Traffic Signal Timing for Optimal Transit Progression in Downtown San Francisco

Christopher Pangilinan, Kristen Carnarius

ABSTRACT

Transit travel times and service reliability have consistently ranked as top concerns for both transit agencies and their customers. Traffic engineering efforts to improve in these areas have typically focused on infrastructure changes such as providing transit only lanes, providing transit signal priority, or building bus bulbs. This paper will focus on a strategy generally reserved for automobile traffic to improve transit service: traffic signal timing.

The San Francisco Municipal Transportation Agency’s signal timing project for the 38L Geary Limited bus route will serve as the case study in the development and evaluation of signal timing for transit progression. For most cases, traffic signal timing for a one-way street is a fairly simple exercise: automobile speeds and distances between intersections are measured to create a progression of vehicle platoons along a corridor. For transit, however, stop spacing and dwell time variability increase the complexity of this task.

This case study will demonstrate how dwell time data collected with automatic passenger counters can allow engineers to time traffic signals for optimal transit progression. This paper will highlight how the APC data was not only be used as an input but was also tapped for post implementation analysis.

The main conclusion of this research is that signal delay can be drastically reduced, improving transit service through traffic signal timing. The strategy has limitations, however, on where it can be applied. One-way corridors where transit stops are limited and transit service is frequent are shown to be the best candidates.

INTRODUCTION

To move vehicles through a signalized corridor in the most efficient manner, signal delay should be minimized. Other than increasing the length of the green phase, one of the most effective ways to accomplish this is to time the traffic signals in a way that maximizes the chance of a vehicle arriving on green. Under such a scheme, the traffic signals at each intersection would have their green phase “offset” from the intersection immediately upstream by the amount of time it takes a vehicle to travel between the intersections. From a driver’s perspective, each traffic signal would turn green just as they arrived as if they were riding a “green wave” through the corridor.

On one-way streets (and some two-way streets), the offset is easily calculated based on the corridor travel speed and distance between intersections. For a transit corridor, however, a signal timing strategy that is optimal for private vehicles can be detrimental to transit service due to the variable dwell times at transit stops and slower transit vehicle speeds. A transit vehicle stopping every few blocks to service passengers will quickly fall behind the pace at which the signals are timed resulting in more red lights and excessive signal delay.

Traffic signals along a transit corridor, however, can be timed for optimal transit vehicle progression. With a rich source of automatic vehicle location (AVL) and automatic passenger counter (APC) data, dwell times and travel times can be taken into account when timing the traffic signals resulting in less signal delay and faster transit service.

This paper documents how a corridor in downtown San Francisco was retimed for the benefit of transit through the use of AVL and APC data. The project’s methodology, results, and implications are discussed in the following sections.

Overview of Route 38L Geary Limited

The San Francisco Municipal Transportation Agency’s (SFMTA) 38L Geary Limited bus route will serve as the case study for this paper. As one of the SFMTA’s “Rapid Routes”, the 38L Geary Limited is a high frequency and high ridership route. During the a.m. and p.m. peak periods, the route operates on a 5-minute headway. Daily weekday ridership averages approximately 21,000 passengers. When combined with the 38L Geary local bus, the corridor serves an average of approximately 54,000 passengers each weekday.

As shown in Figure 1, the route runs east-west between the Transbay Terminal in downtown San Francisco and 48th Avenue at the western end of the city for a total of approximately 6.5 miles one-way. West of Van Ness Avenue, the route runs inbound and outbound on Geary Boulevard. East of Van Ness Avenue, the 38L Geary Limited runs outbound along Geary Street and inbound along O’Farrell Street. The eastern end of the route travels on Market Street to the Transbay Terminal. Limited stops are spaced at an average of 0.3 miles.

This study focuses on the outbound portion of the route on Geary Street between Market Street and Van Ness Avenue. Five limited stops are located at the intersections of Kearny Street, Stockton Street, Powell Street, Leavenworth Street, and Van Ness Avenue. The stops are shown in Figure 2.

Overview of Geary Street

Geary Street between Market Street and Van Ness Avenue, also known as “Inner Geary”, is a two-lane one-way street with a peak period tow-away parking lane that adds a third lane during the p.m. peak hour. Of the three lanes, the right lane is striped as a full-time bus-only lane. As illustrated in Figure 2, There are ten signalized intersections from Grant Avenue to Polk Street that each operate on a pre-timed, two-phase, 60-second cycle. The length of the green interval for Geary Street varies from 22 seconds to 36 seconds. The existing splits have generally been determined by the proportion of traffic volumes at each approach while the existing offsets are generally timed for private vehicle progression. Some exceptions are made for higher priority north-south corridors that intersect with Geary Street.

