Shoreline Adaptive Signal System Final Corridor Performance and Evaluation Report

City of Mountain View

May 19, 2016

TJKM

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1. INTRODUCTION

Shoreline Boulevard is a major north-south four to six lane arterial through the City of Mountain View with sixteen signalized intersections and average daily traffic (ADT) between 25,000 and 35,000 vehicles. The posted speed limit throughout the corridor is 35 miles per hour (mph). Shoreline Boulevard is one of the most heavily congested corridors in the City of Mountain View providing access to an array of commercial businesses such as Google, Microsoft, Intuit and several others as well as residential properties. It also connects recreational land uses such as the Shoreline Regional Park and Golf Course, Shoreline Amphitheatre and movie theatre complex. It provides direct connectivity to major arterials such as El Camino Real, Central Expressway and US 101, and is subjected to heavy pedestrian and bicycle activities.

Under Existing Conditions, Shoreline Boulevard experiences heavy congestion throughout the corridor especially, from US 101 northbound (NB) Ramps-La Avenida Street to Charleston Road in the northbound direction during the a.m. peak period and from Charleston Road to US 101 southbound (SB) Ramp in the southbound direction during the p.m. peak period. During the a.m. and p.m. peak periods, Shoreline Boulevard experiences volumes in the range of 3,000 to 6,000 vehicles.

Some of the major trip generators along Shoreline Boulevard are listed below.

1. North Bayshore Employment Center (daily commuter population of approximately 17,000 people)
2. Shoreline Amphitheatre (seating capacity of 22,500)
3. Movie Theatre and Computer History Museum (9120,000 square feet (sq. ft.) with 400 parking spaces)
4. Access to El Camino Real, Central Expressway and US 101
5. Shoreline Regional Park and Golf Center (700 acres)
6. Downtown Commercial and Civic Center, including City Hall, the Library and the Center of the Performing Arts
7. Two Schools, including Theuerkauf Elementary School (470 student enrollment) and Stevenson Elementary School (306 student enrollment)
8. Eagle Park and Recreation Center (7.4 acres with Community Pool)

PROJECT BACKGROUND

Shoreline Boulevard was re-timed during the MTC Program for Arterial System Synchronization (PASS) 2012-13 Cycle to improve the traffic conditions along the corridor. However, there was a need for a more sustainable option to reduce congestion along the study corridor. The City of Mountain View along with TJKM and Rhythm Engineering implemented "InSync", an adaptive signal system at 15 signalized intersections along the study corridor excluding El Camino Real. TJKM reviewed existing minimum parameters such as minimum green, yellow, red, walk, and flash don't walk (FDW) intervals to ascertain optimal cycle length and split range and determined offsets for the adaptive signal model created by Rhythm Engineering. Rhythm Engineering installed the InSync Adaptive System on Shoreline Boulevard, along with the City of Mountain View as well as TJKM, which assisted with the Implementation, Fine-Tuning process and the Without Project and With Project comparison.

