TETAP

County of Santa Clara

Implementation of Signal Coordination with Light Rail Transit (LRT) Priority

Final Report

Prepared for:

Funded by:

Metropolitan Transportation Commission (MTC)

Prepared by:

Kimley-Horn and Associates, Inc

Tel. No: 925-543-0840
Fax No.: 925-543-0839

July 7, 2009

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I: INTRODUCTION

The County of Santa Clara received Traffic Engineering Technical Assistance Program (TETAP) grant from the Metropolitan Transportation Commission (MTC) under the 2006 cycle to implement signal coordination with Light Rail Transit (LRT) priority at Montague Expressway/N. First Street and to develop recommended signal coordination plans with LRT priority at Lawrence Expressway/Tasman Drive. A TETAP study was conducted during the 2005 Cycle to review signal coordination at Montague Expressway/N. First Street and looked at various LRT priority alternatives. Recommended timing parameters were developed in the initial study but coordination timing plans were not implemented. Since the initial study, the County and Santa Clara Valley Transportation Authority (VTA) agreed to implement and review the Transit Priority alternative from the 2005 study. A new traffic signal controller with new priority software was installed in August 2008 and VTA installed new advanced loop detection to allow for implementation of the Transit Priority operation. With the controller change, new signal timing and signal coordination were installed and the timings were fine-tuned through the end of November 2008.

The goal of this study was to implement the recommended coordination plans at Montague Expressway/N. First Street, conduct fine-tuning of the timings, and complete a “before” and “after” travel time study comparison. In addition, based on the Transit Priority operation, signal coordination and LRT parameters will be developed for the signal at Lawrence Expressway/Tasman Drive for future implementation by the County.

Figures 1 and 2 show the project area and study intersection at Montague Expressway/N. First Street and **Figures 3 and 4** show the project area and study intersection at Lawrence Expressway/Tasman Drive.

Montague Expressway is a heavily traveled expressway that provides an east-west connection between the US-101, I-880, and I-680 freeways and the Cities of Milpitas, San Jose, and Santa Clara. Running along the median of N. First Street and crossing Montague Expressway at grade, the Alum Rock-Santa Teresa and Mountain View-Winchester LRT lines provide service to the Cities of Mountain View, Sunnyvale, Santa Clara, San Jose, Milpitas, San Jose, and Campbell.