Land use along the Inner Geary corridor varies between commercial office, retail, hotel, and residential. Between Market Street and Mason Street is the Union Square retail district that contains high density retail and hotel developments. West of Mason Street, the development consists mostly of high density residential with ground floor retail.

Figure 1: Map of 38 Geary Limited and 38 Geary (local bus)

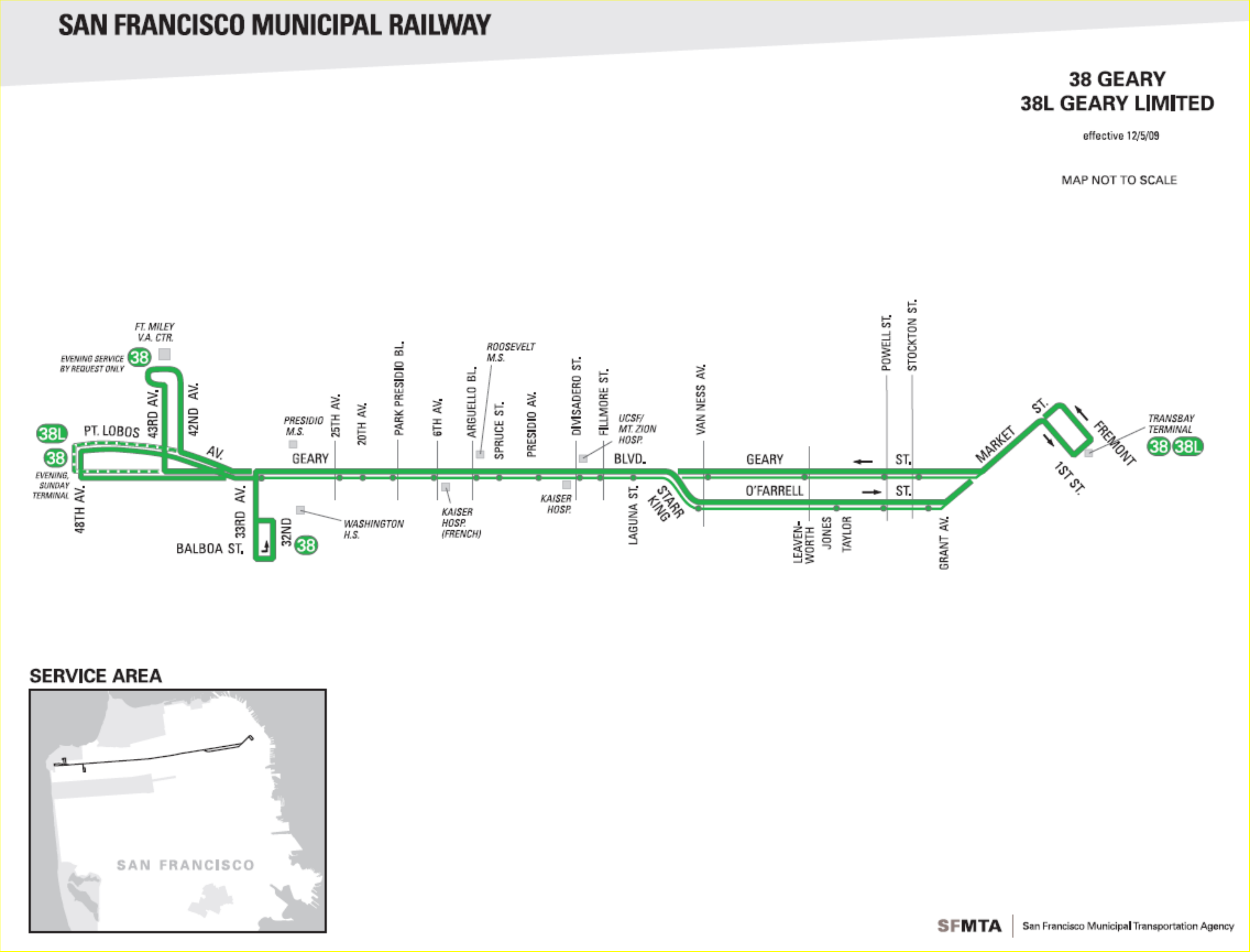


Figure 2: Inner Geary Study Area

38L Geary Limited Bus Stop

METHODOLOGY

The objective of this project was to decrease the travel time of the 38L Geary Limited through the Inner Geary corridor by timing the traffic signals in such a way that the signal delay experienced by the route would be minimized. With the cycle length fixed at 60-seconds for this part of the city's network, there were two other variables to optimize the signal timing for transit. The first was to increase the green times on Geary Street by reconfiguring the splits. This option was not pursued by the project due to the traffic volumes on the north-south streets. This left one remaining option: changing the offsets.

