Transit Signal Priority System – Documentation

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A. Existing Signal System on Geary

Coordination and Transit Signal Priority

In a congested urban environment, signalized intersections manage conflicting movements between vehicles. For autos and buses alike, the time spent waiting at red lights makes up part of total travel time. On busy arterial corridors, signals are often coordinated with one another so that major traffic flows are accommodated. These coordination systems are typically “fixed” so that the green time given to vehicles making through movements does not vary from one cycle to the next. In a fixed timing system, the offsets\(^1\) are also constant.

Transit Signal Priority (TSP) modifies signal timing to favor transit vehicles, reducing the amount of time that a transit vehicle waits at red lights. TSP achieves this by adjusting the start and the end of the green lights to accommodate an approaching transit vehicle.

In order to provide Transit Signal Priority, there must be “extra” time available to be shifted between cycles to allow the signal to remain in Green so that the transit vehicle can proceed through what otherwise would be a Red light. This shift in the available time is referred to a “green extension” (see figure 1). The available extra time for TSP is limited by the many signal timing constraints that define the minimum splits\(^2\) for each phase.

![Figure 1. Traffic Signal Priority: Green Extension](image)

In the cycle with extension, the controller receives notice that transit vehicle will arrive late so it extends main street green, using the ‘extra’ time from the following recovery cycle.

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\(^1\) Offsets define the delay between when a signal turns green at one intersection and the next downstream intersection’s green light. Offsets are generally "keyed" to single “master” intersection.

\(^2\) Split is the total time between the start of Green of one phase to the start of Green of the following phase, including all the Green, WALK, Flashing Red Hand (FRH), Yellow and all-red time.
Existing Signal System and Recent Upgrades

In December 2003, the Geary signal controller system was optimized as part of the Regional Traffic Signalization and Operations Program (RTSOP). As part of this effort, all 55 traffic signals in the system were put on a coordinated 90 second cycle for the AM peak, PM peak, and weekend daytime periods, and an 80 second cycle at all other times. The number of timing plans was consolidated from six to four, so that the plans can be maintained more efficiently. As part of this optimization, the timing of the signals was adjusted to favor the progression of traffic in the eastbound direction during the AM peak and the westbound direction during the PM peak. In addition, these signal timing improvements included adjustments to the cycle lengths, splits, offsets, yellow and all-red times, which improved intersection clearances, traffic progression for vehicles, and crossing safety for pedestrians.

Prior to 2004, all of the signal controllers on Geary were of an older technology with limited capabilities. In 2004, DPT and DPW completed a traffic signal upgrade project on Geary Boulevard at the 15 intersections between Masonic and 10th Avenues. This project included improvements such as larger signal heads, new 2070 intersection controllers, new mast arm and countdown pedestrian signals, which provide better visibility for motorists and improved crossing information for pedestrians. In addition, transit signal priority equipment was installed at 15 intersections on Geary Boulevard between Steiner Street and 32nd Avenue (at both intersections with older signal controllers and the newer 2070 controllers). To use priority efficiently, TSP was installed only at intersections where there are either no bus stops or only far side stops.

The traffic signal at Geary and Masonic is not part of the Geary Boulevard corridor signal system. This intersection is grade-separated from Geary Boulevard due to the tunnel that allows traffic to bypass this intersection, though there are frontage roads on Geary Boulevard that connect to Masonic Avenue. Although this intersection shares the same cycle length as the rest of the signals in the Geary System, the signal operation at this location favors traffic on Masonic Avenue since it carries higher traffic volumes than that of the Geary Boulevard frontage streets connecting to the intersection.

Existing Pedestrian Timing

Since traffic flows for crossing traffic are significantly lower than that of Geary, the splits for the cross streets are primarily determined by pedestrian crossing times. The signals on Geary are fixed and bring a Green and Walk phase for the cross street every cycle. SFMTA's pedestrian safety guidelines strive to provide enough time during the entire split (WALK, FLASHING RED HAND (FRH), YELLOW and ALL-RED intervals) for pedestrians to cross streets from curb to curb at 2.5 fps. If there is a pedestrian refuge, minimum times seek to provide enough time for pedestrians to cross the road at 2.5 fps to the refuge, or at 3.0 fps from curb to curb, since pedestrians that are unable to finish crossing in the time allotted can wait safely at the refuge. These guidelines also provide adequate time for pedestrians to cross at 4.0 fps during the clearance intervals (FRH, YELLOW and ALL-RED). The intention is that the majority of pedestrians will be able to cross the entire street if they start before the FRH starts. Slower pedestrians should start at the beginning of WALK in order to
have enough time reach the other side of the street or a median refuge. Below, Table 1 – “Existing Crossing Time and Curb to Curb Crossing Speed” provides intersection-level information.

The intersection of Geary and Masonic is treated differently than the rest of the corridor. It is a four-phase intersection with extremely long curb to curb pedestrian crossings. If the signal were to provide enough time for pedestrians to cross each crosswalk at 2.5 fps, the cycle length would have to be 170 seconds, forcing pedestrians to endure long waits for a WALK phase. Because there are wide pedestrian refuges in the center of each wide crossing, the existing signal timing favors a shorter cycle length with shorter wait times. The signal timing provides enough to cross from curb to curb at 4.0 feet per second as long as a pedestrian starts crossing before the Flashing Red Hand starts. Slower pedestrians have enough time to reach the center median at speeds slower than 2.5 fps.

