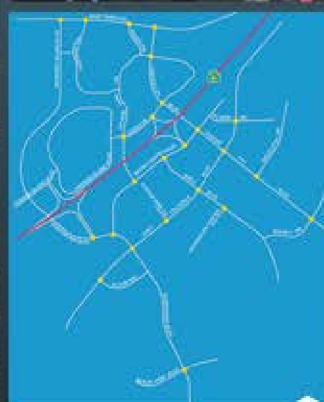
Prepared for the

Metropolitan Transportation Commission
Program for Arterial System Synchronization (PASS)

City of Lafayette



Final Project Report with Benefit/Cost Analysis
Deliverable #4B

Prepared by

TJKM Transportation Consultants

May 27, 2015

Deliverable #4B: Final Project Report with Benefit/Cost Analysis

Metropolitan Transportation Commission
Program for Arterial System Synchronization (PASS)
for the City of Lafayette

May 27, 2015

TJKM

TJKM Transportation Consultants

Disclaimer: The information, data, analyses, and recommendations in this report reflect the date listed on the cover page. It is anticipated that as a regular part of arterial operations and system monitoring, changes may be required to the timings listed in this report, and thus this report may not reflect the conditions in the field after a certain period of time has passed.

TJKM Transportation Consultants

Table of Contents

Introduction and Summary **1**

Existing Conditions Review **4**

Data Collection 4

Existing Signal System and Timing 5

Traffic Volume Data 5

"Before" Floating Car Survey (Existing Estimates of Performance Measures) 8

Actuated Settings Review 12

Yellow and Red Intervals 12

Pedestrian Timing 12

Minimum Green Interval for Bicycles 13

Collision History Review 14

Traffic Signal Timing Analysis and Recommendations **16**

Evaluation Criteria 16

Signal Timing Analysis 16

Recommendations 18

Timing Plan Implementation and Evaluation **21**

Installation of GPS clocks 21

Evaluation 21

Benefit/Cost Ratio Analysis **30**

Benefits to Other Modes 32

Traffic Safety Benefit 32

Benefits to Pedestrians 32

Benefits to Bicyclists 32

Conclusion 32

Glossary **33**

List of Appendices

Appendix A – Traffic Counts

Appendix B – Detailed Floating Car Survey Worksheets

Appendix C – Yellow and Flash Don't Walk Analysis

Appendix D – Collision Analysis

Appendix E – Proposed Timing Sheets (After Fine Tuning and Implementation)

Appendix F – Synchro Model Outputs for Existing and Proposed Conditions

Appendix G – Benefit/Cost Ratio Analysis Worksheets

List of Figures

Figure 1: Vicinity Map 3

List of Tables

Table 1: Existing Signal Controllers, Software, Cycle Lengths and Offsets 6

Table 2: 24-hour Traffic Volumes Summary 7

Table 3: Floating Car, Mt. Diablo Boulevard, "Before" Travel Time Survey 9

Table 4: Floating Car, Mt. Diablo Boulevard between Dolores Drive and Lafayette Circle (West), "Before" Travel Time Survey 10

Table 5: Floating Car, Moraga Road from Mt. Diablo Boulevard to St. Mary's Road, "Before" Travel Time Survey 11

Table 6: CA MUTCD Yellow Interval Requirements 12

Table 7: Intersection Collision Summary 15

Table 8: Existing and Recommended Cycle Lengths and Offsets for Weekday and Weekend Peak Periods for Mt. Diablo Boulevard and Moraga Road Corridor 19

Table 9: Time of Day Signal Coordination Schedule for Weekday and Weekend Peak Periods for Mt. Diablo Boulevard and Moraga Road Corridor 20

Table 10: Floating Car, Mt. Diablo Boulevard, "After" Travel Time Survey 22

Table 11: Floating Car, Mt. Diablo Boulevard between Dolores Drive and Lafayette Circle (West), "After" Travel Time Survey 23

Table 12: Floating Car, Moraga Road from Mt. Diablo Boulevard to St. Mary's Road, "After" Travel Time Survey 24

Table 13: "Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Mt. Diablo Boulevard 27

Table 14:"Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Mt. Diablo Boulevard, between Dolores Drive and Lafayette Circle (West) 28

Table 15: "Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Moraga Road 29

Table 16: Benefit/Cost Analysis... 31

Introduction and Summary

The Metropolitan Transportation Commission (MTC) has initiated a program for the coordination of signals throughout the Bay Area called the Program for Arterial System Synchronization (PASS). The City of Lafayette applied for and received a grant to coordinate traffic signals along the Mt. Diablo Boulevard and Moraga Road Corridors through downtown Lafayette.

The goal of this project is to facilitate traffic progression along the study intersections and to update signal timing plans to maximize operational efficiency of the traffic signals within existing capacity constraints. Given the downtown project setting, signal timing must also be sensitive to non-auto users of the public streets. The goal is to reduce traffic congestion, reduce traffic delays, reduce the emission of harmful greenhouse gases, reduce automobile and transit travel time along the study corridors, and provide safe traffic signal operations for users of all modes. The project objective is to develop traffic signal coordination timing plans for weekday morning commute (a.m.), midday, afternoon school pick-up (school p.m.), evening commute (p.m.) and weekend peak periods respectively.

The twelve traffic signals that are funded in the City of Lafayette as a part of this project are listed below and shown in **Figure 1**. The City-owned traffic signals have 170 type traffic controllers, and operate with BI Tran 200 SA and 233 RV traffic controller software.

The following is a list of traffic signals that are included for the project:

<u>Mt. Diablo Boulevard Traffic Signal System</u>

1. Mt. Diablo Boulevard/Dolores Drive-Mountain View Drive
2. Mt. Diablo Boulevard/Happy Valley Road
3. Mt. Diablo Boulevard/Dewing Avenue
4. Mt. Diablo Boulevard/Lafayette Circle (West)
5. Mt. Diablo Boulevard/Oak Hill Road-Lafayette Circle (East)
6. Mt. Diablo Boulevard/Moraga Road
7. Mt. Diablo Boulevard/First Street
8. Mt. Diablo Boulevard/Second Street
9. Mt. Diablo Boulevard/Brown Avenue

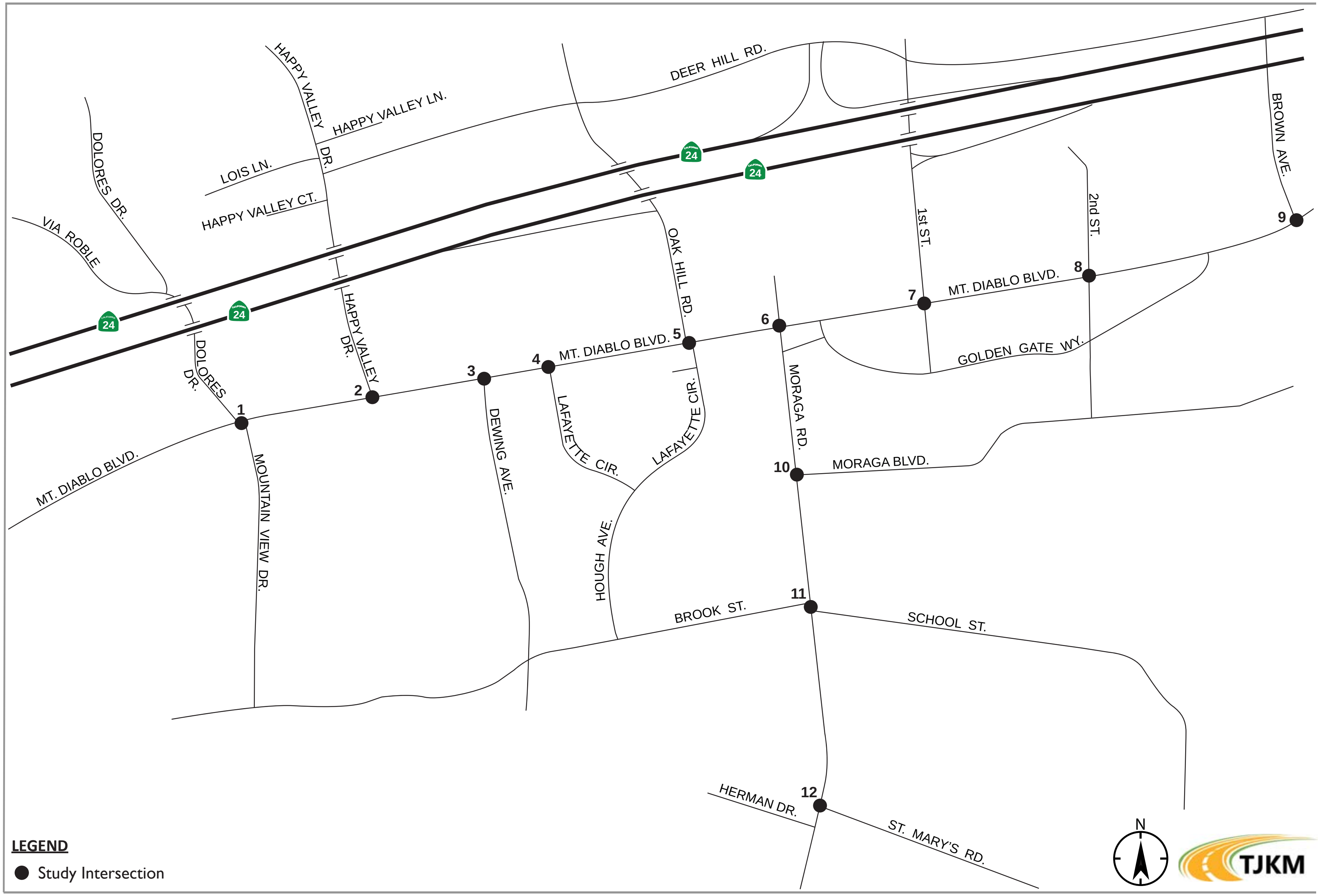
<u>Moraga Road Traffic Signal System</u>

