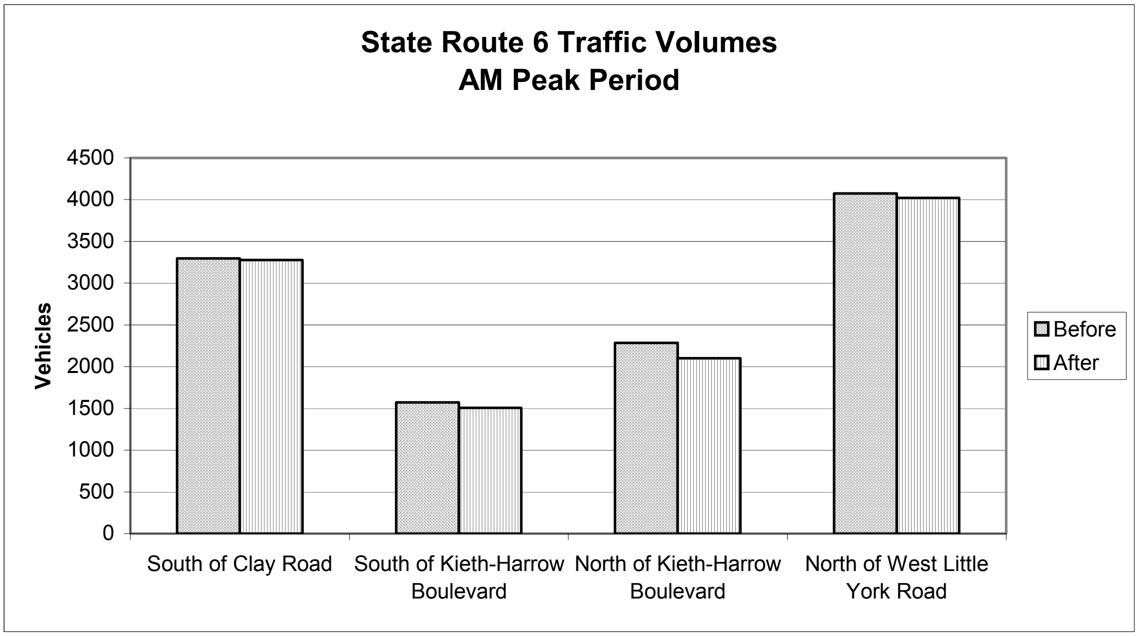

Figure 5a. Bar Chart. SR 6 traffic volumes – AM peak period. Bar chart depicts the following AM peak hour traffic volumes on SR 6 for the before study (3295 vehicles south of Clay Road, 1570 vehicles south of Kieth-Harrow Boulevard, 2283 vehicles north of Kieth-Harrow Boulevard, and 4076 vehicles north of West Little York Road) and after study (3277 vehicles south of Clay Road, 1505 vehicles south of Kieth-Harrow Boulevard, 2100 vehicles north of Kieth-Harrow Boulevard, and 4019 vehicles north of West Little York Road).