Figure 1: Area Map - Montague Expressway/N. First Street

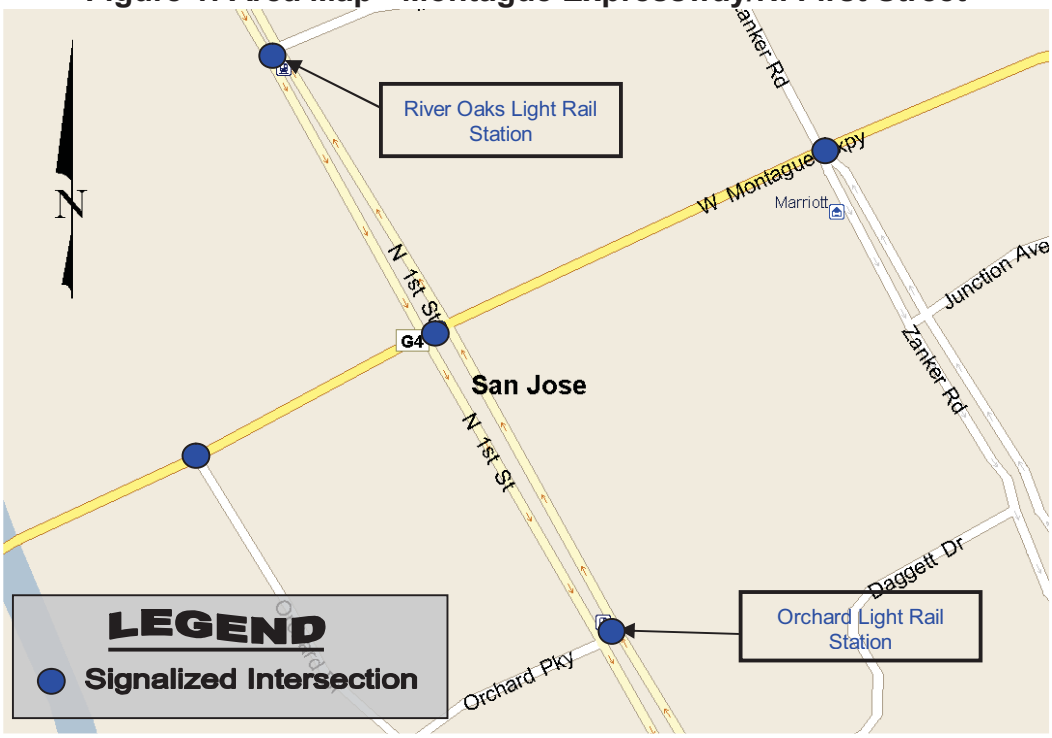

Figure 2: Aerial Photograph - Montague Expressway/N. First Street

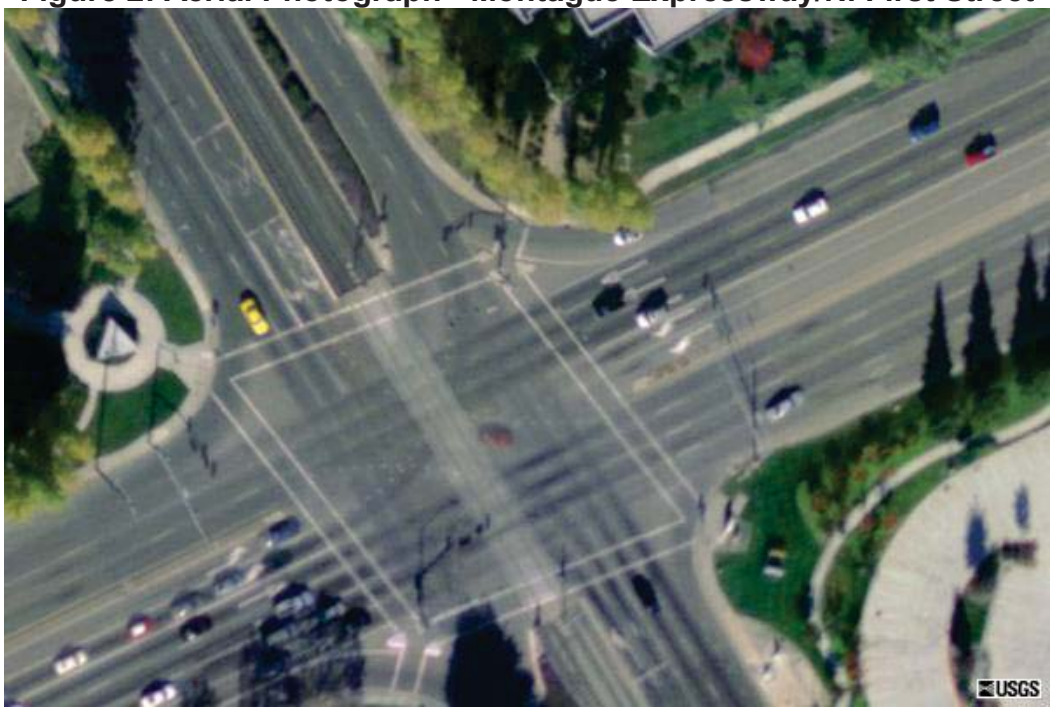

Figure 3: Area Map - Lawrence Expressway/Tasman Drive

Figure 4: Aerial Photograph - Lawrence Expressway/Tasman Drive

2.1 Introduction

Data collection and reduction was the initial stage of the analysis. The following sections highlight the information collected and include these items:

- Data Collection (From Agencies)
- Travel Time Summary
- Field Review

A detailed data collection was completed and summarized for Montague Expressway/N. First Street with the 2005 TETAP Study and is therefore not included in this report. Field observations were not conducted at Lawrence Expressway/Tasman Drive since the primary focus of this TETAP study is to implement and evaluate coordination timing with LRT Priority at Montague Expressway/N. First Street.

2.2 Data Collection (From Agencies)

Kimley-Horn and Associates, Inc. (KHA) met with the County of Santa Clara and VTA to review and finalize the scope of services and project schedule, and discuss project goals. Data collected from the agencies included the following:

- County – Existing signal timing sheets for Lawrence Expressway/Tasman Drive and two adjacent signals
- County – Existing midday peak Synchro model for Montague Expressway
- County – Existing as-built at Lawrence Expressway/Tasman Drive and two adjacent signals
- County – Existing AM, midday, and PM Synchro models for Lawrence Expressway
- County – 24-hour daily hose counts from 2002 and 2004 on Lawrence Expressway and Montague Expressway near the project area
- VTA - Plan showing new advance detector locations

The County and VTA have provided KHA with all of the available data listed above.