10. Moraga Road/Moraga Boulevard
11. Moraga Road/Brook Street/School Street
12. Moraga Road/St. Mary's Road/Herman Drive

TJKM conducted an analysis of existing conditions, including traffic volume and collision data, signal timing and settings. The Synchro traffic models developed as part of the existing conditions analysis were used as the basis for developing the proposed signal coordination plans, which included the evaluation of signal grouping, cycle lengths, splits, offsets, and time-of-day operation. Signal timing parameters related to pedestrian and bicycle movements were also updated. The proposed timing plans were presented to the City Staff for initial feedback, prior to field implementation and optimization. Floating car surveys were conducted before and after implementation of new signal timings to document actual change in traffic conditions.

This report provides a summary of the existing conditions and recommended timings developed for the project, along with the resulting improvements in various measures of effectiveness for the study corridors.

Vicinity Map



260-037

Figure 1

Existing Conditions Review

Data Collection

This report contains data provided by the City of Lafayette and collected by TJKM Transportation Consultants in the field. TJKM Transportation Consultants collected the following data from the City:

- Traffic signal timing sheets
- Historical traffic counts
- Intersection As-Built plans
- Three-year intersection collision history
- Synchro files with existing timing information

TJKM collected the following data in the field to document and model existing conditions:

- Manual turning movement counts and lane geometry for each study intersection for the weekday a.m., midday, school p.m., and p.m. and weekend peak periods. These counts include vehicles, pedestrians, and bicyclists (See Appendix A).
- 24-hour Average Daily Traffic (ADT) counts at five locations within study corridors (See Appendix A).
- Floating car runs in each direction for each of the five peak periods for both study corridors (See Appendix B).
- Field review that identified intersections that are oversaturated, significant differences in the proportions of trucks and buses from default values in Synchro, major driveways and unsignalized intersections that may affect arrival rates and patterns at signalized intersections, parking maneuvers, pedestrian activity, and other traffic patterns that may affect the ability to coordinate signals in the system.
- Field identification of study intersections with uneven vehicle distribution in travel lanes.
- Field identification of locations where the left-turn or right turn queue exceeds the storage length of the turning lane.

The collected and compiled data was used to develop traffic models for existing conditions.

Collision data at the signalized intersections were collected and reviewed with respect to accident patterns that may be correctible by changing basic signal settings and improving coordination. Additionally, existing signal settings were reviewed to identify potential changes that might reduce delay to vehicles, pedestrians and bicyclists. Such settings include clearance intervals for vehicles, pedestrians and bicycles; vehicle detection gap and extension settings; cycle lengths as influenced by minimum and maximum green times; and phase sequence.

Existing Signal System and Timing

Currently, all of the study traffic signals are actuated, and signal interconnect is in place on the Moraga Road corridor, and on the Mt. Diablo Boulevard corridor between Lafayette Circle West and First Street. **Table 1** shows the existing signal controllers, software, and cycle lengths and offsets during each peak period for each study intersection that is operating in coordination mode. Those not operating in coordination mode are noted as running “free”.

Traffic Volume Data

TJKM collected the turning movement counts on Tuesday, September 10, 2013 when schools were in session at all study intersections. The weekend counts were collected on Saturday, September 28, 2013. **Appendix A** contains the vehicle, pedestrian, and bicycle counts for the study intersections. Turning movement counts were entered into the Synchro model for the existing conditions analysis.

In addition, 24-hour tube counts were collected for seven days between Saturday, September 7, 2013 and Friday, September 13, 2013 at the following five locations:

1. Mt. Diablo Boulevard between Lafayette Circle (West) and Dewing Avenue
2. Mt. Diablo Boulevard between Moraga Road and Oak Hill Road/ Lafayette Circle (East)
3. Mt. Diablo Boulevard between First Street and Moraga Road
4. Mt. Diablo Boulevard between Second Street and First Street
5. Moraga Road between School/Brook Street and Moraga Boulevard

The 24-hour traffic volumes are summarized in **Table 2** below. Detailed results along with graphs of 24-hour traffic volumes are presented in **Appendix A**. The 24-hr traffic volumes were used to determine the peak periods for collecting turning movement counts and for providing a time of day schedule for the proposed coordination plans.

In addition to the volume counts summarized in **Table 2**, TJKM conducted field observations to identify operational parameters unique to the study corridors, such as unconventional phase sequencing, conditional service, overlap phases, and saturation flow rates. Those parameters are important in accurately modeling existing traffic conditions as well as developing timing plans that respond to traffic patterns in the field.

Table 1: Existing Signal Controllers, Software, Cycle Lengths and Offsets

ID	Intersection	Controller Model	Software	Interconnected?	A.M.		Midday		School P.M.		P.M.		Weekend	
					Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)
1	Mt. Diablo Boulevard/Dolores Drive-Mountain View Drive	170E	200 SA	No	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
2	Mt. Diablo Boulevard/ Happy Valley Road	170E	233 RV	No	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
3	Mt. Diablo Boulevard/ Dewing Avenue	170E	233 RV	No	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
4	Mt. Diablo Boulevard/ Lafayette Circles (West)	170E	233 RV	Yes	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
5	Mt. Diablo Boulevard/Oak Hill Road-Lafayette Circles (East)	170E	200 SA	Yes	110	43	120	100	120	100	120	103	110	35
6	Mt. Diablo Boulevard/ Moraga Road	170E	233 RV	Yes	110	37	120	0	120	0	120	0	110	0
7	Mt. Diablo Boulevard/ 1st Street	170E	233 RV	Yes	110	0	120	0	120	0	120	0	110	0
8	Mt. Diablo Boulevard/ 2nd Street	170	200 SA	No	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
9	Mt. Diablo Boulevard/Brown Avenue-Almanor Lane	170	200 SA	No	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
10	Moraga Road/ Moraga Boulevard	170E	233 RV	Yes	110	9	120	107	120	107	120	107	110	9
11	Moraga Road/School Street-Brook Street	170E	233 RV	Yes	110	99	120	93	120	93	120	93	110	99
12	Moraga Road/St. Mary's Road-Herman Drive	170E	233 RV	Yes	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free

Notes: Information provided above is correct as of December 2013.
"Free" denotes intersection not operating in signal coordination mode, but is actuated based on demand.