As discussed earlier, setting the offsets along a one-way corridor for optimal transit progression requires knowledge of the transit vehicle's travel time between intersections. For blocks that do not have a transit stop, the travel time is fairly consistent, especially when there is a dedicated bus lane like the one along Inner Geary. For blocks that do have a transit stop, the dwell time must be added to the travel time to get a total travel time for that particular block.

Because dwell times can be quite variable, a large sample size is needed to determine the range and distribution. The SFMTA's APC dataset was used to gather this data. Average travel times for the 38L Geary Limited were also obtained from this dataset.

Data

The SFMTA maintains a large database of APC data that is partitioned by operator sign-up period (3 to 6 months). The APC data is compiled and updated nightly as the buses pull in to their divisions. Approximately 30 percent of the bus fleet is equipped with the APC system and these vehicles are rotated regularly throughout the system to ensure adequate coverage of every bus route. Streetcars, cable cars and light-rail vehicles are not yet equipped but will be in the future. For this project, data was collected and analyzed for dwell times within the study area to help determine the traffic signal offsets.

In addition to the APC data, the SFMTA has access to a large database of AVL data as part of its partnership with the NextBus real-time passenger information system. The AVL data is compiled and updated nightly at the time point level and, unlike the APC data, has 100 percent coverage on all vehicles including bus and rail. The AVL data was collected and analyzed for time point departure times as part of the before and after study.

Model

An Excel model was created to predict the a.m. peak (7 a.m. – 9 a.m.) and p.m. peak (4 p.m. – 6 p.m.) Inner Geary corridor block-to-block travel times for the 38L Geary Limited. The objective of the model was to minimize signal delay for transit vehicles while providing for an optimal progression at safe operating speeds. The resulting output was a set of offsets at each of the 10 intersections along Inner Geary. The offsets were set such that as many buses as possible would arrive 5 seconds after the green interval had begun. The intent is for the bus to arrive at a fresh green interval while allowing slower buses that may have had a longer dwell time the benefit of the entire green time to clear the intersection.

To obtain the offsets, the model had to consider the two components of transit travel time: dwell time and vehicle travel time. Vehicle travel time was determined through one week of field observations. The data had to be manually collected because the APC and AVL datasets are compiled at the stop level and time point level, respectively. In general, buses on the 38L Geary Limited traveled at about 17 miles per hour on blocks with no stops and 10 miles per hour on blocks where there were stops, excluding dwell time.

Dwell time data at the transit stops on Kearny Street, Stockton Street, Powell Street, and Leavenworth Street were collected for the a.m. and p.m. peak periods via the APC system between June and December 2009 (the stop at Van Ness Avenue was excluded because it is located far side of Polk Street, the last intersection included in the study, and thus would not have an impact on the signal timing). As shown in Figure 3 to Figure 6, the dwell time profile varied among each stop in terms of average length and distribution.

With the travel time and dwell time distributions known, the traffic signal offsets could be set. Because the dwell times varied so widely, it would be impossible to time the offsets to accommodate every bus. This resulted in a strategy of setting the offset to accommodate the highest percentage of buses without “punishing” the faster buses by waiting for the slower ones. An exception was made at Leavenworth Street, however. Here the offset was set to accommodate later buses that may have accumulated extra dwell time at the three preceding stops. The green tinted boxes in Figure 3 to Figure 6 demonstrate the strategy’s concept. Each green box represents the length of green time for Geary Street at the respective intersection that the bus stop is on. In Figure 3, for example, the offset was set at the downstream intersection for a dwell time at Kearny Street of 15 seconds. This meant that a bus that dwelled for exactly 15 seconds and traveled at an average of 10 miles per hour would arrive at the next intersection 5 seconds after the green light was initiated. With the green “window” 36 seconds long, buses with dwell times up to 30 seconds would also be expected to arrive on a green light.