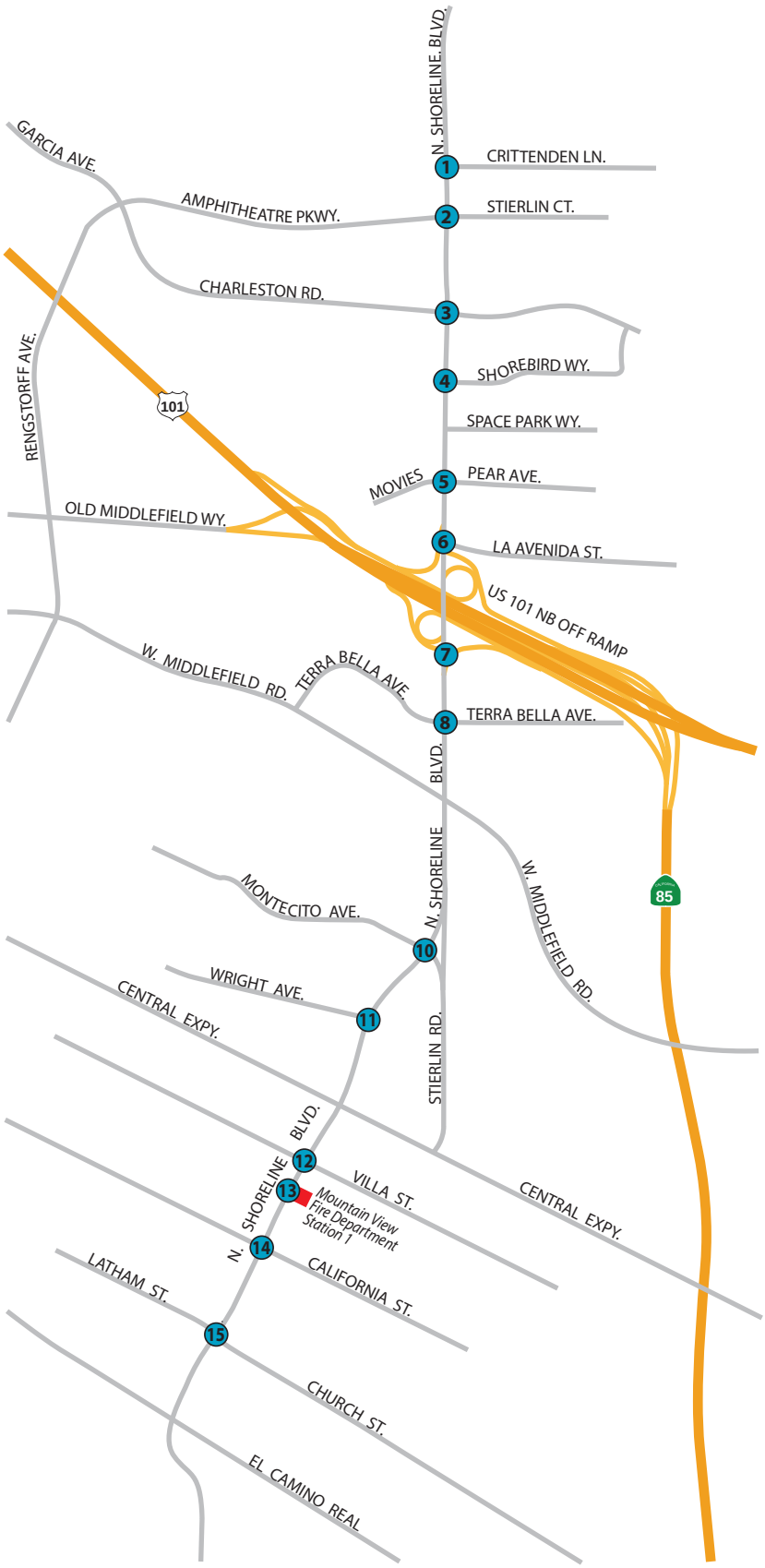
The purpose of this report is to present the Without Project and With Project implementation comparison for the Shoreline Boulevard Adaptive System. This report includes the following six sections: 1) Introduction, 2) Review of Signal Timing Parameters, 3) Traffic Volume Comparison (Without Project and With Project), 4) Floating Car Survey Comparison (Without Project and With Project), 5) Cost-Effectiveness Analysis, and 6) Summary.

STUDY INTERSECTIONS

The fifteen study intersections selected for the project are listed below. The project study area is illustrated in **Figure 1**.