Table 2: 24-hour Traffic Volumes Summary

	Location	Period	EB Average Volumes (vpd)	WB Average Volumes (vpd)	Total (vpd)
A.	Mt. Diablo Boulevard (west of Lafayette Circle (West))	Weekday (M-F)	7,448	7,369	14,817
		Weekend (S-S)	6,055	6,403	12,458
B.	Mt. Diablo Boulevard (west of Moraga Road)	Weekday (M-F)	8,907	7,183	16,090
		Weekend (S-S)	8,025	5,928	13,953
C.	Mt. Diablo Boulevard (west of First Street)	Weekday (M-F)	12,800	10,883	23,683
		Weekend (S-S)	11,152	9,562	20,714
D.	Mt. Diablo Boulevard (east of First Street)	Weekday (M-F)	6,809	6,672	13,481
		Weekend (S-S)	5,040	4,832	9,872
	Location	**Period**	**NB Average Volumes (vpd)**	**SB Average Volumes (vpd)**	**Total (vpd)**
E.	Moraga Road (south of Moraga Boulevard)	Weekday (M-F)	9,373	10,151	19,524
		Weekend (S-S)	9,055	9,360	18,415

Notes:
Data was collected in month of September 2013
*vpd – vehicles per day

"Before" Floating Car Survey (Existing Estimates of Performance Measures)

A floating car run covers a one-way trip of the defined length of a study corridor. These runs capture the travel time, speed, stopping time, number of stops, and other delays on an individual direction along the study corridor. Four floating car runs were conducted during the weekday a.m., midday, school p.m., p.m. and weekend peak periods for the "Before" and "After" surveys. The weekday and weekend "Before" surveys were conducted in the month September 2013 along Mt. Diablo Boulevard and Moraga Road and the "After" surveys were conducted in the month of April, 2015.The floating car survey data were analyzed to obtain overall averages of travel time, delay, and computed travel speed for the entire length of each corridor. These parameters help to qualitatively describe the existing traffic conditions along the corridors, specifically, how well platoons of vehicles are able to move through a corridor and the corresponding amount of congestion/delay encountered.

The results of the floating car surveys conducted under existing conditions are shown in **Tables 3, 4** and **5**. Existing conditions surveys are termed as "Before" surveys. The results of the "Before" floating car surveys will be compared to the "After" floating car surveys that are conducted after implementation of the proposed signal timing plans. The floating car worksheets are contained in **Appendix B**.

The Mt. Diablo Boulevard corridor is divided into sub-sections for the purpose of floating car surveys. This is done to account for the variation in traffic volumes and patterns observed on these sub-sections during the different times of day. Currently, some intersections are coordinated and others are not (see **Table 1**). The sub-sections are helpful in seeing the effects of the new signal timings in terms of improvements in coordination and benefits of coordinating signals that are previously running independently (free).

The floating car surveys were conducted for the following segments along Mt. Diablo Boulevard for each of the five peak periods:

- A.M. Peak Period: Mt. Diablo Boulevard, between Dolores Drive and First Street (0.63 miles)
- Midday Peak Period: Mt. Diablo Boulevard, between Oakhill Road and First Street (0.22 miles)
- School P.M. Peak Period: Mt. Diablo Boulevard, between Dolores Drive and Brown Avenue (0.97 miles)
- P.M. Peak Period: Mt. Diablo Boulevard, between Dolores Drive and Brown Avenue (0.97 miles)
- Weekend Peak Period: Mt. Diablo Boulevard, between Dolores Drive and First Street (0.63 miles)

The floating car surveys were conducted for the following segment along Moraga Road for each of the five peak periods:

- Moraga Road, between Mt. Diablo Boulevard and St. Mary's Road/Herman Drive (0.43 miles)

Table 3: Floating Car, Mt. Diablo Boulevard, "Before" Travel Time Survey

Roadway	Approach	Peak Hour	Signal Delay/Vehicle [min:sec]	Travel Time [min:sec]	Average # of Stops[2]	Average Speed[1] [mph]	% of Signal Delay[3]
Mt. Diablo Boulevard, between Dolores Drive and Brown Avenue*	EB	A.M.[4]	1:05	2:49	2	15	38%
		Midday[5]	1:07	1:45	1	9	64%
		School P.M.[6]	2:37	5:41	5	10	46%
		P.M.[6]	3:07	5:56	4	10	53%
		Weekend[4]	1:27	3:38	3	11	40%
	WB	A.M.[4]	1:29	3:21	3	11	44%
		Midday[5]	1:02	1:41	1	8	61%
		School P.M.[6]	3:19	6:26	6	9	52%
		P.M.[6]	3:45	6:22	4	9	59%
		Weekend[4]	1:58	4:02	3	10	49%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
[4]A.M. and Weekend Peak Periods - Floating car runs between Dolores Drive and First Street.
[5]Midday Peak Period - Floating car runs between Oakhill Road and First Street.
[6]School P.M. and P.M. Peak Periods - Floating car runs between Dolores Drive and Brown Avenue.
*There are nine (9) signalized intersections along this corridor.

Table 4: Floating Car, Mt. Diablo Boulevard between Dolores Drive and Lafayette Circle (West), "Before" Travel Time Survey

Roadway	*Approach*	*Peak Hour*	*Signal Delay/Vehicle [min:sec]*	*Travel Time [min:sec]*	*Average # of Stops*[2]	*Average Speed*[1] *[mph]*	*% of Signal Delay*[3]
Mt. Diablo Boulevard, between Dolores Drive and Lafayette Circle (West)*	EB	A.M.	0:30	1:15	1	14	40%
		School P.M.	0:38	1:34	2	11	40%
		P.M.	0:51	1:44	1	10	49%
		Weekend	0:30	1:25	1	13	36%
	WB	A.M.	0:34	1:25	2	12	41%
		School P.M.	0:39	1:45	1	12	37%
		P.M.	1:32	2:22	2	8	65%
		Weekend	0:18	1:15	1	16	24%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
*There are four (4) signalized intersections along this corridor. The corridor was not coordinated for the weekday midday peak period based on analysis. Hence, floating car survey for this peak period is not provided.

Table 5: Floating Car, Moraga Road from Mt. Diablo Boulevard to St. Mary's Road, "Before" Travel Time Survey

Roadway	Approach	Peak Hour	Signal Delay/Vehicle [min:sec]	Travel Time [min:sec]	Average # of Stops[2]	Average Speed[1] [mph]	% of Signal Delay[3]
Moraga Road*	NB	A.M.	1:43	2:54	2	10	59%
		Midday	1:48	2:54	2	9	62%
		School P.M.	2:12	3:02	2	12	73%
		P.M.	0:43	1:52	2	14	38%
		Weekend	1:12	2:22	2	11	51%
	SB	A.M.	0:14	1:28	1	18	16%
		Midday	0:21	1:28	1	18	24%
		School P.M.	1:35	3:10	2	9	50%
		P.M.	0:35	1:39	1	16	35%
		Weekend	0:13	1:15	2	21	17%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
*There are four (4) signalized intersections along this corridor.

The floating car survey data suggest that traffic progression through the study corridors can be improved. On Mt. Diablo Boulevard, there appears to be a noticeable degree of signal delay between Dolores Drive and First Street. In fact, this delay as a percentage of total travel time through the corridor is consistently around 50% for most of the peak time periods. This is not surprising since traffic volumes are known to be at or approaching saturation levels at the intersections with Oak Hill Road, Moraga Road, and First Street. Signal delay is even higher on the Moraga Road corridor at certain peak times, especially in the northbound direction during the a.m. peak and school p.m. peak times. Signal delays account for over 60% of the overall travel time. Traffic progression on Mt. Diablo Boulevard east of First Street is noticeably better by comparison. In the eastbound direction, signal delays are generally less than 40% of travel time. There is slightly higher delays going westbound into the downtown core, with noticeable delay in the school p.m. peak.

Actuated Settings Review

TJKM reviewed the existing actuated timing settings at the study intersections to determine where settings could be updated to meet current standards, minimize delay, and to enhance pedestrian and bicycle safety. The following methodologies were used for the review of pedestrian and bicycle timings, yellow and red intervals, and minimum green intervals.

Yellow and Red Intervals

The yellow intervals for all movements were reviewed and revised accordingly to be consistent with the CA MUTCD 2012 requirements, as shown in **Table 6**.

Table 6: CA MUTCD Yellow Interval Requirements

Approach Speed (mph)	*CA MUTCD Yellow Interval (secs)*
25	3.0
30	3.2
35	3.6
40	3.9
45	4.3
50	4.7
55	5.0

Source: Table 4D-102 (CA). Minimum Yellow Change Interval Timing, CA MUTCD 2012 Edition

All but one study intersection currently meet the guidelines for yellow clearance time. Only a minor adjustment in yellow time is necessary at Mt. Diablo Boulevard/Brown Avenue to meet MUTCD guidelines. **Appendix C** shows the existing, calculated, and proposed changes to the yellow interval for all study intersections.

Currently, the red clearance intervals range from 0.0 to 2.5 seconds at the study intersections, with most movements having an all red interval of 1.0 seconds. The CAMUTCD indicates that all red is not required, although generally, red clearance intervals range from 0.0 to 2.0 seconds. Based on TJKM's review, no changes to red times are recommended at this time.

Pedestrian Timing

As part of the analysis, TJKM reviewed the minimum walk interval and clearance intervals for all study intersections to identify locations where the walk interval and Flashing Don't Walk (FDW) interval should be adjusted to meet CA MUTCD standards. CA MUTCD advises that the walk interval should preferably be 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used. Currently, the study intersections have a minimum walk time ranging from 5-9 seconds, which meet the CA MUTCD standards.