2.3 "Before" Travel Time Summary

As part of a 2008 RSTP project to re-time Montague Expressway and Lawrence Expressway, Kimley-Horn collected "before" study floating vehicle survey data for the AM and PM peak periods along Lawrence Expressway and Montague Expressway. The travel time surveys were conducted along Montague Expressway from I-680 to US-101 and along Lawrence Expressway from Saratoga Avenue to SR-237. The results of the "before" study for each peak period are summarized in **Tables 1 and 2**.

Table 1 – Montague Expressway "Before" Travel Time Summary

Time Period	Direction	Average Travel Time (min:sec)	Average Delay (min:sec)	Average Stops (#)	Average Speed (mph)
AM	Eastbound	14:04	04:33	5.5	27.0
	Westbound	16:26	04:59	4.7	23.1
PM	Eastbound	15:02	02:50	3.0	25.2
	Westbound	15:27	04:57	5.8	24.5

Note: Travel time survey conducted between I-680 and US-101 with a total distance of 33,390 feet.

Table 2 – Lawrence Expressway "Before" Travel Time Summary

Time Period	Direction	Average Travel Time (min:sec)	Average Delay (min:sec)	Average Stops (#)	Average Speed (mph)
AM	Northbound	19:46	08:16	7.0	26.0
	Southbound	18:19	06:18	9.0	28.1
PM	Northbound	18:59	07:14	9.5	27.1
	Southbound	21:53	09:52	8.8	23.5

Note: Travel time survey conducted between SR-237 and Saratoga Avenue with a total distance of 45,260 feet.

2.4 Field Review

A field review at Montague Expressway/N. First Street was conducted during the AM and PM peak periods to record existing "before" LRT travel times and train delays at the intersection. The data was collected from 6:00 AM to 9:00 AM and from 3:00 PM to 7:00 PM. A detailed summary of the travel time and delay data collected is included in the **Appendix**.

Key observations obtained during field review include the following:

- The trains were observed to obtain a green approximately 90% of the time at the intersection, without stopping. However, if the signal was red while the trains were approaching to the intersection, the trains slowed down in order to avoid stopping at the intersection. Therefore, there were some cases where the train did not stop but did incur delay.
- The northbound trains were observed to stop more frequently than the southbound trains due to the northbound station being located closer to Montague Expressway.
- The estimated maximum stop time for the trains was approximately 5-10 seconds in the AM period and 5-25 seconds in the PM period.
- The average delay at the intersection for trains traveling in the southbound direction was 1.16 seconds in the AM period and 2.20 seconds in the PM period. The average delay for trains traveling in the northbound direction was 2.05 seconds in the AM period and 1.01 seconds in the PM period. Information regarding what caused the delay, such as whether delay was caused by pedestrians crossing N. First Street or from second trains that arrived after another train within a single cycle, was not collected.
- The average travel time from the station to the intersection, for trains traveling in the southbound direction was 67.34 seconds in the AM period and 70.82 seconds in the PM period. The average travel time for trains traveling in the northbound direction was 44.27 seconds in the AM period and 46.83 seconds in the PM period.
- The trains were observed to stop more frequently in the AM period than the PM period.
- The peak traffic conditions at the intersection, including queuing, was observed to occur around 8:00 AM during the morning peak and just past 5:00 PM during the evening peak.
- During the AM peak, the heaviest movements and queues were observed in the northbound through, westbound through, and eastbound left turn movements. During the peak 15 minute period, traffic was observed to be “unserved” in these three movements, typically in the cycles following a LRT priority call. The maximum northbound queue was observed to extend just past the Orchard Parkway intersection to the south, the westbound queue extended just past Zanker Road to the east, and the eastbound left turn queues extended to just over 20 vehicles in each lane.
- During the PM peak, the heaviest movements and queues were observed in the southbound through and through/right, westbound through, and the eastbound

through movements. Similar to the AM Peak, during the PM peak period, traffic was observed to be "unserved" in these three movements, typically in the cycles following a LRT priority call. The maximum southbound queue was observed to extend past the River Oaks Place intersection to the north, the westbound queue extended just past Zanker Road to the east, and the eastbound through queue extended to the bridge approximately 1000´ to the west.

3.1 Introduction

The goal of this study was to implement traffic signal coordination plans at Montague Expressway/N. First Street with LRT priority and to develop signal coordination parameters with LRT priority for the signal at Lawrence Expressway/Tasman Drive for future implementation by the County. In addition, LRT priority will operate during the non-coordinated, off-peak periods so priority parameters for free conditions were developed.