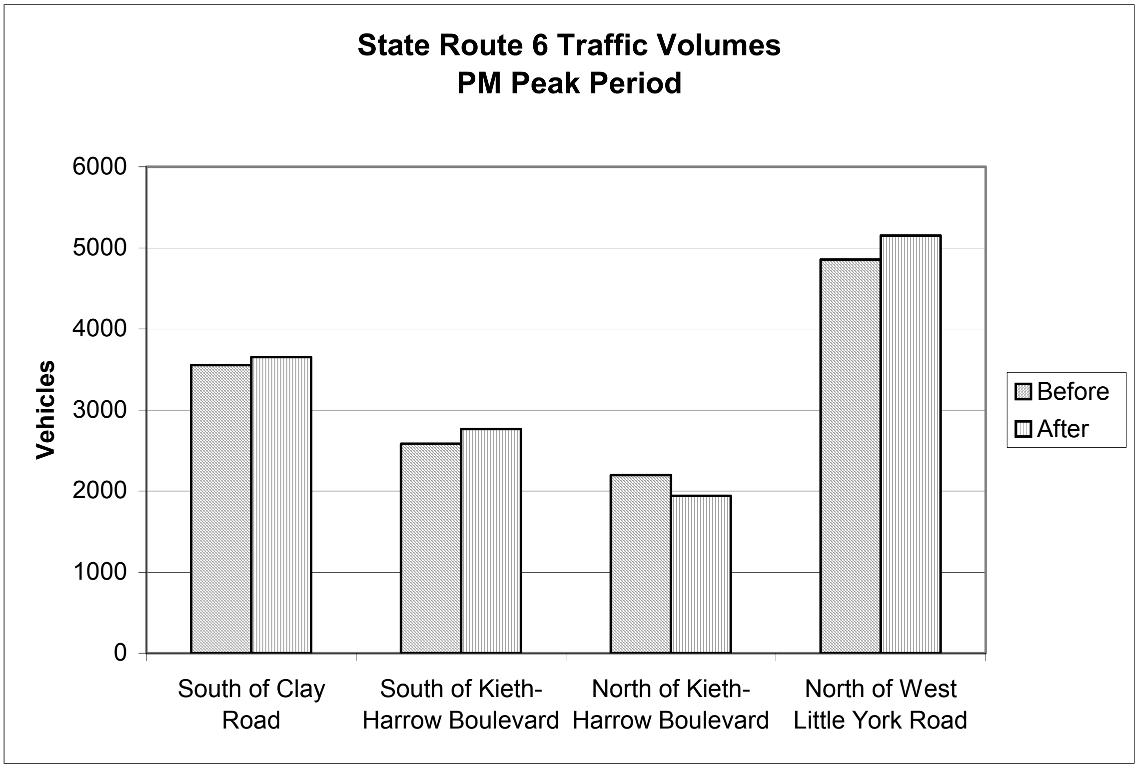

Figure 5b. Bar Chart. SR 6 traffic volumes – PM peak period. Bar chart depicts the following PM peak hour traffic volumes on SR 6 for the before study (3555 vehicles south of Clay Road, 2585 vehicles south of Kieth-Harrow Boulevard, 2198 vehicles north of Kieth-Harrow Boulevard, and 4856 vehicles north of West Little York Road) and after study (3652 vehicles south of Clay Road, 2765 vehicles south of Kieth-Harrow Boulevard, 1940 vehicles north of Kieth-Harrow Boulevard, and 5150 vehicles north of West Little York Road).

Speed data is aggregated for all of the runs during the 'before' and 'after' study periods. Speed statistics are summarized in table 3.

Table 3. Summary of State Route 6 speed statistics

Statistic	Before	After
Number of Observations	134	154
Mean Speed (km/h)	50.1 (31.1 mi/h)	60.3 (37.5 mi/h)
Median Speed (km/h)	48.8 (30.3 mi/h)	63.1 (39.2 mi/h)
Standard Deviation	10.3 (6.4 mi/h)	11.2 (6.2 mi/h)
Range (km/h)	22 – 82 (14 – 51 mi/h)	37 – 82 (23 – 51 mi/h)
Skew	0.08	0.23
85th Percentile Speed (km/h)	61 (38 mi/h)	71 (44 mi/h)

1. *Mean Speed – the arithmetic mean of all observed vehicle speeds*
2. *Median Speed – the speed at the middle value in a series of spot speeds that is arranged in ascending order.*
3. *Standard Deviation – measure of the spread of the individual speeds*
4. *Range – the minimum and maximum observed speeds*

5. *Skew – a characterization of the degree of asymmetry of a distribution around its mean*
6. *85th Percentile Speed – the spot speed value below which 85 percent of the vehicles travel.*

As shown in table 3, the speed statistics improved in the 'after' period. The mean speed, median speed, and the 85th-percentile speed increased by 20-percent, 29-percent, and 16-percent, respectively.

The remaining data is separated into nine groups for comparison. The runs are analyzed in the following groups: all runs, northbound runs, southbound runs, AM peak runs, PM peak runs, northbound AM runs, northbound PM runs, southbound AM runs and southbound PM runs. Figures 6 – 9 illustrate the comparison of the travel times, number of stops, stopped delay and travel time delay for each of the nine groups.