1. Shoreline Boulevard/Crittenden Lane
2. Shoreline Boulevard/Amphitheatre Parkway/Stierlin Court
3. Shoreline Boulevard/Charleston Road
4. Shoreline Boulevard/Shorebird Way
5. Shoreline Boulevard/Pear Avenue/Movies
6. Shoreline Boulevard/La Avenida Street/US 101 NB Ramp
7. Shoreline Boulevard/US 101 SB Ramps
8. Shoreline Boulevard/Terra Bella Avenue
9. Shoreline Boulevard/Middlefield Road
10. Shoreline Boulevard/Montecito Avenue/Stierlin Road
11. Shoreline Boulevard/Wright Avenue
12. Shoreline Boulevard/Villa Street
13. Shoreline Boulevard/Mountain View Fire Department Station #1
14. Shoreline Boulevard/California Street
15. Shoreline Boulevard/Church Street/Latham Street

Vicinity Map



LEGEND

X Study Intersection

N

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138-032

Figure 1

2. REVIEW OF TRAFFIC SIGNAL TIMING PARAMETERS

Pedestrians and bicycles heavily use Shoreline Boulevard. The traffic signal timing parameters such as WALK, FDW, yellow and minimum green intervals for bicycles were updated by TJKM to be consistent with the current California Manual of Uniform Traffic Control Devices (CA MUTCD) standards, and enhance pedestrian and bicycle safety. Recommendations to existing timings are detailed in this section. The following methodologies were used for the review of pedestrian timings, yellow and red intervals, and minimum green intervals.

PEDESTRIAN TIMING

Consistent with the 2014 CA MUTCD, a four to seven seconds minimum WALK indication is acceptable for the City traffic signals. WALK intervals at all intersections fall within this range. As part of the analysis, TJKM reviewed the clearance intervals for all study intersections to identify locations where the FDW interval should be adjusted to meet CA MUTCD standards. Per the 2014 CA MUTCD requirement and City's Guidelines, the following formula was used to determine the minimum length of time for the FDW interval:

$$\boldsymbol{FDW\ (sec)} = \frac{\mathbf{(Curb-to-Curb\ Distance)}(\boldsymbol{ft})}{\mathbf{3.5}\frac{\boldsymbol{ft}}{\boldsymbol{s}}\ \boldsymbol{walking\ time}}$$

Table 1 summarizes the locations where changes to the existing FDW is proposed. **Appendix A** shows the existing, calculated, and proposed changes to the FDW interval for all study intersections.

Table 1: Existing and Proposed FDW Intervals Summary

#	Intersection	Direction	Phase	Existing FDW (sec)	Proposed FDW (sec)
2	Shoreline Boulevard/ Amphitheatre Parkway	SB	2	21	22
		WB	8	21	23
3	Shoreline Boulevard/Charleston Road	SB	6	21	22
		EB	4	22	23
		WB	8	24	25
5	Shoreline Boulevard/Pear Avenue	SB	6	9	10
7	Shoreline Boulevard/US 101 SB Ramp	SB	6	28	35
8	Shoreline Boulevard/Terra Bella Avenue	NB	2	16	18
		EB	4	19	23
		WB	8	19	20
9	Shoreline Boulevard/Middlefield Road	NB	6	38	48
		SB	2	38	48
		EB	8	20	23
		WB	4	20	21
10	Shoreline Boulevard/ Montecito Avenue/Stierlin Road	SB	6	17	18

#	Intersection	Direction	Phase	Existing FDW (sec)	Proposed FDW (sec)
11	Shoreline Boulevard/Wright Avenue	SB	2	17	19
		EB	4	26	29
12	Shoreline Boulevard/Villa Street	NB	6	16	27
		SB	2	16	21
		EB	4	27	36
14	Shoreline Boulevard/California Street	NB	6	19	23
		SB	2	19	22
		EB	4	28	29
		WB	8	28	30
15	Shoreline Boulevard/ Church Street/Latham Street	NB	6	13	15
		SB	2	12	19
		EB	4	27	29
		WB	8	28	29

YELLOW AND RED INTERVALS

The yellow intervals for all movements were reviewed and revised accordingly to be consistent with the CAMUTCD 2014 requirements and as directed by the City as shown in **Tables 2** and **3**.