Figure 3: A.M. Peak Dwell Time Distribution at Geary Street and Kearny Street

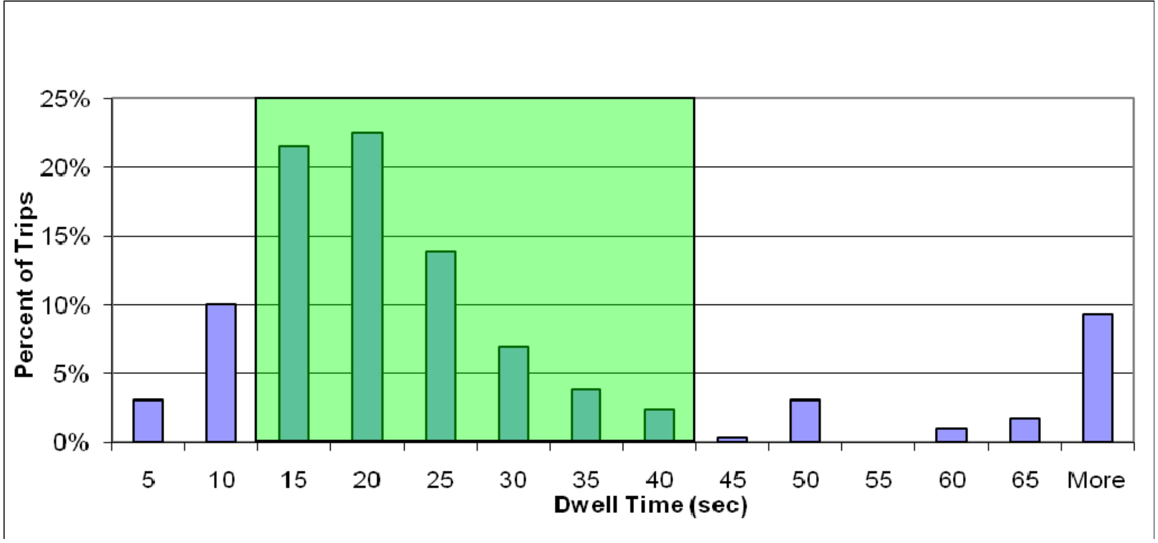


Figure 4: A.M. Peak Dwell Time Distribution at Geary Street and Stockton Street

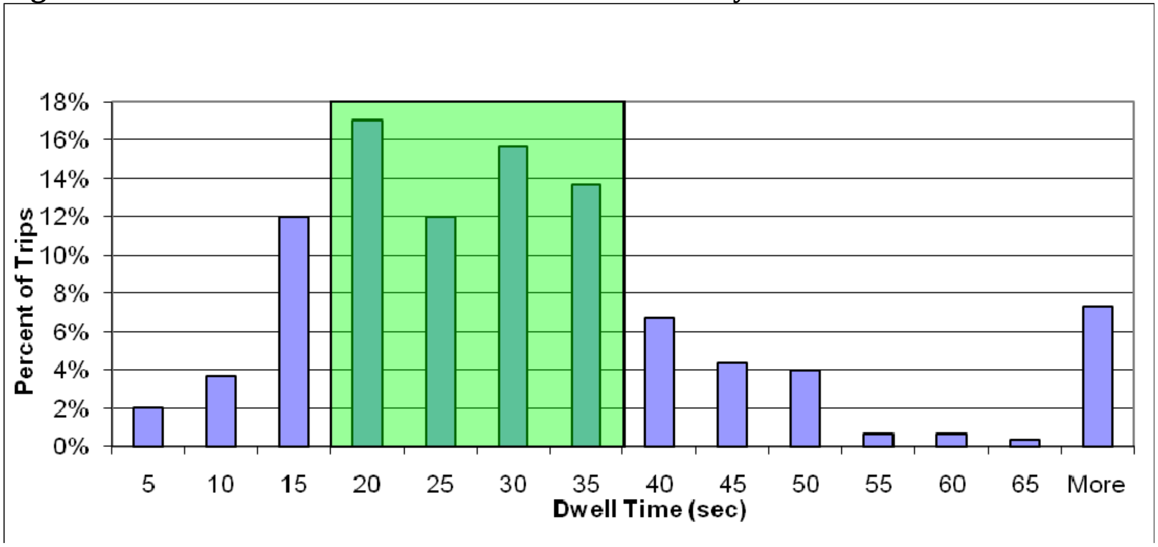


Figure 5: A.M. Peak Dwell Time Distribution at Geary Street and Powell Street

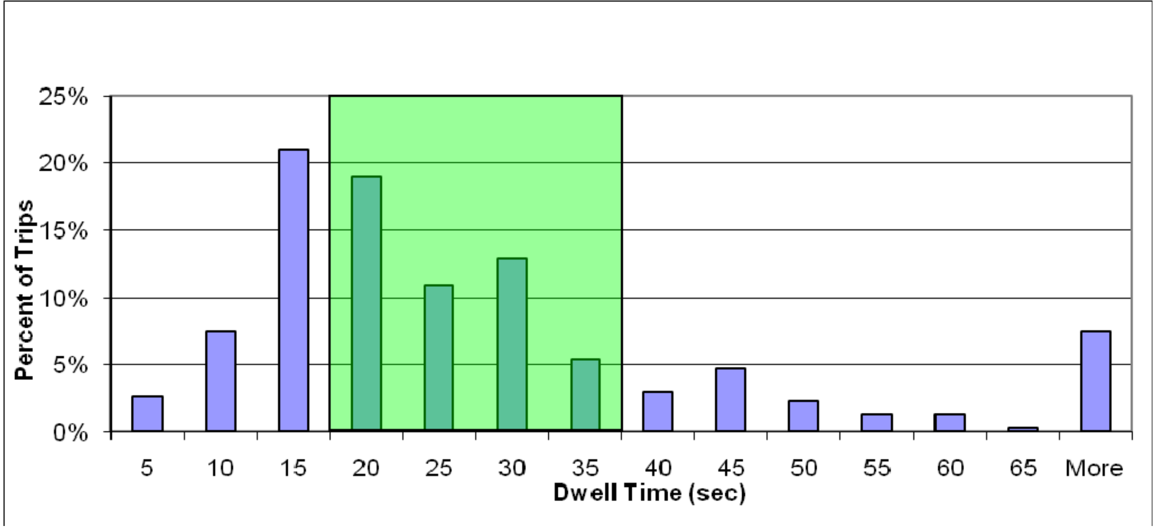
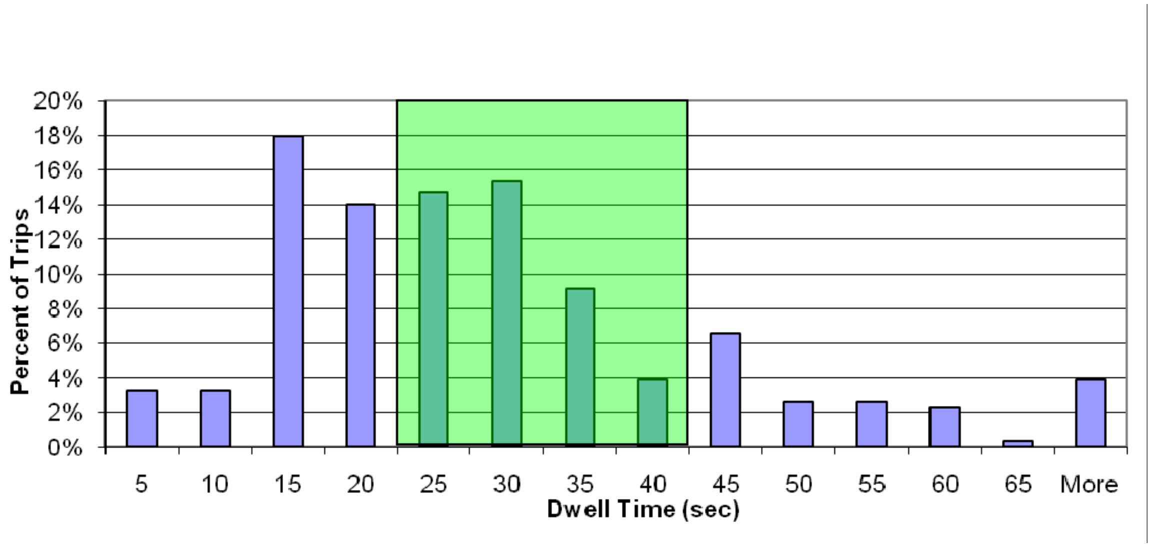


Figure 6: A.M. Peak Dwell Time Distribution at Geary Street and Leavenworth Street



RESULTS

To evaluate the effects of the new Inner Geary signal timing, AVL data was used to measure average travel time and standard deviation of the 38L Geary Limited and the 38 Geary local routes. The AVL data measured the travel times between the Market Street and Montgomery Street time point (one stop east of the study area) and the Geary Street and Van Ness Avenue time point (one stop west of the study area).

The “before” scenario represents data during the 10 weekdays between January 18, and January 29, 2010. The “after” scenario takes data from the 10 weekdays between April 19, and April 30, 2010. Data from the midday period of 11 a.m. to 1 p.m. is also analyzed as the control period where no signal timing changes were made.