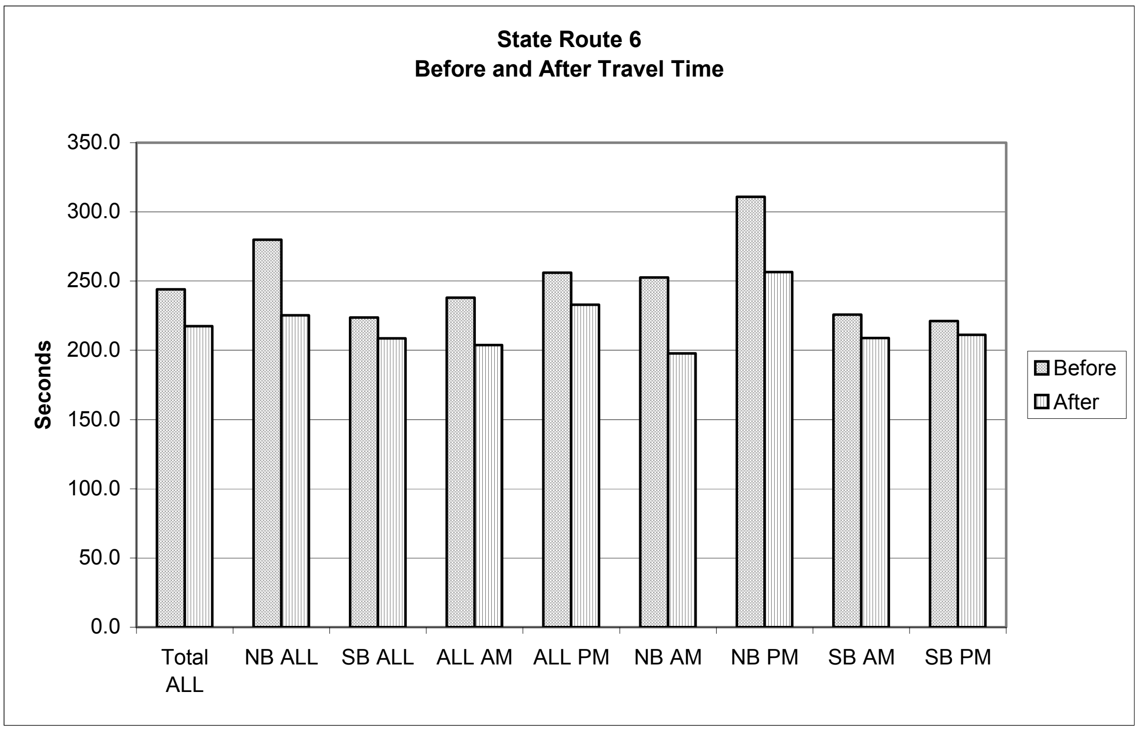

Figure 6. Bar Chart. Summary of 'before' and 'after' travel time (seconds). Bar chart depicts the following average travel times on SR 6 for the before study (244.1 seconds for all runs, 279.8 seconds for all northbound runs, 223.6 seconds for all southbound runs, 238.1 seconds for all AM runs, 256.1 seconds for all PM runs, 252.7 seconds for all northbound AM runs, 310.8 seconds for all northbound PM runs, 225.8 seconds for all southbound AM runs, and 221.2 seconds for all southbound PM runs) and after study (217.7 seconds for all runs, 225.2 seconds for all northbound runs, 208.6 seconds for all southbound runs, 203.9 seconds for all AM runs, 233.0 seconds for all PM runs, 197.9 seconds for all northbound AM runs, 256.5 seconds for all northbound PM runs, 208.8 seconds for all southbound AM runs, and 211.3 seconds for all southbound PM runs).