A traffic operations analysis was conducted at Montague Expressway/N. First Street and Lawrence Expressway/Tasman Drive to develop recommended signal coordination and priority parameters. The operations analysis was conducted during the AM, midday, and PM peak periods and during the off-peak free periods.

An initial coordination plan was developed for each of the peak periods and then priority parameters developed based on the base coordination plan. To evaluate the benefits of coordination itself, a comparison of existing operation without transit priority and with coordination was conducted. For priority operation, two scenarios were developed to compare to existing conditions, an early green alternative and an extended green alternative, and were modeled to capture the "worst" case conditions, or the longest period of early or extended green time. Priority is provided by issuing an early green or extended green to the priority phase by reducing the splits of the non-priority phases. During coordination, priority is provided by reducing the coordinated splits while in free operation it is provided by reducing the MAX1 green times. Therefore, the following traffic models were developed under various conditions to evaluate the recommended timing:

- Existing Free Operation – No Priority
- Existing Free Operation – Existing Priority
- Coordinated Operation – No Priority
- Coordinated Operation – Priority Early Green
- Coordinated Operation – Priority Extended Green
- Off-peak Free Operation – Priority Early Green
- Off-peak Free Operation – Priority Extended Green

To model the priority conditions, the signal timing was developed at the intersections to represent two consecutive cycles, a priority cycle and the following normal or "recovery" cycle. This was accomplished by utilizing the 16 programmable phases within Synchro to model the consecutive cycles. This analysis method enables an evaluation on how well the intersection recovers after a priority service within a single following cycle and provides an average of performance measures over two consecutive cycles rather than separate performance measures for each cycle.

The following sections highlight the signal timing analysis and recommended signal timing parameters for each intersection.

3.2 Montague Expressway/N. First Street Analysis

The analysis and development of recommended timing parameters at the Montague Expressway/N. First Street intersection was completed during the AM and PM peak periods with the initial TETAP study conducted in 2005, with following analysis completed with this study. Development of coordination timing included development of a basic coordination plans and then development of priority parameters for operation during a LRT priority call. In addition, parameters for free operation were developed. Initial signal coordination plans, free operation parameters, and LRT priority parameters were presented in the *Draft Report.* Since implementation of the new controller and controller software was delayed for over a year, the signal coordination and priority parameters were adjusted slightly from initially developed and implemented along with other signals on Montague Expressway with the 2008 Regional Signal Timing Program (RSTP) study. Based on the RSTP recommended timings, coordination was implemented at Montague Expressway/N. First Street with cycle lengths of 190 seconds, 150 seconds, and 190 seconds during the AM, midday, and PM peak periods, respectively, with the Montague Expressway/N. First Street operating free between the peak periods.

3.3 Lawrence Expressway/Tasman Drive Analysis

An analysis and development of recommended timing parameters was completed at Lawrence Expressway/Tasman Drive for the AM, midday, PM, and off-peak periods. The analysis and recommendations included signal coordination operation, free

operation, transit priority parameters, and time-of-operation and were presented in the *Draft Report* for this project. Since the analysis and *Draft Report* were completed, new signal timing was developed and implemented along the corridor with the 2008 RSTP project. Therefore minor adjustments would be required to the timing parameters at the time of implementation of the LRT priority operation at this intersection.

4.1 Introduction

A new traffic signal controller with new priority software was installed at Montague Expressway/N. First Street in August 2008 and VTA installed new advanced loop detection to allow for implementation of the Transit Priority operation. With the controller change, new signal timing and signal coordination were installed and the timings were fine-tuned through the end of November 2008. Once the timings were fine-tuned, after travel time studies along Montague Expressway and delay studies for the Light Rail Trains at the intersection were conducted. The following sections summarize the implementation and fine-tuning process and the results of the after study.

4.2 Fine-Tuning

Once the controller and signal timing was implemented, KHA worked with the County to fine-tune the signal timing at the intersection. Fine-tuning was conducted by standing at the intersection, driving along Montague Expressway, and monitoring traffic from the traffic operations center (TOC) over a three month period, between August and November, 2008. The fine-tuning consisted of optimizing transit priority parameters, signal splits, and offsets with a goal of improving traffic operations while minimizing impact the LRT trains. In addition to timing adjustments, fine-tuning included several controller software upgrades to provide additional functionality and to resolve a number of issues observed with the operation. During initial deployment of the priority operation, it was determined that the controller software functionality was more limited than originally expected. The following summarize some of the initial issues observed:

- In free operation, the controller operated in a more high priority mode with limited ability to program return phases after a priority call, resulting in significant congestion and some skipping of phases.
- During coordinated operation, there was some skipping of phases during transition of the signal into coordination and after some LRT priority calls.
- Since Montague Expressway was programmed as the coordinated phases, rather than the LRT priority phases (N. First Street), the controller had limited ability to provide an “extended” green. An “extended” green would only be provided if the trains would arrive at the intersection within about a 5-10 seconds window after

N. First Street would terminate. This resulted in nearly no occurrence of a "extended green" priority operation and only the occurrence of an "early green" priority operation.