Table 2: Minimum Yellow Interval Requirements (For Speed determined by 85th Percentile)

Speed (Determined by 85th Percentile Speed) (mph)*	Minimum Yellow Interval (sec)
25 or less	3.0
30	3.2
35	3.6
40	3.9
45	4.3
50	4.7
55	5.0
60	5.4
65	5.8

Notes:
*See Section 4D.26 Standard under paragraph14b
Source: CA MUTCD 2014, Table 4D-102 (CA). Minimum Yellow Change Interval Timing

Table 3: Minimum Yellow Interval Requirements (For Posted or Prima Facie Speed)

Posted Speed or Unposted Prima Facie Speed (mph)	Minimum Yellow Interval* (sec)
15	3.0
20	3.2
25	3.6
30	3.7
35	4.1
40	4.4
45	4.8
50	5.2
55	5.5
60	5.9

Notes:
*Speed Values for Table 4D-102b (CA) are inclusive of 7 MPH added for speeds equal to 30 MPH or higher and 10 MPH for speeds equal to or lower than 25 MPH for determining the minimum values of the yellow intervals.
Source: CA MUTCD 2014, Table 4D-102 (CA). Minimum Yellow Change Interval Timing

Table 2 is referenced for yellow interval analysis for locations for which 85th percentile speeds are provided by the City and **Table 3** is referenced where 85th percentile speeds were unavailable and posted speed limit is used instead. The posted speed limit was used for yellow interval analysis for all approaches for the study intersections along Shoreline Boulevard. The locations where changes to the existing yellow times are proposed are summarized in **Table 4**. **Appendix A** shows the existing, calculated, and proposed changes to the yellow intervals for all study intersections.

Table 4: Existing and proposed Yellow Intervals Summary

#	Intersection	Direction	Phase	Existing Yellow (sec)	Proposed Yellow (sec)
1	Shoreline Boulevard/ Crittenden Lane	NB	2	3.6	4.1
		SB	6	3.6	4.1
2	Shoreline Boulevard/ Amphitheatre Parkway	NB	6	3.9	4.1
		SB	2	3.9	4.1
		EB	4	3.9	4.1
3	Shoreline Boulevard/ Charleston Road	NB	2	3.6	4.1
		SB	6	3.6	4.1
		EB	4	3.6	4.1
		WB	8	3.6	4.1
4	Shoreline Boulevard/ Shorebird Way	NB	2	4.0	4.1
		SB	6	4.0	4.1

#	Intersection	Direction	Phase	Existing Yellow (sec)	Proposed Yellow (sec)
5	Shoreline Boulevard/ Pear Avenue	NB	2	4.0	4.1
		SB	6	4.0	4.1
		EB	8	3.5	3.7
		WB	4	3.5	3.7
6	Shoreline Boulevard/ La Avenida Street/US 101 NB Off Ramp	SB	6	4.0	4.2
		WB	7	3.2	3.7
		NWL	8	3.6	3.7
7	Shoreline Boulevard/US 101 SB Ramp	NB	2	4.0	4.1
		SB	6	4.0	4.1
		EB	4	3.2	3.7
8	Shoreline Boulevard/ Terra Bella Avenue	NB	2	4.0	4.1
		SB	6	4.0	4.1
		EB	4	3.0	3.6
		WB	8	3.0	3.6
9	Shoreline Boulevard/ Middlefield Road	NB	6	4.0	4.1
		SB	2	4.0	4.1
		EB	8	4.0	4.1
		WB	4	4.0	4.1
10	Shoreline Boulevard/ Montecito Avenue	NB	2	4.0	4.1
		SB	6	4.0	4.1
11	Shoreline Boulevard/ Wright Avenue	NB	6	4.0	4.1
		SB	2	4.0	4.1
12	Shoreline Boulevard/Villa Street	NB	6	4.0	4.1
		SB	2	4.0	4.1
		EB	4	3.5	3.6
14	Shoreline Boulevard/ California Street	NB	6	4.0	4.1
		SB	2	4.0	4.1
		EB	4	3.6	4.1
		WB	8	3.6	4.1
15	Shoreline Boulevard/ Church Street/Latham Street	NB	6	3.6	4.1
		SB	2	3.6	4.1
		EB	4	3.0	3.6
		WB	8	3.0	3.6

Currently, the red clearance intervals range from zero to two seconds at the study intersections along Shoreline Boulevard. The CA MUTCD indicates that all red is not required, although generally recommended, ranging from zero to two seconds. Based on the review of the existing red clearance intervals, no changes to red times are recommended at this time.