Table 1: Existing Signal Parameters

<table>
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<th>Intersection</th>
<th>Signal?</th>
<th>Crossing Width (^1) (ft)</th>
<th>Transit Priority?</th>
<th>Controller Type</th>
<th>Split (s)</th>
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### Geary Corridor Bus Rapid Transit Study • Appendix E

SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY

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Distance from curb to curb of widest crosswalk.

### B. Future Signal System: BRT Signal Priority

#### BRT TSP system principles

When designing a TSP system for BRT, there are many factors to consider when determining the level of priority the transit will receive, in terms of signal timing, right of way, etc. The table below lists some of the considerations.
| **Peak Hourly Traffic Volumes** | TSP by nature affects traffic progression. Vehicles traveling in the same platoon as a transit vehicle may benefit from improved progression, and all other vehicles may experience a reduced level of progression. On high-volume arterials operating at or near capacity, these reduced levels of progression may be near the tipping point, where a small reduction in a major movement’s green-time may have compounding effects on queue lengths and vehicular flow rates. If the transit vehicles operate in unrestricted mixed flow lanes, transit travel times may be delayed to the point where TSP creates more traffic congestion and delays than signal time savings. TSP must be carefully designed to give transit priority without causing traffic congestion over the tipping point. |
| **Lanes per Direction** | The number of lanes that accommodates the peak hourly volumes determines the availability of restricted transit lanes. |
| **Transit Right of Way** | Transit in shared unrestricted mixed-flow lanes is affected by poor progression, whereas transit in a dedicated lane is unaffected by traffic congestion. |
| **Cycle Length** | Longer cycle lengths have more time available to adjust or shift signal phases to accommodate transit as needed – but longer cycles can create longer delays for both vehicles and pedestrians. Excessive cycle lengths can encourage traffic violations (e.g. speeding, red light running), and diversions to parallel streets. |
| **Cross Street Traffic Volumes & Actuation** | Cross streets with high volumes need more green time, which reduces the effective amount of extra time available for TSP related signal adjustments. If a corridor’s cross street is actuated, it is only given time when there is a vehicle (or pedestrian) waiting to cross the intersection. |
| **Pedestrian Volumes & Actuation** | Pedestrians need more time to cross a street than cars. Actuated pedestrian signals can be used to only show the WALK signal when needed and leave more time available for TSP related signal adjustments. However, this requires pedestrians to press a button in order to get a WALK signal, which is less pedestrian friendly than having the WALK signal come up each cycle automatically. |
| **Transit Lines & Headways per line** | More frequent buses can result in more requests for TSP, which could result in poorer progression for traffic or transit vehicles that do not receive TSP. Queue lengths and delays may also increase. |
Intersecting Transit lines on Cross streets | Transit on cross street that does not have the benefit of TSP will be negatively affected by TSP on main street.
---|---
Possible TSP Feature: Extend Green? | If there is time available to extend the green phase, transit will be more likely to get through.
Possible TSP Feature: Early Green? | If there is enough advance notice, the signal can prepare to bring main street Green up early if a transit vehicle will arrive late in the cross street’s green light.
Possible TSP Feature: Shorten or Skip Phases for Transit Priority? | If you conflicting phases can be shortened and or skipped, transit will be more likely to get through. As this can result in long delays for conflicting phases, SFMTA does not use this feature.

### BRT TSP applications on Geary

On Geary, the minimum split is determined by the heavy vehicular volumes, whereas the minimum split of the side streets is generally based upon the width of Geary and the calculated time required by pedestrians to cross the roadway.

### Traffic Volumes on Geary

On Geary Boulevard, there is an average daily traffic ranging from 32,000 to 65,000 depending on the location along the route. These high traffic volumes require enough green time to get the vast majority of cars through each cycle regardless of the time of day. The TSP strategy used was carefully designed to avoid creating back-ups, particularly in the designated left turn lanes. In addition, if traffic experiences increased congestion, it may divert to neighboring streets – some of which may also carry transit and be adversely affected. Taking these concerns into consideration, the transit priority strategy developed for the BRT scenarios was not as aggressive as it could be, and could become more aggressive with further analysis of these issues in the future.

### Pedestrian Crossing Times

For the purposes of the Synchro and VISSIM models, it was assumed that cross street splits would be lengthened from its existing timing so that pedestrians could cross from curb to curb at 2.5 fps at every intersection during all time periods. In addition, at intersections where there was currently enough time to cross at speeds slower than 2.5 fps, the cross street split was not shortened. While increasing the pedestrian

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3 If the left turn pockets are over capacity, they will “spill-back” into and block the higher volume through traffic lanes and in some cases the upstream intersection, affecting traffic (and transit) on the cross streets.
crossing time creates a more pedestrian friendly environment, it restricts the time available for TSP\(^4\).