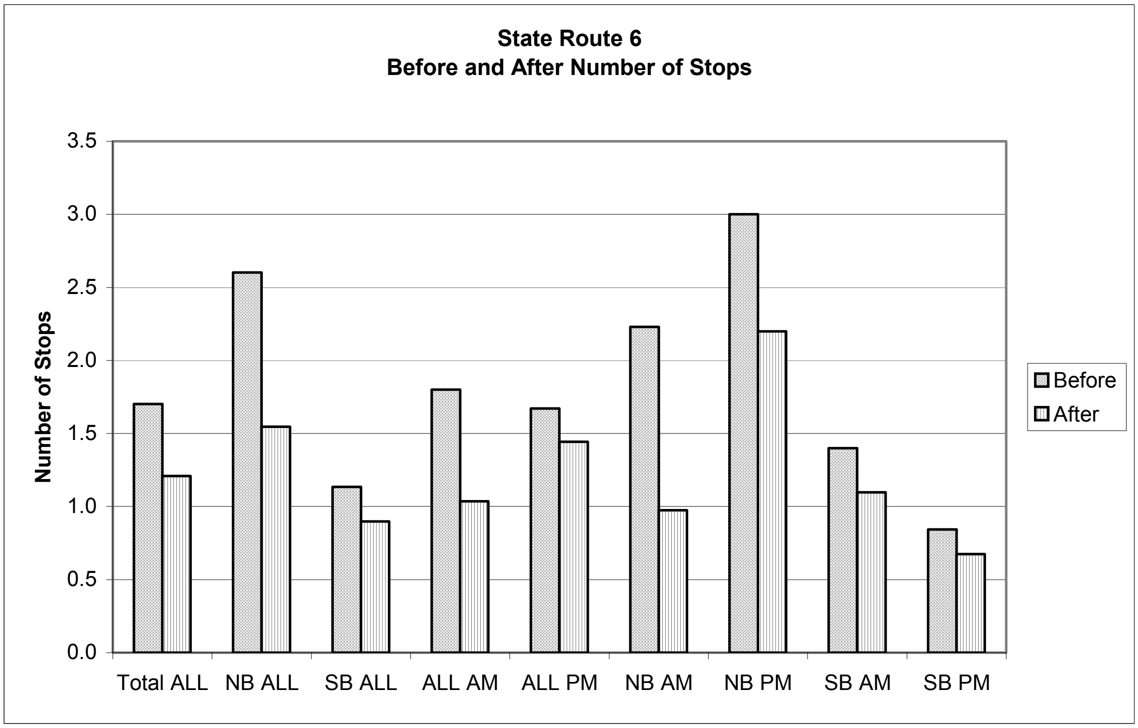

Figure 7. Bar Chart. Summary of 'before' and 'after' number of stops. Bar chart depicts the following average number of stops on SR 6 for the before study (1.7 stops for all runs, 2.6 stops for all northbound runs, 1.1 stops for all southbound runs, 1.8 stops for all AM runs, 1.7 stops for all PM runs, 2.2 stops for all northbound AM runs, 3.0 stops for all northbound PM runs, 1.4 stops for all southbound AM runs, and 0.8 stops for all southbound PM runs) and after study (1.2 stops for all runs, 1.5 stops for all northbound runs, 0.9 stops for all southbound runs, 1.0 stops for all AM runs, 1.4 stops for all PM runs, 1.0 stops for all northbound AM runs, 2.2 stops for all northbound PM runs, 1.1 stops for all southbound AM runs, and 0.7 stops for all southbound PM runs).