MINIMUM GREEN INTERVALS FOR VEHICLES AND BICYCLES

The study intersections operate with a narrow range of minimum green times from four to 15 seconds, with most left-turn movements and through movements having minimum green time of 10 seconds. Typically, for minimum green intervals, a minimum of four seconds and maximum of 10 seconds should be used. In special circumstances, where the main-street phase is very heavy, a minimum green time of greater than ten seconds is acceptable.

Review of the minimum green times for bicycles was completed for study intersections along Shoreline Boulevard as described below due to the heavy bicycle activity along this corridor.

The CAMUTCD, within section 4D.105 (CA), requires that minimum green time be sufficient for a stopped bicycle to cross the road when the traffic signal turns green at locations where bicycle detection exists. Even where bicycle specific detection does not exist, it is recommended the minimum green be sufficient for bicycles crossing at locations with dedicated bicycle lanes or locations without detection. Therefore, the minimum green times were reviewed based on the following methodology:

$$G_{min} + Y + R_{clear} \geq 6 \text{ sec} + (W+6\text{ft})/14.7\text{ft/sec}$$

Where:
G = Length of minimum green interval (sec) (Calculated as shown or 8 seconds, whichever is greater)
W= Distance from limit line to far side of last conflicting lane (ft)
R = Length of red clearance interval (sec)
Y = Length of yellow interval (sec)

Table 5 summarizes locations where changes to minimum green intervals were proposed. **Appendix A** contains the minimum green intervals for bicycles analysis worksheet.

Additional review of the minimum and maximum green times was completed during the implementation of the adaptive signal plans. No adjustments to these parameters were identified.

Table 5: Existing and proposed Minimum Green Intervals Summary

#	Intersections	Direction	Phase	Existing Minimum Green Interval (sec)	Proposed Minimum Green Interval (sec)
6	Shoreline Boulevard/ La Avenida Street/ US 101 NB Off Ramp	NBT	2	10.0	13.0
		SBT	6	10.0	14.0
		WBL	7	10.0	15.0
7	Shoreline Boulevard/ US 101 SB Ramp	NBL	5	4.0	8.0
		EBL	4	4.0	8.0
9	Shoreline Boulevard/ Middlefield Road	NBT	6	10.0	11.0
		NBL	1	10.0	12.0
		SBT	2	10.0	11.0
		SBL	5	10.0	13.0
15	Shoreline Boulevard/ Church Street/ Latham Street	WBT	8	10.0	11.0

3. TRAFFIC VOLUME COMPARISON (WITH AND WITHOUT PROJECT)

TJKM received turning movement counts for vehicles, pedestrians and bicycles from the City of Mountain View for the without project analysis. The without project data was collected on Thursday, June 4, 2015 for the a.m. (7:00 a.m.–10:00 a.m.) and p.m. (4:00 p.m.–7:00 p.m.) peak periods. Turning movement data for vehicles, pedestrians and bicycles was also collected after the implementation of the project on Thursday, May 5, 2016 at four locations listed below for the same time frame.

1. Shoreline Boulevard/Pear Avenue
2. Shoreline Boulevard/La Avenida Street/US 101 NB Off Ramp
3. Shoreline Boulevard/Terra Bella Avenue
4. Shoreline Boulevard/Middlefield Road

The approach volumes during the a.m. (7:00 a.m.–10:00 a.m.) and p.m. (4:00 p.m.–7:00 p.m.) peak periods for the NB and SB directions along Shoreline Boulevard were compared for the without project and with project conditions. Optimal throughput comparison generally provides reasonably accurate results at slightly less congested locations. The approach volumes at Shoreline Boulevard/Terra Bella Avenue and Shoreline Boulevard/Middlefield Road were compared for this reason. **Table 6** provides the without project and with project approach volumes comparison. **Appendix B** contains the without project and with project turning movement counts for vehicles, pedestrians and bicycles for the a.m. and p.m. peak periods for the intersections listed above.