With the controller software upgrades, the free operation was improved and the issue with skipping of phases during both free and coordinated operation was resolved. Since Montague Expressway is the coordinated phase, the signal can only extend the LRT priority phases (N. First Street through) up to the amount of time that can be reduced from the subsequent signal phases after the priority phases and before the beginning of the Montague Expressway through phases (coordinated phases). Therefore, the LRT priority phase could only be extended by the time that could be reduced from the N. First Street northbound and southbound left turn phases and the Montague Expressway eastbound and westbound left turn phases. Adjustments were made to increase the amount of time that could be reduced from the left turn phases along with other priority parameter adjustments, but this "window" is still narrower than initially anticipated. Consequently, there was a higher than expected delay for LRT trains since there is a lower opportunity to receive an "extended green" and a higher percentage of trains are required to wait for an "early green".

After final controller software upgrades were completed, follow-up fine-tuning adjustments were made. The following summarizes some of the fine-tuning adjustments made during the implementation and review process:

- The coordination splits and priority splits were adjusted to balance the vehicular delay with the LRT delay. Splits were adjusted with the goal of minimizing LRT delay while limiting the impact to vehicular traffic. While reducing signal phase time, it was a goal to serve vehicular traffic that was "cut off" during the priority cycle within the subsequent cycle.
- Train arrival times were adjusted with a goal of providing a green to the LRT trains just prior to arriving at the intersection.
- To minimize impact on the trains during coordination, the controller was programmed to allow granting of a LRT priority calls in consecutive cycles. It should be noted that multiple calls cannot be granted within a single cycle.
- The offset at Montague Expressway/N. First Street and adjacent intersections was adjusted to minimize stops at N. First Street during coordination.

The final transit priority coordinated operation splits and phase reduction parameters are summarized in **Table 3**.

Table 3 - Final Montague Expressway/N. First Street Minimum Phase Splits - Transit Priority Coordinated Operation

Period	Parameter	Phase Time (sec)								Maximum Extended Time (phase 4 & 8) (sec)
		1	2	3	4	5	6	7	8	
AM	Coordinated Split	40	79	23	48	25	94	23	48	15
	Minimum Phase Split	35	54	18	-	20	69	18	-	
	Max Reduction	10	25	10	-	10	25	10	-	
PM	Coordinated Split	28	79	35	48	25	82	30	53	15
	Minimum Phase Split	23	39	30	-	20	42	25	-	
	Max Reduction	10	40	10	-	10	40	10	-	

4.3 "After" Studies and Final Timing Evaluation

After fine-tuning of the signal timing, "after" study data was collected to evaluate the intersection operation. "Before" and "after" implementation floating vehicle surveys were conducted along Montague Expressway, as part of the 2008 Regional Signal Timing Program (RSTP) project, during the AM and PM peak hours to measure the vehicular travel time and delays through the intersection. The "after" study delay was compared to the "before" study delay at N. First Street and summarized in **Table 4**. Based on the reductions in vehicular travel time and delay, additional performance measures including fuel consumption and emission reductions were calculated for each peak period and are summarized in **Table 5**.

Table 4 - Montague Expressway/North First Street "Before" versus "After" Performance Summary

Peak Period	Average Delay (seconds per vehicle)				% Difference		Total Volume (vehicle per hour)		Total Yearly Delay Savings (vehicle-hour)	Total Yearly Delay Savings (person-hour)
	Before		After							
	WB	EB	WB	EB	WB	EB	WB	EB	WB/EB	WB/EB
AM	112	43	44	33	-60.7%	-23.3%	1,710	1,805	18,655	20,520
PM	89	50	31	17	-65.2%	-66.0%	2,140	2,215	27,390	30,130

Notes:
1. Approach delay is based on "before" and "after" travel times studies conducted with the 2008 Regional Signal Timing Project (RSTP).
2. Delay Savings are for the two peak hours during each period (AM & PM) for 250 business days a year.
3. The Total Yearly Delay Savings per person is based on an average of 1.1 people per vehicle based on occupancy studies completed by the County under the 2008 Congestion Management program.