In the BRT scenarios, sidewalk bulb-outs reduce crossing distances by 6-12 feet, depending on whether one or both corners have a bulb. Accordingly, the narrower crosswalks require less time for pedestrians to cross Geary, making more time available for transit signal priority.

Traffic Progression of Cross Streets

Because Geary Boulevard has many cross streets with high traffic volumes, it is important to maintain coordination with the signals on the cross streets, many of which have transit lines themselves.

Transit Signal Priority

Traffic Controller Software & Hardware

In 2000, 2070 controllers\(^5\) were selected as the standard traffic controller for San Francisco, and the city began upgrading older signal controllers to this standard. Seventeen of the 37 signals in the study area have already been upgraded to 2070s. In 2003, after a thorough process, D4 became the preferred software for the 2070. Made by a local San Francisco manufacturer, Fourth Dimension Traffic\(^6\), D4 is a phase-based, four-ring signal program with a unique combination of features for optimizing fixed time or actuated control under both coordinated and free operations, and easily configurable advanced actuated signal control and transit signal control. The 2070 using D4 software has communications capabilities with fiber optic connections, which can be used to connect to the city’s SFgo Integrated Transportation Management Center. With this technology, TSP can take advantage of

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\(^4\) There are some strategies that could be used to increase the time available for TSP, but would created a less pedestrian friendly environment, so these features were not modeled. These features could be used for a more aggressive TSP strategy.

a) Reducing pedestrian crossing time: It was assumed that no pedestrian phase would be shortened from the existing splits. As the time available for TSP is driven partly by the pedestrian crossing time, a policy decision could be made to reduce the cross streets splits to the minimum required to the 3.0 fps standard and have slower pedestrians stop at the median (savings about 7 seconds per cycle). The signals could reduce the WALK only when there is a transit call, so pedestrians would only be affected if there was a bus that needed TSP.

b) Pedestrian actuation: Another way to create more time for TSP is through the use of pedestrian push buttons. At all intersections on Geary, the pedestrian signals are on “recall”, meaning they display a WALK every cycle and do not require that pedestrians press a push button to request the WALK. If the pedestrian phases were actuated, the signals would only provide WALK with enough time for pedestrians to cross at 2.5 fps only if pedestrians press a push-button; otherwise the signals would not display a WALK.


\(^6\) [http://www.4dtraffic.com/](http://www.4dtraffic.com/)
“peer-to-peer” communications and communicate with other adjacent signal controllers.

For the Geary BRT traffic simulation process, it has been assumed that all signal controllers on Geary would be upgraded as part of the BRT project to 2070 controllers, to take advantage of the more sophisticated features of SFgo.

**TSP Logic**

In the absence of transit vehicles, the signals on the Geary corridor will be designed to operate in a fixed-time mode. The offsets vary by time of day to accommodate peak traffic flows. As a transit vehicle approaches and passes a signal, this optimal progression is modified to favor transit. In order to maintain progression and coordination along the corridor, individual signals will have the ability to “recover” from TSP within one cycle and return to the optimal progression. Maintaining this ability to recover within one cycle limits the extent of allowable TSP.

Taking into consideration the limited time available for TSP on Geary Boulevard, the level of TSP modeled in the future scenarios is less aggressive, compared with other TSP systems on less congested corridors with longer blocks, lightly trafficked cross streets, and fewer conflicting left-turn movements.

In essence, the TSP will ensure that a bus will be able to pass through the upstream intersection as long as it arrives at the edge of the upstream block while Geary has a Green. The TSP for the Geary BRT alternatives provides up to a moderate 11 seconds extension at most intersections. The length of the extension was determined by the block spacing; the typical block from crosswalk to crosswalk is approximately 240’ long— which at 20 MPH, a bus can travel in 11 seconds. At some intersections, the allowable extension was longer based on the distance from the upstream intersection. At a few intersections, TSP was not provided because the signal would be nearing capacity and have insufficient time available to recover from a TSP extension within the single cycle.

For the center-running BRT scenario, the intersection of Geary and Masonic was modified because the underpass below the intersection is converted to a transit-exclusive roadway with a new platform station. Vehicular traffic which currently travels through the tunnel would now be connected directly to Masonic Avenue via frontage streets on Geary. The frontage streets would be upgraded with additional traffic lanes to provide more capacity in order to handle the increase in vehicular traffic. In addition, another platform stop and bus only lanes for the 43-Masonic line would be established in the median area on the block of Geary between Masonic and Presidio Avenues. With the increase in the number of cars passing through this signal, there is insufficient time available for TSP. For the traffic simulation process, Geary Boulevard was given a majority of the green time so that all movements on the Geary approaches would not fail and traffic progression would be maintained in both directions. However as a result, the north-south approaches on Masonic fail due to insufficient green time. Although these conditions would result in level of service of F, emphasis was placed on providing as much green time to Geary as needed due to the increase in traffic on the frontage streets and the provision of transit service on the
local 38-Geary and 43-Masonic lines. More design and analysis would be needed in subsequent stages of project development to improve these conditions.