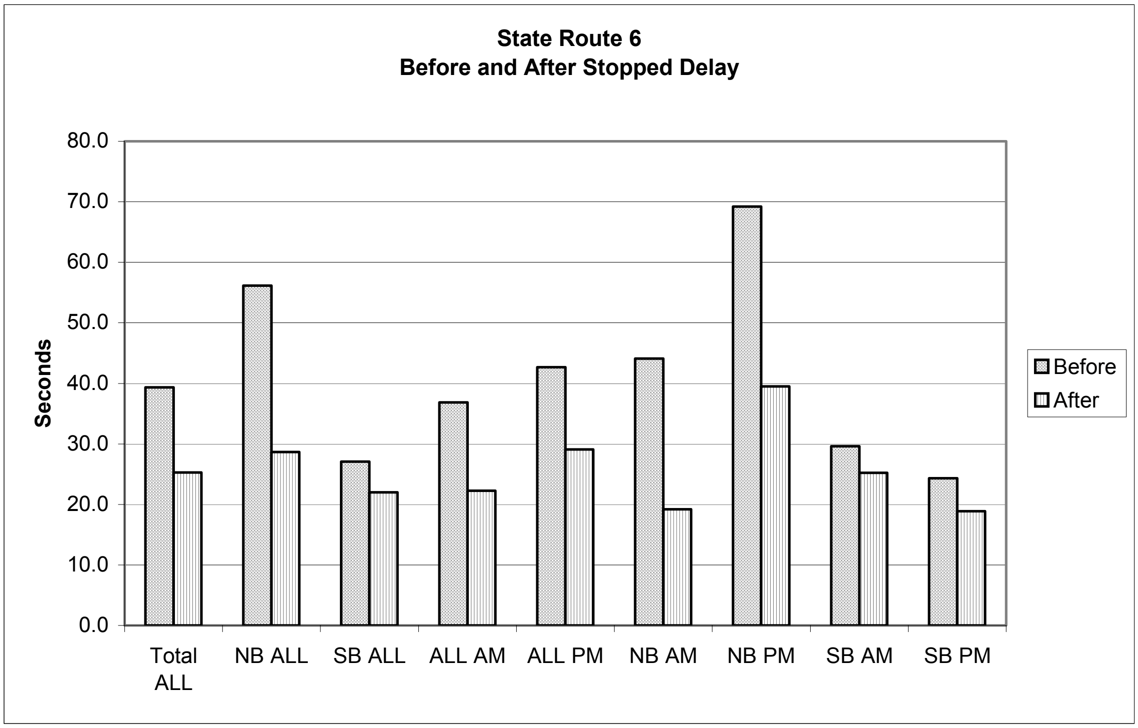

Figure 8. Bar Chart. Summary of ‘before’ and ‘after’ stopped delay (seconds). Bar chart depicts the following average stopped delay times on SR 6 for the before study (39.3 seconds for all runs, 56.1 seconds for all northbound runs, 27.1 seconds for all southbound runs, 36.8 seconds for all AM runs, 42.7 seconds for all PM runs, 44.1 seconds for all northbound AM runs, 69.2 seconds for all northbound PM runs, 29.6 seconds for all southbound AM runs, and 24.3 seconds for all southbound PM runs) and after study (25.7 seconds for all runs, 28.7 seconds for all northbound runs, 22.0 seconds for all southbound runs, 22.2 seconds for all AM runs, 29.1 seconds for all PM runs, 19.2 seconds for all northbound AM runs, 39.5 seconds for all northbound PM runs, 25.2 seconds for all southbound AM runs, and 18.9 seconds for all southbound PM runs).