Table 6: Peak Period Approach Volumes Comparison - Without Project and With Project

#	Intersection	Approach	Without Project Approach Volumes		With Project Approach Volumes	
			A.M.	P.M.	A.M.	P.M.
3	Shoreline Boulevard/ Terra Bella Avenue	SB	2395	3789	2590	4167
4	Shoreline Boulevard/ Middlefield Road	NB	2895	2414	3165	2518

As shown in Table 6, there has been a 9% and 4% increase in the northbound throughput during the a.m. and p.m. peak periods respectively and an 8% and 10% increase in the southbound throughput during the a.m. and p.m. peak periods respectively.

The hourly approach volumes were also compared for the each hour during the periods of data collection and it was observed that generally, there has been an increase in the peak hour approach volumes with the implementation of the project. **Table 7** summarizes the comparison between the hourly approach volumes for the a.m. (9:00 a.m.–10:00 a.m.) and p.m. (5:00 p.m.–6:00 p.m.) peak hours.

Table 7: Peak Hour Approach Volumes Comparison - Without Project and With Project

#	Intersection	Approach	Without Project Approach Volumes		With Project Approach Volumes	
			A.M.	P.M.	A.M.	P.M.
1	Shoreline Boulevard/ Pear Avenue	NB	2184	768	2232	878
		SB	504	1842	507	1922
2	Shoreline Boulevard/ La Avenida Street/ US 101 NB Off Ramp	NB	1191	680	1291	389
		SB	516	2098	495	2212
3	Shoreline Boulevard/ Terra Bella Avenue	NB	982	749	926	683
		SB	883	1484	993	1562
4	Shoreline Boulevard/ Middlefield Road	NB	829	844	924	872
		SB	625	1371	570	1458

4. FLOATING CAR SURVEY COMPARISON (WITH AND WITHOUT PROJECT)

Floating car runs were conducted to cover both northbound and southbound directions along the entire length of the study corridor. These runs capture the travel time, speed, stop delay and number of stops on a unidirectional or bi-directional roadway segment in each direction. TJKM conducted "Before" or without project floating car survey on February 12, 2016 when the schools were in session for the weekday a.m. (7:00 a.m.–10:30 a.m.) and p.m. (3:30 p.m.–7:00 p.m.) peak periods. The floating car survey data was analyzed to obtain overall averages of travel time, delay, number of stops per vehicle, and speed for the entire length of each corridor.

The results of the floating car surveys conducted under "Before" or without project conditions were then compared to the "After" or with project conditions, after the implementation and fine-tuning of the adaptive signal system. The "After" or with project floating car surveys were conducted on Thursday, April 21, 2016 for the weekday a.m. and p.m. peak periods. **Tables 8** and **9** summarize the results of the floating car surveys. **Table 10** compares the "Before" and "After" floating car survey analysis. The "Before" and "After" floating car worksheets are contained in **Appendix C**.

Table 8: Floating Car "Before" Travel Time Survey, Shoreline Boulevard, between Crittenden Lane and Church Street/Latham Street

Roadway	Approach	Peak Period	Average Stop Delay (min:sec)	Average Travel Time (min:sec)	Average # of Stops	Average Speed[1] (mph)
Shoreline Boulevard (Length of Segment – 2.52 miles)	NB	A.M.	7:04	12:48	8	13
		P.M.	2:46	8:11	5	13
	SB	A.M.	3:51	9:26	7	16
		P.M.	6:53	12:52	9	12

Note:
[1]Average speed along the corridor including stop delays.