Table 3. Length of Possible Future Transit Signal Priority Extension

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Existing extension</th>
<th>2015 No Project</th>
<th>2015 Center</th>
<th>2015 Side</th>
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<tr>
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<tr>
<td>Steiner</td>
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<tr>
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<tr>
<td>Divisadero</td>
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<td>None</td>
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<tr>
<td>Baker/Josephs</td>
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<td>14</td>
</tr>
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<td>Presidio (overpass)</td>
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<td>None</td>
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</tr>
<tr>
<td>Masonic (overpass)</td>
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<td>Collins</td>
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<td>12th</td>
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<tr>
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<td>None</td>
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</tr>
</tbody>
</table>
### Features

#### a. Detection

In order for a traffic signal controller to determine whether or not a signal phase should be given the necessary extension, there needs to be an accurate and reliable way to send a signal to the signal controller when the transit vehicle is approaching. While there are several detection methods that can be used, San Francisco has identified three methods of transit vehicle detection for this project: infrared, inductive loops, and GPS. These three detection methods are described in detail below.

1. **Inductive loops**

   Inductive loops are a relatively inexpensive and if installed correctly, a reliable method used to detect vehicles. They are commonly used in conjunction with dedicated left turn phases and permanent traffic count stations utilized by the California Department of Transportation (Caltrans). This type of detector is comprised of a coil of wire embedded in the pavement. A small current is then run through this embedded wire to create an inductive field. When any vehicle drives over the loop, it will change the inductive field and be detected. Inductive loops are used as “presence” loops and generally cannot differentiate between different types of vehicles. For a BRT system, inductive loops can only be used for signal priority if there is a separate right-of-way which excludes all non-transit vehicles. This could only be used on Geary in the Center BRT scenario.

2. **Infrared (OPTICOM)**

   San Francisco’s current TSP technology is the 3M™ Opticom™ Priority Control System, an infrared light-based system that consists of emitters on the front of buses, and a detector installed on a pole at the intersection. These detectors can measure a signal from as far as a half-mile away. The on-bus emitters can be programmed so that they do not request transit signal priority when bus doors are open for loading and unloading. As the signal strengthens when a bus is near the detector, thresholds can be set so that a bus is only detected a defined distance away.

   There are a number of operational issues with infrared. Before transit signal priority system is activated, there must be an intensive tuning process required to set the threshold for where the bus should be detected. Trees must be pruned to maintain a

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7 [http://www.3m.com/us/safety/tcm/products/opticom/index.jhtml](http://www.3m.com/us/safety/tcm/products/opticom/index.jhtml)
direct line of sight. Infrared emitters and detectors require regular cleaning and adjustments as the strength of the signal varies due to the cleanliness of the lens in the detector and emitter. The angle of the bus as it approaches the detector affects how strong a signal is detected, causing variation in how far away the bus is detected. Constant adjustments must be made to the detector on the pole due to wind and vibrations over time. Finally, there is a 1 to 5 second delay between when a bus finishes loading and when the emitter is recognized by the detector, decreasing the effectiveness of TSP at intersections after a bus stop.

(3) GPS

With advances in technology, Global Positioning System (GPS) is being integrated into some TSP systems. GPS based detection systems promise to be more accurate and less expensive to maintain than the current infrared detector system. GPS systems use satellite technology and radio signals to determine an equipped vehicle's position and trajectory. GPS units are more accurate than the infrared units which serve to reduce the overall number of false or incorrect calls. Based on a limited number of operational tests, these GPS detector units have appeared to be more sophisticated than most consumer grade systems, and they have been able to broadcast their position in the “urban canyons” of San Francisco.

In addition to the operational advantages of the more accurate GPS devices, these devices require less care and maintenance than the infrared devices.

SFMTA currently has several other devices that utilize GPS technology, and there is an effort to reduce the number of stand-alone devices on Muni coaches, especially when similar functions may be combined. SFMTA is also presently working with the San Francisco Fire Department to implement a demonstration program that would install the GPS Opticom.

b. Fiber Optics for Advanced Transit Arrival Prediction

In future analysis, TSP could be designed using peer-to-peer communication to provide more advanced notification of a transit vehicle’s arrival. When a transit vehicle is detected at an intersection, the local traffic controller can pass that information to the downstream controllers via fiber optic cables through “peer-to-peer” communication. The TSP strategy used to respond to each individual transit vehicle would depend upon where in the cycle the vehicle is expected to arrive. Bus arrival times would take into account travel time through multiple upstream intersections and dwell time at upstream stops. If bus arrivals can be accurately predicted several intersection upstream, the signals could use more aggressive TSP strategies, such as Early Green.

In order for the TSP system to take advantage of the arrival prediction information, the traffic progression and TSP strategy must be flexible enough so that the traffic controller can make adjustments. The TSP strategy used in the BRT scenarios did not take advantage of the peer-to-peer features due to the uncertainty if buses would be able get through multiple upstream signals. Providing TSP when a bus is not guaranteed to make every light could lead to delays for transit, rather than reducing the travel time. For example, a situation could arise where a signal controller extends Geary green, delaying the cross street green for 10 seconds because a bus is coming,
but the bus gets stopped at an upstream intersection and does not make it until after Geary has a red light. This would cause increase the bus’s signal delay because the Green for Geary will come up 10 seconds later than if no extension had been provided in the previous cycle. If future analysis shows that the arrival times can be predicted reliably, this feature should be utilized to provide increased priority for transit.