Table 5 - Montague Expressway Benefits Summary

Peak Period	Fuel Consumption Savings (gal)		Emission Reduction (lbs)								Total Yearly Cost Savings
			ROG		NOx		PM10		CO		
	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	
AM	33,224	5,746	440	66	426	66	38	14	3,440	686	$578,760
PM	35,322	25,842	468	322	454	308	46	32	3,702	3,040	$827,700

Notes:
1. Fuel consumption, emissions reduction, and total yearly cost savings calculated using the MTC's benefit-cost method from the Regional Signal Timing Program (RSTP) based on travel time savings between Lick Mill Boulevard and Zanker Road (adjacent intersections to N. First Street).
2. Benefits claimed include time savings, fuel consumption savings, and health cost savings associated with emissions reductions for weekday peak hours only.
3. Emission Reduction, fuel savings and cost savings are for the two peak hours, during each period (AM & PM) only of a business day (250/year). Timing plans were implemented for periods longer than the two peak hours shown and therefore the project results in additional reductions beyond those calculated.

As shown in **Tables 4 and 5**, there was a reduction in delay in both directions along Montague Expressway during the AM and PM peak periods. As a result, there was a total cost savings of approximately $579,000 in the AM period and approximately $828,000 in PM period from the delay reduction.

In addition to travel time comparison along Montague Expressway, vehicle queuing observations were made "after" implementation of the new signal timing operation and compared to the "before" study observations to understand the impact on overall

intersection operations. As noted in Section II, general queue observations were collected under "before" study conditions for critical movements during the AM and PM peak periods. In the AM period, the heaviest movements and queues were observed in the northbound through, westbound through, and eastbound left turn movements. During the PM peak period, the heaviest movements and queues were observed in the southbound through and through/right, westbound through, and the eastbound through movements. **Table 6** summarizes a comparison of observed maximum queues for critical movements during the AM and PM peak periods under the "before" and "after" conditions. For other non-critical movements not noted, observed queuing was similar under the "before" and "after" conditions.

Table 6 - "Before" versus "After" Maximum Queuing for Critical Movements

Condition	Observed Maximum Queue Length for Critical Movements (number of vehicles per lane)					
	AM Peak Period			PM Peak Period		
	NB Through	WB Through	EB Left	SB Through	WB Through	EB Through
"Before"	~30-35	~50-55	~20-25	~65-70	~50-55	~35-40
"After"	~20-25	~25-30	~15-17	~45-50	~25-30	~20-25

As shown in Table 6, there was a reduction in maximum queues observed for all critical movements during the AM and PM peak periods. The reduction in queue lengths included the side street movements on N. First Street movements such as the NB Through movement in the AM peak period and the SB Through movement in the PM peak period.

In addition to the vehicular travel time studies and queue observations, a delay study of the LRT trains was conducted to compare the "before" conditions with the "after" conditions. "After" study delay information was collected during the AM and PM peak period and compared to the "before" study data collected at the beginning of the project and is summarized in **Table 7**.

Table 7 - "Before" versus "After" Delay Summary for LRT at N. First Street

Peak Period	Average Delay (seconds per train)				Occupancy (person per hour)		Total Person Delay (person-seconds)				Total Yearly Delay Increase (person-hour)
	Before		After		NB	SB	Before		After		
	NB	SB	NB	SB			NB	SB	NB	SB	NB/SB
AM	3.9	3.4	28.6	27.5	190	185	740	625	5,435	5,090	1,270
PM	1.0	3.1	22.4	32.7	220	295	220	915	4,930	9,645	1,865

Notes:
1. Average "before" study delay is based on data collected with the 2005 TETAP study and current TETAP study.
2. Average delay is the average for the two peak hours during each peak period.
3. Delay Increase is for the two peak hours during each period (AM & PM) for 250 business days a year.
4. LRT occupancy data (person per train) was provided by Santa Clara County. Data was collected in January 2009 by County staff riding the trains and observing the number of passengers on the train.

As expected with the change in operation, there was an increase in delay in both directions for the LRT trains at Montague Expressway/North First Street during both the AM and PM peak periods. In review of the detailed study data, 47% of trains did not stop at the intersection under the "after" conditions. The highest delay at the intersection for trains occurs when a train arrives just after a previous train has received a priority call, thus do not receiving a priority call.