As shown in Table 1, the average travel time during the a.m. peak period for the 38L Geary Limited fell 13 seconds or 2.7 percent after the signal timing changes were implemented. The standard deviation, however, increased by 4 seconds or 8.6 percent. The decreased travel time compares favorably with the midday time period where average travel time fell by only 3 seconds or less than 1 percent. During the p.m. peak period, the average travel time and standard deviation both fell by 3.4 percent and 5.6 percent respectively. Both numbers compare favorable to the midday time period.

Also shown in Table 1 are the numbers for the 38 Geary local route. While the offsets were timed for the limited route, the local route also saw improved travel times and reliability.

Table 1: Summary of Results

	AM Peak Period 7 a.m. to 9 a.m.			PM Peak Period 4 p.m. to 6 p.m.			Midday 11 a.m. to 1 p.m.		
	Before	After	Percent Difference	Before	After	Percent Difference	Before	After	Percent Difference
38L Geary Limited									
n	136	163	N/A	154	175	N/A	168	146	N/A
Average Travel Time (min:sec)	0:07:55	0:07:42	-2.7%	0:09:33	0:09:13	-3.4%	0:08:23	0:08:20	-0.8%
Standard Deviation (min:sec)	0:00:55	0:00:59	8.6%	0:01:31	0:01:26	-5.6%	0:01:19	0:01:21	2.4%
38 Geary									
n	143	159	N/A	134	153	N/A	144	115	N/A
Average Travel Time (min:sec)	0:09:40	0:09:50	1.7%	0:11:32	0:11:02	-4.4%	0:10:48	0:10:41	-1.1%
Standard Deviation (min:sec)	0:01:09	0:01:02	-9.7%	0:01:47	0:01:26	-19.7%	0:01:33	0:01:25	-9.1%

DISCUSSION AND CONCLUSION

This project was able to show that despite the variability inherent in transit travel times, traffic signals along a transit corridor could be timed to optimize the progression of transit vehicles. Setting the offsets to accommodate total transit travel time, including dwell time, led to lower average travel times and less variability, especially during the p.m. peak hour. During the a.m. peak hour, the model indicated that the signal timing was already close to optimal thus the results were more muted.

While the scale of the time savings seems small, an average of 20 seconds in the p.m. peak for the limited route, they are actually quite significant when viewed as a percentage of the Inner Geary corridor travel time, in this case a savings of 3.4 percent. If applied over the full limited running time of 89 minutes, the result would be a savings of over 3 minutes. With a headway of 5 minutes, this is a significant step towards being able to remove one bus from the route and maintaining the same headway. Not to mention the travel time benefits for all the passengers on each bus. Obviously, however, to achieve these savings, the signal timing would need to be optimized throughout the entire route.

One of the major difficulties in applying this signal timing strategy over a longer segment of the route is the compounding effect each transit stop has on dwell time variability. With dwell times varying by over 10 seconds for each stop, the net effect is that by the third stop, the transit vehicle could be arriving at the next intersection 30 seconds earlier or later than predicted. To minimize this effect, dwell time variability must be reduced through stop consolidation and/or techniques such as proof of payment that reduce overall dwell times.

Overall, this project demonstrated that there are benefits available to transit service by timing the signals in a transit corridor. AVL and APC data systems can be used by traffic engineers to determine the traffic signal timing plan. The strategy, however, can be difficult to implement if dwell time and travel time variability is excessive. Techniques to reduce variability, including transit only lanes, generous stop spacing, proof of payment, and all-door boarding can help make the signal timing plan more effective.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the SFMTA's Sustainable Streets Division and Muni. We would also like to thank Britt Tanner of SFMTA for developing the Excel model used in this project as well as Ricardo Olea and Tony Young for providing technical oversight. Thanks to the many SFMTA summer interns of 2009 for assisting in the data collection efforts.

AUTHOR INFORMATION

Christopher Pangilinan
Division of Sustainable Streets
San Francisco Municipal Transportation Agency
1 South Van Ness Avenue, 7th Floor
San Francisco, California 94103
Phone: 415-701-4578
Fax: 415-701-4737
Email: chris.pangilinan@sfmta.com

Kristen Carnarius
Division of Sustainable Streets
San Francisco Municipal Transportation Agency
1 South Van Ness Avenue, 7th Floor
San Francisco, California 94103
Phone: N/A
Fax: N/A
Email: kcarnarius@gmail.com