C. Transit Operations Issues

Vehicle Identification and Schedule Adherence

If there are technology developments in the future, there are many opportunities to provide ‘smart’ priority. However, it would not be possible to take advantage of these opportunities without reconsidering the current operations and maintenance of the buses.

- Priority based on passenger loading: A TSP system can give higher priority to buses with more passengers. In order to do so, the automatic passenger counter system must be connected to the emitter that requests priority.

- Priority based on route or schedule adherence: TSP could be used to give a higher priority for certain bus routes, or those buses that are late.

In order to provide priority by route, the vehicle emitter would have to be programmed to indicate what route it is currently serving. This would require that routes have dedicated buses, or that the emitters are reprogrammed anytime that the bus is moved from one route to another. Though the BRT system envisioned would likely have a dedicated fleet of vehicles for BRT lines, at present, this would be difficult to achieve as buses frequently change routes, sometimes serving more than one route a day, or switching routes as demands change, for instance to respond to a disabled transit vehicle. The existing infrastructure does not easily enable reprogramming emitters each day, whether in the bus yard or in the field.

To provide TSP to buses based on their lateness, the emitter or the signal would need to know not only the buses’ route, but also the schedule, which is beyond the capabilities of the technology currently in use. This feature may become available in the future as technology advances.
Memorandum

Date: 11.16.06

RE: Geary Citizens Advisory Committee

November 16, 2006

To: Geary Citizens Advisory Committee

From: Julie Kirschbaum – Senior Transportation Planner

Through: Tilly Chang – Deputy Director for Planning

Subject: ACTION – Accept the Evaluation of Transit Performance and Traffic Impacts for the Geary Corridor Bus Rapid Transit (BRT) Study

Summary

VISSIM, a micro-simulation model that analyzes transit, auto and pedestrian trip patterns, and Synchro, a traffic analysis tool that analyzes vehicular delay at intersections, were used to estimate the average travel time benefits for transit and the traffic impacts for autos with and without BRT. In addition, the BRT alternatives were compared to the basic transit priority improvements for both in-vehicle and wait time variability. These findings build on previous analyses that evaluated BRT benefits, and impacts. Of the key findings, the models estimate a significant decrease in transit travel times for the BRT alternatives, with only a minor increase in travel time for drivers. Since most people are traveling west in the PM peak period, the signals are timed to optimize the westbound direction, which increases the travel time savings relative to the eastbound direction. The average in-vehicle travel time savings are even more pronounced if one considers reduced wait times from more frequent limited headways and the decreased need to add in extra travel time, since both wait times and travel times would be less variable. The network benefits are also significant, as many people would use the Geary buses to transfer to other rapid transit lines, such as the proposed Van Ness BRT line. We are seeking a Committee action to accept the evaluation of transit performance and traffic impacts for the Geary Corridor BRT Study.

BACKGROUND

The Geary Corridor Bus Rapid Transit Study is evaluating conceptual designs and service plan changes that improve transit travel times and reliability, and enhance pedestrian safety and urban design on Geary Boulevard. Over the past several months, the study team has evaluated the potential benefits and impacts by examining multiple metrics that group into the following categories:

- Benefits. Transit Operations & Performance; Transit Rider Experience; Pedestrian Safety & Access; and Urban Design and Landscaping

- Impacts/Constraints. Traffic & Parking Impacts; Capital & Operating Costs; and Construction Impacts

A key purpose of the Study’s evaluation framework, is to help us understand how the proposed alternatives benefit transit operations and affect traffic conditions. This information builds on the evaluation results presented previously for transit rider experience, pedestrian conditions, urban design, traffic diversions and parking changes.
DISCUSSION

Maintaining a robust and stable ridership is the first goal of the Geary BRT project and faster and more reliable transit service is critical to achieving this outcome. Reliability improvements also factor into the rider experience, since highly variable service can be frustrating and potentially a disincentive to use transit. For a BRT project to be successful it must do more than just help transit riders, it should also improve the neighborhood livability and commercial vitality. In addition to promoting an investment in pedestrian safety, streetscape and urban design, this goal also includes minimizing impacts, such as traffic congestion, on local residents and businesses.

The transit performance benefits and the traffic impacts for two transit priority alternatives and three BRT alternatives were estimated using two transportation models: 1) VISSIM, a micro-simulation model that analyzes transit, auto and pedestrian patterns, and 2) Synchro, a traffic analysis tool that evaluates vehicular delay at intersections. The modeling work began by collecting data on the observed volumes of transit riders, pedestrians and automobiles, along with the current configuration for travel lanes, bus stop locations and traffic signal timing. The models were then calibrated to ensure that they could closely replicate observed transit and auto travel times. Models that can accurately predict current conditions, can then be used to understand the impacts and benefits of future changes. As a final step, the auto and transit trip volumes were scaled based on the travel demand modeling results (presented to the GCAC in July 2006) to reflect anticipated land use and employment changes between 2005 and 2015.