The following formula was used to determine the minimum length of time for the FDW interval:

$$FDW\ (\text{sec}) = \frac{(Shortest\ curb - to - curb\ distance\ of\ crosswalk)(ft)}{3.5\frac{ft}{s}\ walking\ time} - Yellow\ (\text{sec}) - All\ Red\ (\text{sec})$$

It should be noted that pedestrian crossings are generally associated with vehicular phases except when exclusive pedestrian scramble phase is provided. The “walk” and FDW intervals for a pedestrian crosswalk related to a vehicular phase constitutes the minimum split (or minimum green time allocation) for that phase. Increase in walk or flashing don’t walk intervals will increase the minimum split for that movement. In some cases, this “over-allocates” green time in the context of vehicle traffic demand of that movement and can worsen the level of service for other movements at that intersection, depending on their demand and wait time.

Appendix C shows the existing and proposed FDW intervals with inadequate existing FDW intervals highlighted. TJKM recommends changing twenty-one crossing intervals at twelve intersections in order to meet the CA MUTCD standard.

Minimum Green Interval for Bicycles

Minimum Green interval is the minimum duration of green that must be displayed for a given phase. Currently, the study intersections operate with a range of minimum green times from 2 to 16 seconds, with most left turn movements having a minimum green time of 4 seconds and most through movements having a minimum green time of 10 seconds.

According to CA MUTCD, the minimum phase length required for bicycle timing is the sum of the minimum green timing plus yellow timing plus all red timing, as is determined by the following equation:

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

Where:

G_{min} = Length of minimum green interval (sec)
Y =Length of yellow interval (sec)
R_{clear} =Length of red clearance interval (sec)
W =Distance from limit line to far side of last conflicting lane (ft)

This formula aims to ensure that a bicycle is able to clear the intersection within the minimum green, yellow and red clearance times allocated for that direction of travel. Based on the above consideration, changes to minimum green times were proposed at eleven intersections. **Appendix C** contains the proposed changes to minimum green times at each intersection.

Collision History Review

Collisions reported at the study intersections along Mt. Diablo Boulevard and Moraga Road were obtained from the City of Lafayette database for a period of two years from June 2010 to December 2011, and from January 2013 to June 2013. Data for 2012 as available from the State is incomplete. Hence, this limited list was not included in the analysis. Collisions that occurred within 150 feet of an intersection were considered as occurring at the intersection. Review of collision analysis helps to determine if some of the collisions that occur at the intersections are attributable to signal timings. For example, a higher number of rear-end collision can sometimes occur due to insufficient yellow change interval at the intersections. Similarly, right-angle collisions can occur due to insufficient red clearance interval.

The collision rates at the intersections along the study corridors were compared with the statewide mean collision rates for roadways and intersections with similar characteristics. **Table 7** summarizes the number of collisions involving vehicles, pedestrians and bicyclists that were reported at the study intersections during the two-year analysis period. **Appendix D** contains the complete dataset used to conduct the collision analysis, including collision reports received from the City. As indicated in **Table 7**, the intersection collision rates are below state average at all intersections within the study area.

Table 7: Intersection Collision Summary

ID	Study Intersections	Year 2010				Year 2011				Year 2013				Total				Intersection Collision Rate (ICR)	Statewide Average Collision Rate	Intersection Collision Rate > Statewide Average Collision Rate?
		Driver	Ped	Bic	All	Driver	Ped	Bic	All	Driver	Ped	Bic	All	Driver	Ped	Bic	All			
1	Mt. Diablo Boulevard/Dolores Dr.-Mountain View Dr.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.55	No
2	Mt. Diablo Boulevard/Happy Valley Road	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0.08	0.55	No
3	Mt. Diablo Boulevard/Dewing Avenue	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0.10	0.55	No
4	Mt. Diablo Boulevard/Lafayette Circle (West)	0	1	0	1	1	0	0	1	0	0	0	0	1	1	0	2	0.22	0.55	No
5	Mt. Diablo Boulevard/Oak Hill Rd-Lafayette Circle (East)	1	0	1	2	0	0	0	0	0	0	0	0	1	0	1	2	0.13	0.55	No
6	Mt. Diablo Boulevard/Moraga Road	0	0	1	1	0	0	0	0	1	1	0	2	1	1	1	3	0.13	0.55	No
7	Mt. Diablo Boulevard/1st Street	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0.06	0.55	No
8	Mt. Diablo Boulevard/2nd Street	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0.11	0.55	No
9	Mt. Diablo Boulevard/Brown Avenue-Almanor Lane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.55	No
10	Moraga Road/Moraga Boulevard	0	0	0	0	2	0	0	2	1	0	0	1	3	0	0	3	0.20	0.55	No
11	Moraga Road/Brook Street	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.55	No
11	Moraga Road/School Street	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0.06	0.55	No
12	Moraga Road/St. Mary's Rd-Herman Drive	1	0	0	1	0	0	0	0	1	0	0	1	2	0	0	2	0.14	0.55	No
	Totals	**4**	**1**	**2**	**7**	**3**	**0**	**1**	**4**	**5**	**1**	**0**	**6**	**12**	**2**	**3**	**17**			

Notes:

ICR = 1000000*A / (365*T*ADT)
ICR= Observed collision rate; Number of Accidents/Vehicles Miles Travelled
A = Number of collisions over study period
T = Total number of years over which intersection accidents were collected; June 2010 to December 2011 and January 2013 to June 2013 = 2 years
ADT = Average Daily Intersection Traffic

Traffic Signal Timing Analysis and Recommendations

The primary goal of the timing analysis is to develop traffic signal coordination timing plans for the weekday a.m., midday, school p.m. and p.m. peak periods and weekend peak period to reduce traffic congestion, reduce traffic delays, reduce the emission of harmful greenhouse gases, reduce automobile travel time, and provide safe traffic operations for users of all modes along the study corridors.

Evaluation Criteria

The following were considered in the evaluation of the existing timing plans and the development of the proposed timing plans.

- Average travel time, average stop delay and average stops.
- Lead - lag and split phasing sequences were reviewed to determine instances where it may improve the efficiency of the coordination system. Proposed changes to the existing lead-lag sequences were discussed with City staff.
- Level of Service (LOS) and saturation flows were reviewed by lane groups and approaches for each intersection.
- Progression priority was determined based on traffic volumes per approach.
- Peak period for time of day coordination plans was based on the average daily traffic volume (ADT) analysis.
- Progression bandwidths were selected to maximize the efficiency of the coordinated timing plans.
- Capacity evaluation was based on an analysis of queuing and degree of saturation for each lane group, approach, and cycle lengths.
- Signal timings assume accommodation of pedestrian and bike clearance per CA MUTCD 2012.

Signal Timing Analysis

The following steps outline the signal timing analysis in order to develop recommendations for new or updated coordinated signal operation on the study corridors.

Step 1: Model development

This task includes the development of a base map using an aerial photo that covers all of the study intersections.

The Synchro 8.0 computer software was used to model the existing operating conditions on the study corridors. This task includes the input of turning movement count data into the model. Field data such as saturation flow rates, initial lost times, lane utilization and results from the travel time survey were used to calibrate the model parameters so that the simulation results replicated the observed field conditions in the network as accurately as possible. It is impossible to precisely reflect all variations of random factors that affect traffic patterns. Furthermore, the study corridors include many unconventional signal phasing and sequencing that cannot be replicated by standard computer software.

Step 2: Signal grouping

The natural cycle length is the optimum cycle length for an intersection if it were to operate free (uncoordinated). The coordinatability factor measures the desirability of coordinating two adjacent traffic signals and is based on travel time, storage space, proportion of traffic in the platoon, the main street traffic volume, and natural cycle length differences between adjacent intersections. A coordinatability factor above a threshold of 50 indicates that two adjacent traffic signals are likely to benefit from coordination.

As part of the signal timing process, the natural cycle lengths for each intersection and the coordinatability factors for the signals in the network were reviewed to determine the range of cycle lengths to use in the optimization process, and also which groups of signals would benefit most from coordination.

Step 3: Progression movement determination

This refers to progressing one or both directions of a two-way arterial during coordination. Progression preferences are dictated by directional traffic distribution. If traffic is balanced in both directions, a balanced bandwidth is selected to provide equal preference for both directions. Bandwidth denotes a "window" of green time where a platoon of vehicles may move through the corridor without stopping.

For this study, progression priority was set with the objective of maximizing bandwidth while minimizing delay for left-turn movements.