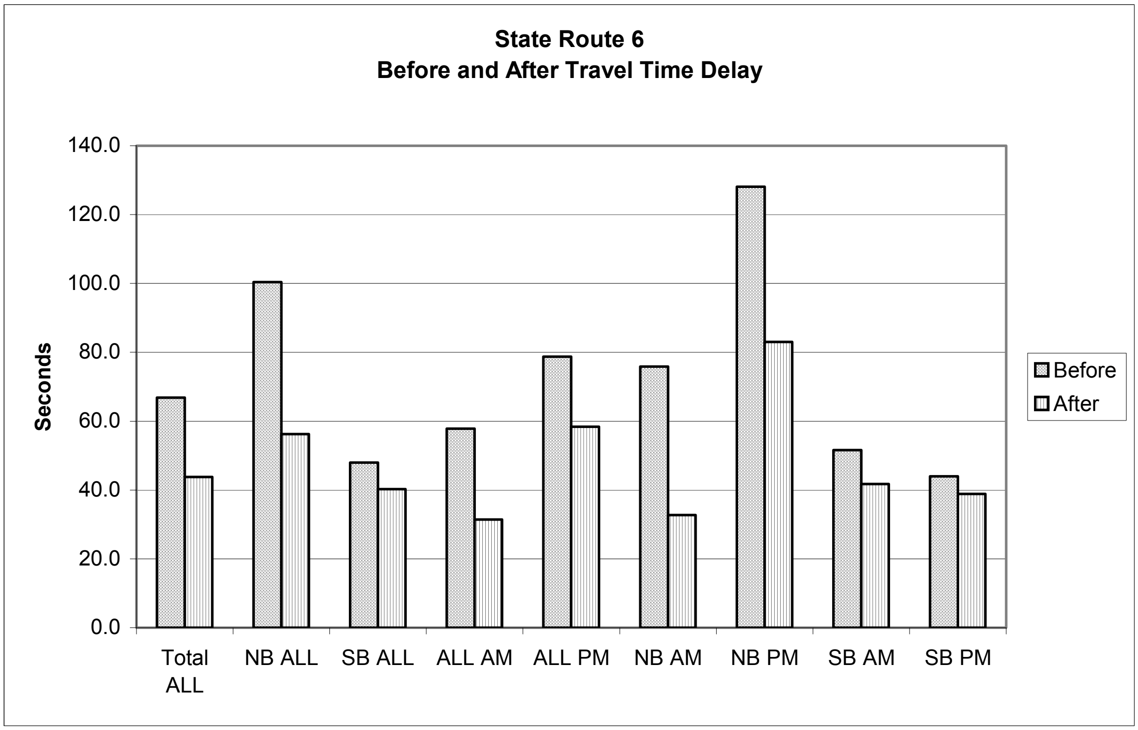

Figure 9. Bar Chart. Summary of 'before' and 'after' travel time delay (seconds). Bar chart depicts the following average travel time delay times on SR 6 for the before study (66.8 seconds for all runs, 100.4 seconds for all northbound runs, 47.9 seconds for all southbound runs, 57.8 seconds for all AM runs, 78.7 seconds for all PM runs, 75.9 seconds for all northbound AM runs, 128.1 seconds for all northbound PM runs, 51.6 seconds for all southbound AM runs, and 43.9 seconds for all southbound PM runs) and after study (44.1 seconds for all runs, 56.2 seconds for all northbound runs, 40.3 seconds for all southbound runs, 31.4 seconds for all AM runs, 58.4 seconds for all PM runs, 32.8 seconds for all northbound AM runs, 83.0 seconds for all northbound PM runs, 41.8 seconds for all southbound AM runs, and 38.9 seconds for all southbound PM runs).

Based on the total runs for the 'before' period and 'after' period, all of the performance measures improved overall. Compared to the 'before' results, in the 'after' period the travel time decreased by 26.4 seconds; the number of stops decreased by 0.5; the stopped delay decreased by 13.7 seconds, and the travel time delay decreased by 22.7 seconds.

7. BENEFITS ANALYSIS

An analysis was performed in order to estimate the operational benefits of the ACS Lite technology. The benefit is calculated using the statistics resulting from the GPS travel time runs, by subtracting the "Before" and "After" measures of effectiveness. These benefits are based on the total delay (travel time delay), number of stops and fuel consumption for all runs for each peak period. The following unit costs were assigned for the analysis:

- Total Delay -- $12.10 per hour (Source: Texas Transportation Institute)
- Stops -- $0.014 per stop (Source: Texas Transportation Institute)
- Fuel Consumed -- $0.59 per Liter ($2.25 per gallon)

The peak hour benefits are adjusted and aggregated assuming that the AM and PM peak hours (7-9 AM and 4-6 PM) were 29 percent of the daily total volumes. Annual benefits are computed assuming 260 weekdays per year.

The analysis, as shown in table 4, indicates an average annual benefit, after the activation of the ACS Lite software, of approximately $578,000.

Table 4. Summary of ACS Lite Technology benefits analysis

	Before (per veh)	After (per veh)	Savings (per veh)	Peak Hours[1] (all vehs)	Peak Hours Savings
Total Delay (hour)	0.01856	0.01214	0.00642	39.16252	$474
Total Stops	1.7	1.2	0.5	3051.6	$43
Fuel (Liters)	0.490	0.455	0.035	214.837	$128
Peak Hours Benefit					**$644**
Daily Benefit					**$2,222**
Annual Benefit					**$577,648**

[1]Peak hours = Average savings(Average Corridor Peak Hour Volume*4 peak hours)*

8. SUMMARY

In summary, a comparative analysis was performed on the data collected along the SR 6 corridor before and after the activation of the ACS Lite. The performance measures included speed, travel time, delay, number of stops and fuel consumption. All of the measures of effectiveness showed an overall improvement. The benefits analysis, analyzing total delay, number of stops and fuel consumption, indicates that based on the data collected, there would be annual savings of approximately $578,000 due to operational improvements derived from the ACS Lite technology.