Transit travel time savings come from a package of improvements that reduce conflicts between buses and autos, reduce the amount of time spent at red lights, and speed up boarding. Five alternatives were evaluated as part of this work. Table 1 provides more details about the features that were included in each alternative.

- **Alt. 1: Basic Transit Priority.** The 2015 baseline alternative, which includes some transit improvements, but is not a full-featured BRT investment.

- **Alt. 2: Basic Plus Transit Priority.** A 2015 transit priority alternative that is not a full-featured BRT alternative, but includes more transit improvements such as increased enforcement and a dedicated lane in the peak period/peak direction.

- **Alt. 3: Side BRT.** A full-featured BRT alternative that includes an all day BRT lane adjacent to the parking lane and high quality bus stations.

- **Alt. 4/5: Center BRT.** Two full-featured BRT alternatives that include an all day, center-running, BRT lane and high quality bus stations. Alt. 4 has two islands and Alt. 5 has one center median.

All of the alternatives were compared to the 2015 basic transit priority alternative (Alt. 1), to isolate the incremental benefits from the additional priority treatments and/or BRT investments. Alternative 2 was added to the analysis at the request of community stakeholders who were interested in more analysis of smaller-scale transit priority treatments en lieu of a full featured BRT system. The operational benefits of a center-running BRT with side platforms (Alt. 4) and a center-running BRT with center platforms (Alt 5) are the same, which is why they are combined in the following analysis.
Table 1. Key Features of Each Alternative

<table>
<thead>
<tr>
<th>Alt. 1 Basic Transit Priority</th>
<th>Alt. 2 Basic Plus Transit Priority</th>
<th>Alt. 3 Side BRT</th>
<th>Alt. 4/5 Center BRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Transit signal priority</td>
<td>• Transit signal priority</td>
<td>• Transit signal priority</td>
<td>• Transit signal priority</td>
</tr>
<tr>
<td>• Low floor buses</td>
<td>• Low floor buses</td>
<td>• Low floor buses</td>
<td>• Low floor buses</td>
</tr>
<tr>
<td>• Real-time information</td>
<td>• Real-time information</td>
<td>• Real-time information</td>
<td>• Real-time information</td>
</tr>
<tr>
<td>• Increased enforcement</td>
<td>• Increased enforcement</td>
<td>• Increased enforcement</td>
<td>• Increased enforcement</td>
</tr>
<tr>
<td>• Longer bus stops (where needed)</td>
<td>• Longer bus stops (where needed)</td>
<td>• A few potential local stop consolidations</td>
<td>• A few potential local stop consolidations</td>
</tr>
<tr>
<td>• More potential local stop consolidations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Peak hour/direction dedicated bus lane</td>
<td>• All day dedicated bus lane</td>
<td>• All day dedicated bus lane</td>
<td></td>
</tr>
<tr>
<td>• Proof of payment/ multidoor boarding</td>
<td>• Ticket vending machines at limited bus stops</td>
<td>• Ticket vending machines at limited bus stops</td>
<td>• Proof of payment/ multidoor boarding</td>
</tr>
<tr>
<td>• Ticket vending machines at limited bus stops</td>
<td>• Level boarding/Bus bulbs at limited stops</td>
<td>• Level boarding from platforms at all stops</td>
<td></td>
</tr>
<tr>
<td>• Level boarding/Bus bulbs at limited stops</td>
<td>• High-quality bus stations</td>
<td>• High-quality bus stations</td>
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<tr>
<td>• High-quality bus stations</td>
<td>• Pedestrian safety and landscaping improvements</td>
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<td></td>
</tr>
<tr>
<td>• Pedestrian safety and landscaping improvements</td>
<td>• Expanded hours of 38L-Geary Limited</td>
<td>• Expanded hours of 38L-Geary Limited</td>
<td></td>
</tr>
</tbody>
</table>

Estimated Transit Travel Times: For the PM peak period, the VISSIM model estimates that the limited service for center-running BRT (Alt. 4 & 5) is 31% faster (-8 min) in the westbound direction and 20% faster (-5 min) in the eastbound direction than the basic transit priority alternative (Alt 1). The additional westbound travel time savings comes from the signal timing, which is optimized for the westbound direction in the PM peak, since the majority of both auto and transit passengers are traveling westbound in the evening. In the morning period, these results would be reversed. For the local bus, the model estimates a 28% travel time savings (-9 min) in the westbound direction and a 22% travel time savings (-5 min) in the eastbound direction.

The side BRT alternative is faster than the basic transit priority alternative, however; the side alternative travel times would be more variable than the center alternatives because some buses would be slowed down by parking and turning vehicles, as well as double parked vehicles. For the PM peak period, the VISSIM model estimates that the limited service for side running BRT (Alt 3) is 27% faster (-7 min) in the westbound direction and 20% faster (-5 min) in the eastbound direction than the basic transit priority alternative (Alt 1). For the local bus, the model estimates a 22% travel time savings (-7 min) in the westbound direction and a 25% travel time savings (-8 min) in the eastbound direction. Since the public workshops the first week of November, we have modified the signal priority and signal timing for the side alternative to improve the travel time savings. If we continue into the next phase of work, we will continue to refine and improve the transit travel time savings for both side and center alternatives.