Step 4: Phase sequence evaluation

Leading and lagging left-turn phasing and sequential changes in split phases were reviewed. This was done with the objective to improve the efficiency of signal operation on the corridors. Leading or lagging left-turn phasing can be introduced to maximize progression bandwidth.

Left-turn lead/lag phasing sequence was selected and tested for each time period for all intersections with protected left-turns.

Step 5: Signal timing optimization

Based on the natural cycle lengths of the intersections in the network, a cycle length range was specified for optimization. The optimization process also included testing of various splits and offset. Higher cycle lengths provide better progression for the corridor, but result in the increase in side street or overall intersection delay and increase waiting time for pedestrians. Lower cycle lengths reduce side street delay but may not provide adequate green time to the coordinated phases along the main line. This may result in higher saturation/congestion, delay, and queuing along the corridor.

Synchro software was utilized for the optimization process. The splits and offset optimizations were conducted for the weekday a.m., midday, school p.m., and p.m. and weekend peak periods. Once the cycle lengths were selected, detailed recommended timing plans, to include review of splits and offsets were developed and were presented to City Staff and the City's Consultant Traffic Engineer for their review.

Recommendations

Tables 8 and **9** summarize the proposed signal coordination groupings along the two study corridors at different times of day. Currently on Mt. Diablo Boulevard, the signals are coordinated between Oak Hill Road and First Street during all four week-day peak periods and the weekend Saturday peak. TJKM proposes to add the adjacent four signals to the west, between Lafayette Circle (West) and Dolores Drive to this coordinated system for the morning, school pick-up, evening, and weekend peaks. These intersections will operate "free" similar to existing conditions during the midday peak period.

To the east of the existing coordinated system, TJKM recommends adding Second Street and Brown Avenue to the coordinated system for the school pick-up and evening peak periods only. These intersections will operate "free" similar to existing conditions at all other times.

On Moraga Road, the current signals are coordinated between Mt. Diablo Boulevard and Brook/School Street for all study peak periods. TJKM proposes to maintain the coordinated system as existing with St. Mary's Road-Herman Drive operating "free" at all times.

As mentioned previously, the decision to add intersections to the coordinated system and the groupings of intersections with varying cycle lengths within the system is based on a combination of evaluation of the coordinatability of the intersections, their levels of service, the resulting measures of effectiveness, and weighing the known trade-offs of running an intersection in coordinated mode.

Table 8: Existing and Recommended Cycle Lengths and Offsets for Weekday and Weekend Peak Periods for Mt. Diablo Boulevard and Moraga Road Corridor

ID	Intersection	Scenario	A.M. – Plan 1		Midday – Plan 2		School P.M. – Plan 3		P.M. – Plan 4		Weekend – Plan 5	
			Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec))	Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)	Cycle Length (sec)	Offset (sec)
1	Mt. Diablo Boulevard/Dolores Drive-Mountain View Drive	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	100	74	Free	-	100	97	100	90	100	53
2	Mt. Diablo Boulevard/ Happy Valley Road	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	100	18	Free	-	100	0	100	0	100	40
3	Mt. Diablo Boulevard/ Dewing Avenue	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	100	29	Free	-	100	20	100	12	100	41
4	Mt. Diablo Boulevard/ Lafayette Circles (West)	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	100	20	Free	-	100	28	100	15	100	50
5	Mt. Diablo Boulevard/Oak Hill Road-Lafayette Circles (East)	Existing	110	43	120	100	120	100	120	103	110	35
		Proposed	120	113	126	116	126	71	120	30	120	53
6	Mt. Diablo Boulevard/ Moraga Road	Existing	110	37	120	0	120	0	120	0	110	0
		Proposed	120	101	126	119	126	60	120	39	120	41
7	Mt. Diablo Boulevard/1st Street	Existing	110	0	120	0	120	0	120	0	110	0
		Proposed	120	92	126	101	126	39	120	32	120	21
8	Mt. Diablo Boulevard/ 2nd Street	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	Free	-	Free	-	60	35	60	10	Free	-
9	Mt. Diablo Boulevard/ Brown Avenue-Almanor Lane	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	Free	-	Free	-	120	11	120	96	Free	-
10	Moraga Road/ Moraga Boulevard	Existing	110	9	120	107	120	107	120	107	110	9
		Proposed	120	48	126	88	126	52	126	59	120	35
11	Moraga Road/ School Street-Brook Street	Existing	110	99	126	93	126	93	126	93	118	99
		Proposed	120	45	126	73	126	40	126	73	120	15
12	Moraga Road/ St. Mary's Road- Herman Drive	Existing	Free	-	Free	-	Free	-	Free	-	Free	-
		Proposed	Free	-	Free	-	Free	-	Free	-	Free	-

Table 9: Time of Day Signal Coordination Schedule for Weekday and Weekend Peak Periods for Mt. Diablo Boulevard and Moraga Road Corridor

ID	Intersection	A.M. - Plan 1		Midday - Plan 2		School P.M. - Plan 3		P.M. - Plan 4		Weekend- Plan 5	
		Time Period	Cycle Length (sec)	Time Period	Cycle Length (sec)	Time Period	Cycle Length (sec)	Time Period	Cycle Length (sec)	Time Period	Cycle Length (sec)
1	Mt.Diablo Boulevard/Dolores Drive-Mountain View Drive	7:30-9:30	100	-	Free	14:45-15:45	100	15:45-18:45	100	10:00-15:30	100
2	Mt. Diablo Boulevard/ Happy Valley Road	7:30-9:30	100	-	Free	14:45-15:45	100	15:45-18:45	100	10:00-15:30	100
3	Mt. Diablo Boulevard/Dewing Avenue	7:30-9:30	100	-	Free	14:45-15:45	100	15:45-18:45	100	10:00-15:30	100
4	Mt. Diablo Boulevard/ Lafayette Circles (West)	7:30-9:30	100	-	Free	14:45-15:45	100	15:45-18:45	100	10:00-15:30	100
5	Mt. Diablo Boulevard/Oak Hill Road-Lafayette Circles (East)	7:00-9:30	120	11:30-14:45	126	14:45-15:45	126	15:45-18:45	120	10:00-15:30	120
6	Mt. Diablo Boulevard/ Moraga Road	7:00-9:30	120	11:30-14:45	126	14:45-15:45	126	15:45-18:45	120	10:00-15:30	120
7	Mt. Diablo Boulevard/ 1st Street	7:00-9:30	120	11:30-14:45	126	14:45-15:45	126	15:45-18:45	120	10:00-15:30	120
8	Mt. Diablo Boulevard/ 2nd Street	-	Free	-	Free	14:45-15:45	60	15:45-18:45	60	-	Free
9	Mt. Diablo Boulevard/ Brown Avenue-Almanor Lane	-	Free	-	Free	14:45-15:45	120	15:45-18:45	120	-	Free
10	Moraga Road/ Moraga Boulevard	7:00-9:30	120	11:30-14:45	126	14:45-15:45	126	15:45-18:45	126	10:00-15:30	120
11	Moraga Road/School Street-Brook Street	7:00-9:30	120	9:30-14:45	126	14:45-15:45	126	15:45-18:45	126	10:00-15:30	120
12	Moraga Road/St. Mary's Road- Herman Drive	-	Free	-	Free	-	Free	-	Free	-	Free

Timing Plan Implementation and Evaluation

TJKM in collaboration with the City staff initiated the implementation of the proposed timings during the month of March 2015. TJKM with the assistance of the City Staff utilized QuicLoad Laptop Software which permits uploading and downloading of traffic signal timing parameters by connecting the laptop directly to the traffic signal controller to input the proposed timings at each study intersection. After implementation of the proposed timings, TJKM fine-tuned the offsets where needed based on in-person field observations of traffic conditions operating under the revised timing parameters. The fine-tuning of the timing plans also included driving along the study corridor, identifying locations where vehicles stop, and refining the offsets and splits to improve traffic flow along the study corridor. Fine-tuning was performed for each traffic peak period over a number of weekdays and weekends. See **Appendix E** for the revised timing sheets after fine-tuning and implementation.

Installation of GPS clocks

To properly operate the coordination timing on a corridor basis, GPS clocks were installed at all project intersections to synchronize the time of the clocks present in the field controllers.

Evaluation

After the new timing plans had been implemented, a new round of travel time surveys was conducted during the a.m., midday, school p.m. and p.m., and weekend peak periods to determine the effectiveness of the new plans along the Mt. Diablo Boulevard and Moraga Road study corridors.

The "After" floating car runs for the study corridors are summarized in **Tables 10, 11** and **12**. Detailed "After" travel time summary sheets are contained in **Appendix B**.