Table 9: Floating Car "After" Travel Time Survey, Shoreline Boulevard, between Crittenden Lane and Church Street/Latham Street

Roadway	Approach	Peak Period	Average Stop Delay (min:sec)	Average Travel Time (min:sec)	Average # of Stops	Average Speed[1] (mph)
Shoreline Boulevard (Length of Segment – 2.52 miles)	NB	A.M.	3:33	8:39	4	18
		P.M.	2:53	7:47	5	19
	SB	A.M.	2:30	7:13	4	21
		P.M.	1:38	6:23	3	24

Note:
[1]Average speed along the corridor including stop delays.

Table 10: "Before" and "After" Floating Car Survey Comparison

Roadway	Peak Period	Approach	Survey	Average Stop Delay (min:sec)	Average Travel Time (min:sec)	Average # of Stops	Average Speed (mph)
Shoreline Boulevard (Length of Corridor – 2.52 miles)	A.M.	NB	Before	7:04	12:48	8	13
			After	3:33	8:39	4	18
			Percentage Change	-50%	-32%	-50%	38%
		SB	Before	3:51	9:26	7	16
			After	2:30	7:13	4	21
			Percentage Change	-35%	-23%	-43%	31%
	P.M.	NB	Before	2:46	8:11	5	13
			After	2:53	7:47	5	19
			Percentage Change	4%	-5%	0%	46%
		SB	Before	6:53	12:52	9	12
			After	1:38	6:23	3	24
			Percentage Change	-76%	-50%	-67%	100%

As the tables show, the implementation of the adaptive signal system has generally resulted in reductions to stop delay per vehicle, stops per vehicle, and total travel time, as well as an increase in the average speed of the corridor based on the observations from the "After" floating-car surveys.

Shoreline Boulevard showed significant decrease in average stop delay, travel time, number of stops and an increase in speed in the northbound direction during the weekday a.m. peak period which is the peak direction of travel and in the southbound direction which is the peak direction of travel during the p.m. peak period. Overall, there was a reduction in stop delay along the corridor by approximately 39%, in travel time by approximately 28%, in number of stops per vehicle by approximately 40% and an increase in speed by approximately 54% for all peak periods.

5. COST-EFFECTIVENESS ANALYSIS

City of Mountain View applied for the Transportation Fund for Clean Air (TFCA) Grant for the implementation of Shoreline Adaptive Signal System project. A cost-effectiveness analysis was conducted based on the TFCA requirements after the completion of the project. Cost-effectiveness worksheets were used to calculate project emission reductions and TFCA cost-effectiveness which is measured in dollars ($)/ton of emission reductions. Based on the analysis conducted, the cost-effectiveness for Shoreline Boulevard was $135,735/ton. **Table 11** summarizes the results of the cost-effectiveness analysis. **Appendix D** contains the cost-effectiveness analysis spreadsheet.

Table 11: TFCA -Arterial Management Cost-Effectiveness Results

Cost Effectiveness Results	Annual	Lifetime	
1. ROG Emissions	0.44	0.88	Tons
2. NOx Emissions	1.14	2.28	Tons
3. PM Emissions	0.07	0.14	Tons
4. Weighted PM Emissions	1.36	2.73	Tons
5. CO2 Emissions Reduced	1013.60	2027.20	Tons
6. Emission Reductions (ROG, NOx & PM)	1.65	3.30	Tons
7. TFCA Project Cost - Cost Effectiveness (ROG, NOx & PM)		$242,190	/Ton
8. TFCA Project Cost - Cost Effectiveness (ROG, NOx & Weighted PM)		$135,735	/Ton







6. SUMMARY

Overall, the implementation of the "InSync" adaptive signal system along Shoreline Boulevard has resulted in significant reduction in traffic congestion. The observed benefits are summarized below.

1. Reduction in Average Stop Delay per Vehicle – 39%
2. Reduction in Average Travel Time per Vehicle – 28%
3. Reduction in Average Number of Stops per Vehicle – 40%
4. Increase in Average Speed per Vehicle – 54%
5. Cost-Effectiveness in dollars per ton due to the implementation of the project - $135,735/ton

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