If we invest a similar level of resources in traffic management (e.g., turn pockets and signal timing
changes), the westbound travel time savings for Alt. 2, Basic Plus Transit Priority, would be similar to the side alternative (approximately 8 min savings for the local bus and 7 minutes savings for the limited bus). In the eastbound direction, during the PM peak Alt. 2 would have the same travel times as the baseline alternative. This would also be true at all other times of day, except the AM peak in the eastbound direction.

The passenger hours saved varies by the relative travel time savings across time periods. Basic Plus Transit Priority saves passengers 2,200 hours per day, compared to 4,800 for side BRT and 5,500 for center BRT. In addition, the primary recipients of the travel time savings with Alt. 2 are peak-period commuters, whereas the BRT alternatives benefit all Geary transit riders.

Table 2A. Average Travel Time Savings (Westbound)

<table>
<thead>
<tr>
<th>Westbound PM Peak between Gough &amp; 33rd Avenue</th>
<th>Average Travel Time</th>
<th>Change in Travel Time from Alt 1 (Basic)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alt 1 Basic</td>
<td>Alt 2 Basic+</td>
</tr>
<tr>
<td>Auto</td>
<td>15 min</td>
<td>13 min</td>
</tr>
<tr>
<td>38</td>
<td>32 min</td>
<td>25 min</td>
</tr>
<tr>
<td>38L</td>
<td>26 min</td>
<td>19 min</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Average Speed</th>
<th>Change in Speed from Alt 1 (Basic)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alt 1 Basic</td>
<td>Alt 2 Basic+</td>
</tr>
<tr>
<td>Auto</td>
<td>16 mph</td>
<td>18 mph</td>
</tr>
<tr>
<td>38</td>
<td>7 mph</td>
<td>9 mph</td>
</tr>
<tr>
<td>38L</td>
<td>9 mph</td>
<td>12 mph</td>
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</table>

Note 1: Alt. 2 (Basic Plus Transit Priority) has travel times similar to Alt 1 (Basic Transit Priority), except in the peak period, peak direction when travel times are similar to Alt. 3 (Side BRT).

Note 2: Because the underpass BRT design at Masonic fails for auto traffic, the travel times above assume that the autos stay in the tunnel at Masonic in the center-running alternative. We will work on designs with this characteristic in the next phase of work.
Table 2B. Average Travel Time Savings (Eastbound)

<table>
<thead>
<tr>
<th>Eastbound PM Peak between Gough &amp; 33rd Avenue</th>
<th>Change in Travel Time from Alt 1 (Basic)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alt 2 Basic+</td>
</tr>
<tr>
<td>Auto</td>
<td>14 min</td>
</tr>
<tr>
<td>38</td>
<td>32 min</td>
</tr>
<tr>
<td>38L</td>
<td>25 min</td>
</tr>
<tr>
<td>Auto</td>
<td>17 mph</td>
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<tr>
<td>38</td>
<td>7 mph</td>
</tr>
<tr>
<td>38L</td>
<td>9 mph</td>
</tr>
</tbody>
</table>

Note 1: Alt. 2 (Basic Plus Transit Priority) has travel times similar to Alt 1 (Basic Transit Priority), except in the peak period, peak direction when travel times are similar to Alt. 3 (Side BRT).

Note 2: Because the underpass BRT design at Masonic fails for auto traffic, the travel times above assume that the autos stay in the tunnel at Masonic in the center-running alternative. We will work on designs with this characteristic in the next phase of work.

Estimated Auto Travel Times: Tables 2A and 2B also present the estimated travel time changes for autos, which are relatively minor compared to the travel time savings for transit. The auto travel times for the center alternatives are presented without the impact of the auto delay at Masonic, because the current design is failing for automobiles and we believe that a solution that works for both auto and transit can and must be identified in the EIR phase of the Study.

In the westbound direction, the VISSIM model estimated that auto travel times in the PM peak period improve between 33rd and Gough for the side alternative, and stay the same for the center BRT alternatives. In the eastbound direction, the model is estimating no change in travel times for the side alternative and a 2-minute increase for the center alternatives.