Table 10: Floating Car, Mt. Diablo Boulevard, "After" Travel Time Survey

Roadway	Approach	Peak Hour	Signal Delay/Vehicle [min:sec]	Travel Time [min:sec]	Average # of Stops[2]	Average Speed[1] [mph]	% of Signal Delay[3]
Mt. Diablo Boulevard, between Dolores Drive and Brown Avenue*	EB	A.M.[4]	1:01	2:30	2	16	40%
		Midday[5]	0:00	0:32	0	23	0%
		School P.M.[6]	1:28	3:51	3	16	39%
		P.M.[6]	0:47	3:10	1	19	25%
		Weekend[4]	0:52	2:27	1	18	36%
	WB	A.M.[4]	0:53	2:20	2	16	38%
		Midday[5]	0:00	0:36	0	22	0%
		School P.M.[6]	1:34	4:03	3	15	39%
		P.M.[6]	1:41	3:58	3	15	43%
		Weekend[4]	1:33	3:33	3	12	44%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
[4]A.M. and Weekend Peak Periods - Floating car runs between Dolores Drive and First Street.
[5]Midday Peak Period - Floating car runs between Oakhill Road and First Street.
[6]School P.M. and P.M. Peak Periods - Floating car runs between Dolores Drive and Brown Avenue.
*There are nine (9) signalized intersections along this corridor.

Table 11: Floating Car, Mt. Diablo Boulevard between Dolores Drive and Lafayette Circle (West), "After" Travel Time Survey

Roadway	*Approach*	*Peak Hour*	*Signal Delay/Vehicle [min:sec]*	*Travel Time [min:sec]*	*Average # of Stops[2]*	*Average Speed[1] [mph]*	*% of Signal Delay[3]*
Mt. Diablo Boulevard, between Dolores Drive and Lafayette Circle (West)*	EB	A.M.	0:22	1:02	1	18	35%
		School P.M.	0:18	0:58	1	20	32%
		P.M.	0:00	0:40	0	21	0%
		Weekend	0:07	0:49	0	22	16%
	WB	A.M.	0:15	0:57	1	18	26%
		School P.M.	0:36	1:18	2	13	46%
		P.M.	0:10	0:50	1	21	20%
		Weekend	0:06	0:46	0	23	13%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
*There are four (4) signalized intersections along this corridor. The corridor was not coordinated for the weekday midday peak period based on analysis. Hence, floating car survey for this peak period is not provided.

Table 12: Floating Car, Moraga Road from Mt. Diablo Boulevard to St. Mary's Road, "After" Travel Time Survey

Roadway	Approach	Peak Hour	Signal Delay/Vehicle [min:sec]	Travel Time [min:sec]	Average # of Stops[2]	Average Speed[1] [mph]	% of Signal Delay[3]
Moraga Road*	NB	A.M.	0:27	1:41	1	17	26%
		Midday	0:09	1:17	1	22	12%
		School P.M.	1:04	2:08	1	13	50%
		P.M.	0:49	1:59	2	15	41%
		Weekend	0:57	2:04	1	13	46%
	SB	A.M.	0:13	1:15	0	22	19%
		Midday	0:00	1:01	0	26	0%
		School P.M.	0:08	1:16	1	21	12%
		P.M.	0:20	1:28	1	20	23%
		Weekend	0:02	1:10	1	23	3%

Notes:

[1]Average speed along the corridor including stop delays, not reflective of actual speeds of vehicles while moving.
[2]Average number of stops made by a car from all the travel time runs collected on the study corridors including stops at red lights as well as other stops between intersections due to congestion.
[3]Signal Delay as percentage of travel time.
*There are four (4) signalized intersections along this corridor.

To gauge the effect of the new timing plans, the "Before" and "After" conditions were compared. **Tables 13, 14** and **15** summarize the estimated measures of effectiveness (MOE) based on the recommended timing plans for the study corridors and compares them to Existing Conditions MOEs. For a fair comparison to existing conditions and to reflect the variation in traffic character, the Mt. Diablo Boulevard corridor is divided into two sections - Dolores Drive to Brown Avenue, and Dolores Drive to Lafayette Circle (West). The section of Dolores Drive to Lafayette Circle (West) was analyzed separately to provide a comparison between existing conditions where the intersections operated under "free" condition and the proposed timing plans. Moraga Road is treated as a single corridor.

Appendix F contains the Synchro model output results for the Arterial Level of Service and the MOEs for the study corridor, and the comparison of MOEs under "Before" and "After" conditions. As the tables show, the implementation of recommended signal timing plan has generally resulted in reductions to signal delay per vehicle, stops per vehicle, and total travel time, as well as increases to the average speed of the corridors based on the observations from the "After" floating-car surveys.

Along various sub-sections tested on Mt. Diablo Boulevard between Dolores Drive and Brown Avenue, data showed significant decrease in signal delay, travel time, stops; and increase in speed during the weekday a.m., midday, school p.m. and p.m., and weekend peak periods in the eastbound and westbound direction. It was observed that there was approximately an average reduction of 50% in stops per vehicle along Mt. Diablo Boulevard for all peak periods with the implementation of the proposed timing plans.

Moraga Road (between Mt. Diablo Boulevard and St. Mary's Road-Herman Drive) also showed significant decrease in signal delay, travel time, stops; and increase in speed. It was observed that there was approximately an average reduction of 50% in stops per vehicle along Moraga Road for all peak periods with the implementation of the proposed timing plans. However, it should be noted that Moraga Road operates under saturated traffic conditions during most of the peak periods, where travel speeds are in the low teens. The reduction in stops helps reducing delay to a certain extent in the overall travel time from one end of the corridor to the other, thus producing a faster overall average travel speed. However, congestion still occurs with the revised signal timings, which are not expected to produce “free flow” conditions in traffic given that demand far exceeds the available capacity during the highest peak of the peak period.

Generally, the results show benefits to updating the current coordination timings, and adding certain uncoordinated intersections to the system during certain times of day. On Mt. Diablo Boulevard the travel time improved up to one or two minutes for most peak periods. On Moraga Road, the benefits are much more limited, however, the travel time improved up to one minute during certain times of day. It was observed that there was an average reduction in stops by approximately 50% for both study corridors and a substantial increase in speed during certain times of day.

During Fine-tuning and Implementation of the proposed timing plans and “After” floating car surveys, the following observations were made:

1. The intersection of Mt. Diablo Boulevard and Happy Valley Road has “conditional” service for the eastbound left turn movement from Mt. Diablo Boulevard onto Happy Valley Road during “Free” operation. Conditional service allows this movement to be served twice in a given cycle to reduce the build-up of queues. Due to technological constraints within the traffic controller, conditional service is incompatible with a coordinated plan. It was noted during field observations that p.m. peak queuing in the eastbound direction can extend well beyond the available turn pocket. This queuing is somewhat exacerbated in coordinated mode of operation during certain cycles. However, typically the new timing allows the eastbound left turn queue to clear almost completely every cycle. Furthermore, even when the left turn queue spills over to the number one through lane, there is sufficient capacity in the remaining through lane to accommodate traffic without significant delay.
2. On the Mt. Diablo Boulevard corridor, several intersections are proposed to be added to the coordinated system for certain times of day. It was expected that the new coordinated timing will provide improved conditions along the main line but minor movements within an intersection would degrade slightly. TJKM’s field observations noted that the intersections of Dolores Drive, Happy Valley Road, Dewing Avenue and Lafayette Circle (West) are not significantly impacted due to the proposed coordination plans during fine-tuning and implementation. A comparision of “Before” and “After” floating car surveys reflects that the coordination benefits the corridor overall.
3. There are existing pedestrian crosswalks crossing mainline traffic at the intersection of Mt. Diablo Boulevard and Golden Gate Way. Heavy pedestrian activity was observed at this intersection during the weekday p.m. peak period. TJKM observed this intersection during the implementation and fine-tuning phase to assess if vehicular progression is impacted by the pedestrian activity, and if the proposed coordination will have any adverse effect on the safety and mobility of pedestrians. It was noted that coordination during p.m. peak period was not hampered due to the pedestrian traffic, and no pedestrian safety issues were noted during field observations.

4. The intersection of Mt. Diablo Boulevard and Moraga Road experiences heavy westbound left turn traffic onto Moraga Road at various times. This movement has been coordinated with the southbound through movement along the Moraga Road corridor to provide continuous progression. It was noted that the entire queue collected for the westbound left movement on Mt. Diablo Boulevard was able to be served within the green time allocation of one signal cycle, and the traffic did not have to stop at any intersections along Moraga Road.
5. Another problem noted before implementation was the large percentage of northbound right turning traffic at the Mt. Diablo Boulevard and Moraga Road intersection that continues onto Mt. Diablo Boulevard to make a left at First Street. This resulted in heavy queuing for the eastbound left turn at First Street. This queuing extends back to the Mt. Diablo Boulevard and Moraga Road intersection and blocks eastbound through traffic heading toward First Street. The coordination plans were developed and fine-tuned such that the northbound right turning vehicles from Moraga Road heading towards First Street to make the eastbound left would get served as soon as they reached First Street. This reduced queuing and spillover from First Street back to Moraga Road along Mt. Diablo Boulevard.

Table 13: "Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Mt. Diablo Boulevard

Roadway	Peak Hour	Approach	Scenario	Signal Delay (min:sec)	Travel Time (min:sec)	Stops/Veh	CO Emissions (Kg)	NOx Emissions (Kg)	Speed (mph)
Mt. Diablo Boulevard, between Dolores Drive and Brown Avenue	A.M.	EB	Existing	1:05	2:49	2	3.07	0.6	15
			Proposed	1:01	2:30	2	2.44	0.47	16
			% Change	-6%	-11%	0%	-21%	-22%	7%
		WB	Existing	1:29	3:21	3	3.75	0.73	11
			Proposed	0:54	2:21	2	3.25	0.63	16
			% Change	-39%	-30%	-33%	-13%	-14%	45%
	Midday	EB	Existing	1:07	1:45	1	2.04	0.4	9
			Proposed	0:00	0:32	0	1.72	0.34	23
			% Change	-100%	-70%	-100%	-16%	-15%	156%
		WB	Existing	1:02	1:41	1	1.53	0.3	8
			Proposed	0:00	0:36	0	1.44	0.28	22
			% Change	-100%	-64%	-100%	-6%	-7%	175%
	School P.M.	EB	Existing	2:37	5:41	5	6.56	1.28	10
			Proposed	1:28	3:51	3	6.02	1.17	16
			% Change	-44%	-32%	-40%	-8%	-9%	60%
		WB	Existing	3:19	6:26	6	4.76	0.93	9
			Proposed	1:34	4:03	3	4.6	0.89	15
			% Change	-53%	-37%	-50%	-3%	-4%	67%
	P.M.	EB	Existing	3:07	5:56	4	7.18	1.4	10
			Proposed	0:47	3:10	1	6.69	1.3	19
			% Change	-75%	-47%	-75%	-7%	-7%	90%
		WB	Existing	3:45	6:22	4	4.85	0.94	9
			Proposed	1:41	3:58	3	4.44	0.86	15
			% Change	-55%	-38%	-25%	-8%	-9%	67%
	Weekend	EB	Existing	1:27	3:38	3	4.56	0.89	11
			Proposed	0:52	2:27	1	3.84	0.75	18
			% Change	-40%	-33%	-67%	-16%	-16%	64%
		WB	Existing	1:58	4:02	3	3.69	0.72	10
			Proposed	1:33	3:33	3	3.26	0.63	12
			% Change	-21%	-12%	0%	-12%	-13%	20%

Table 14:"Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Mt. Diablo Boulevard, between Dolores Drive and Lafayette Circle (West)

Roadway	Peak Hour	Approach	Scenario	Signal Delay (min:sec)	Travel Time (min:sec)	Stops/Veh	CO Emissions (Kg)	NOx Emissions (Kg)	Speed (mph)
Mt. Diablo Boulevard, between Dolores Drive and Lafayette Circle (West)	A.M.	EB	Existing	0:30	1:15	1	1.15	0.22	14
			Proposed	0:22	1:02	1	0.86	0.17	18
			% Change	-27%	-17%	0%	-25%	-23%	29%
		WB	Existing	0:34	1:25	2	1.77	0.34	12
			Proposed	0:15	0:57	1	1.50	0.29	18
			% Change	-56%	-33%	-50%	-15%	-15%	50%
	School P.M.	EB	Existing	0:38	1:34	2	1.77	0.35	11
			Proposed	0:18	0:58	1	1.27	0.25	20
			% Change	-53%	-38%	-50%	-28%	-29%	82%
		WB	Existing	0:39	1:45	1	1.54	0.30	12
			Proposed	0:36	1:18	2	1.35	0.26	13
			% Change	-8%	-26%	100%	-12%	-13%	8%
	P.M.	EB	Existing	0:51	1:44	1	2.30	0.45	10
			Proposed	0:00	0:40	0	1.56	0.30	21
			% Change	-100%	-62%	-100%	-32%	-33%	110%
		WB	Existing	1:32	2:22	2	1.67	0.33	8
			Proposed	0:10	0:50	1	1.59	0.31	21
			% Change	-89%	-65%	-50%	-5%	-6%	163%
	Weekend	EB	Existing	0:30	1:25	1	1.84	0.36	13
			Proposed	0:07	0:49	0	1.34	0.26	22
			% Change	-77%	-42%	-100%	-27%	-28%	69%
		WB	Existing	0:18	1:15	1	1.35	0.26	16
			Proposed	0:06	0:46	0	1.15	0.22	23
			% Change	-67%	-39%	-100%	-15%	-15%	44%

Table 15: "Before" and "After" Comparison of System Measures of Effectiveness (MOEs) for Moraga Road

Roadway	Peak Hour	Approach	Scenario	Signal Delay (min:sec)	Travel Time (min:sec)	Stops/Veh	CO Emissions (Kg)	NOx Emissions (Kg)	Speed (mph)
Moraga Road	A.M.	NB	Existing	1:43	2:54	2	3.73	0.73	10
			Proposed	0:27	1:41	1	3.37	0.66	17
			% Change	-74%	-42%	-50%	-10%	-10%	70%
		SB	Existing	0:14	1:28	1	2.10	0.41	18
			Proposed	0:13	1:15	0	2.12	0.41	22
			% Change	-7%	40%	-100%	1%	0%	22%
	Midday	NB	Existing	1:48	2:54	2	2.83	0.55	9
			Proposed	0:09	1:17	1	2.84	0.55	22
			% Change	-92%	-56%	-50%	0%	0%	144%
		SB	Existing	0:21	1:28	1	2.21	0.43	18
			Proposed	0:00	1:01	0	2.11	0.41	26
			% Change	-100%	-31%	-100%	-5%	-5%	44%
	School P.M.	NB	Existing	2:12	3:02	2	3.32	0.64	12
			Proposed	1:04	2:08	1	3.30	0.64	13
			% Change	-52%	-30%	-50%	-1%	0%	8%
		SB	Existing	1:35	3:10	2	2.75	0.53	9
			Proposed	0:08	1:16	1	2.64	0.51	21
			% Change	-92%	-60%	-50%	-4%	-4%	133%
	P.M.	NB	Existing	0:43	1:52	2	2.98	0.58	14
			Proposed	0:49	1:59	2	2.76	0.54	15
			% Change	14%	6%	0%	-7%	-7%	7%
		SB	Existing	0:35	1:39	1	3.32	0.65	16
			Proposed	0:20	1:28	1	3.25	0.63	20
			% Change	-43%	-11%	0%	-2%	-3%	25%
	Weekend	NB	Existing	1:12	2:22	2	3.04	0.59	11
			Proposed	0:57	2:05	1	3.23	0.63	13
			% Change	-21%	-12%	-50%	6%	7%	18%
		SB	Existing	0:13	1:15	2	2.42	0.47	21
			Proposed	0:03	1:10	1	2.38	0.46	23
			% Change	-77%	-7%	-50%	-2%	-2%	10%

Benefit/Cost Ratio Analysis

As stated previously, this study is funded by the Metropolitan Transportation Commission (MTC). As part of the before/after comparison, MTC requires a benefit/cost analysis to determine the amount of theoretical public benefit derived from investing in the Program for Arterial System Synchronization (PASS). The benefit/cost analysis also accounts for improvement in traffic operation for autos and safety for pedestrians and bicyclists.

A summary of some key findings from the results of the benefit-cost analysis is as follows:

- Average reduction in travel time – 35%
- Average speed increase – 62%
- Average fuel savings – 24%
- Average reduction in stops – 45%
- The results of the analysis showed a total 5-year lifetime travel time savings of approximately $4,401,363 and fuel consumption savings of approximately $58,810
- Total cost of the projects including the consultant cost and agency staff costs is approximately $98,960 for development and implementation of the coordination plans
- The project obtained a benefit/cost ratio of nearly 48:1

Table 16 summarizes the results of the measures of effectiveness and benefit/cost analysis conducted for the study corridor. As indicated under each of the “Before” vs. “After” conditions tables, it was observed that there was a significant improvement in traffic signal coordination and travel time reduction along the study corridor. The project is expected to result in a significant reduction in greenhouse gases/harmful emissions. **Appendix G** contains a detailed spreadsheet for the benefit/cost analysis with all the assumptions that were considered in the analysis. The methodology and assumptions used in estimating the various public benefits are consistent with those accepted by MTC in evaluating similar projects under the PASS program.

Table 16: Benefit/Cost Analysis

Costs				
Consultant Costs (Basic Services/Plans)				$70,800
Consultant Costs (Additional Plans, TSP, IM Flush Plans, etc.)				$6,500
Other Project Costs (GPS Clocks, Communications equipment, etc.)				$3,960
Agency Staff Costs (Local agency, MTC, Caltrans, etc.)[8]				$17,700
Total Costs				**$98,960**
Benefits				
Measures	***First Year***		***Lifetime (5 Years)***[7]	
	Savings	*Monetized Savings*	*Savings*	*Monetized Savings*
Travel Time Savings (hrs)	84,074	$1,640,735	225,533	$4,401,363
Fuel Consumption Savings (gal)	5,681	$21,923	15,239	$58,810
ROG Emissions Reduction (tons)	0.02	$28	0.06	$76
NOx Emissions Reduction (tons)	0.01	$244	0.04	$656
PM2.5x Emissions Reduction (tons)	0.00	$235	0.00	$630
CO Emissions Reduction (tons)	0.15	$12	0.41	$32
Total Lifetime Benefits				**$4,461,567**
Overall Project Benefits			***Auto***	
Average Decrease in Travel Time			35%	
Average Speed Increase			62%	
Average Fuel Savings			24%	
Benefit/Cost Ratio			**48:1**	

Notes:

1. General methodology, fuel consumption factors, and health costs of motor vehicle emissions based on California Department of Transportation, Office of Transportation Economics. California Life-Cycle Benefit/Cost Analysis Model and Technical Supplement to the User's Guide, 2009
2. Benefits claimed include travel time savings, fuel consumption savings, and health cost savings associated with emissions reductions for the coordinated peak periods indicated above. Yearly savings calculated based on 250 days of workdays in a year. 3. Value of time assumed to be 50 percent of the wage rate for off-the-clock travel or $19.52 in 2013 constant dollars. Bay Area average wage rate is $20.82 per hour in 1990 constant dollars, based on Travel Demand Models for the San Francisco Bay Area [BAYCAST-90] Technical Summary, Table 4, p. 28, June 1997. Adjusted for inflation using CPI, from US Dept of Labor, Bureau of Labor Statistics, CPI - All Urban Consumers, San Francisco-Oakland-San Jose, CA area, All Items, Not Seasonally Adjusted (Series Id:CUURA422SA0). Vehicle fleet assumed to be 100 percent automobiles.
4. Average vehicle occupancy assumed to be 1.118 persons per vehicle and is used in calculating travel-time savings in autos only. This is based on the San Francisco Bay Area Baycast Travel Model run for the RTP 2009 (using the 2010 network) developed by the Metropolitan Transportation Commission.
5. Average fuel cost is from US Dept of Labor Bureau of Labor Statistics, CPI - Average Price Data, San Francisco-Oakland-San Jose, CA area, Gasoline unleaded regular per gallon. Average of monthly prices in the Bay Area from January 2013 – December 2013 is $3.859.
6. Health cost of ROG Emissions ($1,259 per ton), NOx Emissions ($17,997 per ton), and CO Emissions ($77 per ton) are based on the California Department of Transportation, Office of Transportation Economics from Exhibit III-43, p. III-69 of the California Life-Cycle Benefit/Cost Analysis Model Volume 3 Technical Supplement to User's Guide, Revision 2 (February 2012). The 2013 costs are calculated with a standard assumption of 2% increase per year from the 2011 costs. PM2.5x Emissions ($312,351 per ton) costs, are based on Victoria Transport Policy Institute's Air Pollution Costs, with 2013 costs calculated with a standard assumption of 2% increase per year from 2007 costs.

7. Project life assumed to be five years. Benefits assumed to be 100 percent on first day after implementation, declining steadily to zero by end of the fourth year. Benefits equivalent to sum of discounted average annual benefits, where averages are 90% of First Year for year 0, 70% for year 1, 50% for year 2, 30% for year 3, and 10% for year 4.
8. All public agencies involved staff costs assumed to be 25% of the project consultant costs.

Benefits to Other Modes

Additionally, the PASS project in Lafayette provided an opportunity to update traffic signal timing parameters for consistency with established guidelines as follows:

Traffic Safety Benefit

To enhance traffic safety, the yellow clearance timing parameters were confirmed or updated based on posted speed limits along the study corridor.

Benefits to Pedestrians

The “Walk” timing and “Flash Don’t Walk” clearance timing parameters were also updated to provide adequate time for pedestrians to safely cross the intersections, based on the new walking speed of 3.5 feet/second, as specified in 2012 California MUTCD standards.

Benefits to Bicyclists

For improved bike safety, the minimum green intervals were updated to ensure that bicyclists can clear the intersections.

Conclusion

The traffic signal coordination plans are expected to improve traffic progression and promote uniform travel speeds along the study corridor thus reducing driver frustration. Implementation of the timing plans has resulted in reduction in traffic delay and automobile travel time, allowing reduction in harmful greenhouse gas emissions. Other benefits include improvements to pedestrian and bicycle mobility in terms of updated signal timing accommodation consistent with current standards and guidelines.

Glossary

Actuated Signal

An Actuated Signal uses vehicle detectors to vary phase timing according to demand.

Actuated Coordinated

In an Actuated Coordinated system, the minor movement phases are actuated and the major-road through movement phases are non-actuated. The controller's force-off settings are used to ensure that the non-actuated phases are served at the appropriate time during the signal cycle such that progression for the major-road through movement is maintained.

Actuated Uncoordinated

In this type of system, the cycle length is allowed to vary each cycle based on detection. The cycle length constraint is removed in an Actuated Uncoordinated system especially during oversaturated period to provide effective reallocation of green time, provided the gap timers are set accurately. This provides green time based on vehicle demand with all served phases fully actuated and no recalls set. Traffic flow is controlled without considering the operation of adjacent traffic signals.

All Red

All Red is the interval during which all phases receive a red indication. The purpose of the all red interval is to allow vehicles that entered the intersection during the yellow interval to clear the intersection before a green indication is given to a conflicting movement.

Coordinated Operation

It is a mode of operation whereby the phase sequencing and timing at one signal is synchronized with those of adjacent signals in order to enhance traffic flow through the system.

Cycle Length

Cycle Length is the time required for a complete sequence of phases at a signal. It is typically measured as the time elapsed from the end of main street green to the end of main street green again. Cycle length remains constant with fixed time signals but varies from cycle to cycle with actuated signals.

Lane Utilization

The Lane Utilization Factor determines how the traffic volumes assigned to a lane group are distributed across each lane. A value of one (1) indicates equal distribution across all lanes. A value less than one lower's the saturation flow rate because all lanes are not working at full capacity.

Minimum Gap Time

It is the minimum value to which a passage time can be reduced by the gap reduction function.

Minimum Initial

Minimum Initial is a volume density setting. It is the minimum duration of green that must be displayed for a given phase.

Offset

The offset for a signalized intersection is defined as the time difference between the intersection reference point and that of the system master. The intersection reference point is typically specified to occur at the planned start (or end) of the green interval for the first coordinated phase. The “first coordinated phase” is the coordinated phase that occurs first (of all coordinated phases) for a given phase sequence and splits.

Pedestrian Clearance Interval/Flashing Don’t Walk

Interval during which pedestrians who have already entered the crosswalk are allowed to complete their crossing. If pedestrian heads are provided, this is the ‘Flashing Don’t Walk’ interval. If pedestrian heads are not provided, this is a portion of the vehicle green phase.

Split Phasing:

Split phasing represents an assignment of the right-of-way to all movements of a particular approach, followed by all of the movements of the opposing approach. Split phasing may be necessary when intersection geometry results in partially conflicting vehicle paths through the intersections or where the approaches are offset such that opposing left turning vehicles would have to occupy the same space to complete their turns. If the intersection has high left turn and through volume, the traffic engineer may have to use shared left turn and through lanes to make efficient use of the approach which would also result in split phasing for the approach.

Vehicle Extension (Passage time)

The amount of time, the green interval is extended for a vehicle actuation. If the controller receives another vehicle actuation before the passage time has expired, the passage timer will be reset to the passage time. The passage time is programmed in the controller and typically ranges from 2.0 sec. to 6.0 sec.

Walk Interval

Interval during which pedestrians waiting on the curb may enter the crosswalk and begin a crossing.