Considering the additional parts of a transit trip (walking to the station and waiting for the bus), it is important to try to minimize the difference between auto and transit in-vehicle travel times. Table 3 presents information on how much slower the in-vehicle bus travel times are, compared to the auto travel times. Without BRT (Alt. 1), in-vehicle time for 38L-Limited riders is about 75% longer than driving, and in-vehicle time on the local bus is more than twice as long as driving. With the BRT alternatives, the in-vehicle travel time for the local bus is reduced relative to autos, and the in-vehicle time for the limited service is almost as fast as the in-vehicle travel time for cars. This is especially true for the center alternative which comes within 15% of the auto travel times in the westbound direction.
Table 3. Average In-Vehicle Bus Travel Time Relative to Average Auto Travel Time

<table>
<thead>
<tr>
<th></th>
<th>Transit is x% slower than auto</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alt. 1</td>
</tr>
<tr>
<td><strong>Westbound</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>113%</td>
</tr>
<tr>
<td>Limited</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Eastbound</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>129%</td>
</tr>
<tr>
<td>Limited</td>
<td>79%</td>
</tr>
</tbody>
</table>

Table 4. Average Intersection Delay for Motor Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 Basic Transit Priority</th>
<th>Alt 3 Side BRT</th>
<th>Alt 4, 5 Center BRT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Van Ness to Collins</strong></td>
<td>22 sec</td>
<td>23 sec</td>
<td>23 sec</td>
</tr>
<tr>
<td><strong>Blake to 12th Avenue</strong></td>
<td>10 sec</td>
<td>10 sec</td>
<td>12 sec</td>
</tr>
<tr>
<td><strong>Park Presidio to 36th Avenue</strong></td>
<td>9 sec</td>
<td>10 sec</td>
<td>10 sec</td>
</tr>
</tbody>
</table>

**Intersection Delay:** In addition to understanding the end-to-end travel times, it is also helpful to know how conditions vary by intersection. We used both Synchro and VISSIM to estimate the changes in intersection delay between the proposed alternatives and the baseline alternative (Alt. 1). In the past, traffic analysis focused primarily on the intersection delay per vehicle; however, this analysis is limited because it treats all vehicles the same, even though a bus carries significantly more people. More recently, traffic engineers have begun analyzing “person delay,” to capture the relative efficiencies of buses versus cars. For example, slowing down a single bus with 60 passengers for 30 seconds creates 30 minutes of total person delay. The equivalent amount of delay would be incurred if you slowed down 50 cars for 30 seconds, since the average car on Geary carries 1.2 passengers.

Figures 1A and 1B show the results of the Synchro analysis for individual intersections and Table 4 shows the average intersection delay for three segments of the corridor. From the Synchro models, we estimate that the automobile traffic continues to flow smoothly with the BRT alternatives in the PM peak period on both on Geary and the parallel streets, and that the delay at any given intersection does not approach breakdown conditions. The only exception is the center-running alternative at Masonic, which averages 92 seconds of delay. If we permit left turns from Masonic onto Geary, as is currently allowed, the delay increases even further. Because of the width and traffic volumes on both Masonic and Geary, combined with the complexity of turning movements, the delays at Masonic are relatively high, even without a BRT project. When the additional traffic from the underpass is added to the surface in the Underpass BRT design, the intersection reaches breakdown conditions. In the next phase of work, additional center-running design options should be identified for Masonic that allow autos to continue to use the underpass.
Figure 1A. Level of service analysis between Arguello and Park Presidio

Basic Transit Priority

Level of Service (LOS) measures delays to auto traffic at an intersection. LOS grades range from "A" (least delay) to "F" (most delay).

Side BRT

Center BRT

Figure 1B. Level of service analysis between Van Ness and Arguello

Basic Transit Priority

Level of Service (LOS) measures delays to auto traffic at an intersection. LOS grades range from "A" (least delay) to "F" (most delay).

Side BRT

Center BRT
From the VISSIM models, we are able to calculate changes in person delay. Although there are many more cars than buses on Geary, a high percentage of people travel by transit. For example at Gough, about 33% of the person-trips are by transit. This percentage declines slightly to 25% by the time one reaches the outer avenues (e.g., 22nd Avenue). This is because buses, which carry up to 80 passengers per vehicle, are much more efficient than cars on Geary, which carry on average 1.2 passengers per vehicle. Table 4 presents the vehicle delay for buses and vehicles, and also calculates the average person delay per intersection. The following key findings can be extrapolated from Table 5:

- Intersection delay for buses can be significantly reduced with the BRT alternatives, without a significant impact to cars traveling on Geary. For Alt. 1, the average bus is delayed 17 seconds without BRT, the Side BRT alternative reduces this delay to 11 seconds and the Center BRT alternatives reduce the delay to 9 seconds. The auto delay changes by less than 1 second.

- Autos and buses traveling on Geary have significantly less delay at intersections than cars traveling on the perpendicular streets. The signal timing is designed to favor Geary at most intersections, because the volume of passengers on Geary is significantly higher than on the cross streets.

- When the vehicle delays are linked to the volume of vehicles in each direction and the average number of passengers in each vehicle type, the average person delay does not change between the basic priority and center alternatives. The average person delay improves by 2 seconds for the side alternative.

### Table 5. Intersection Delay in Seconds

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 Basic Priority</th>
<th>Alt 3 Side BRT</th>
<th>Alt 4, 5 Center BRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay for Buses Traveling on Geary (sec/bus)</td>
<td>17 sec</td>
<td>11 sec</td>
<td>9 sec</td>
</tr>
<tr>
<td>Concurrent Movement Delay All Vehicles (sec/vehicle)</td>
<td>11 sec</td>
<td>10 sec</td>
<td>12 sec</td>
</tr>
<tr>
<td>Conflicting Movement Delay All Vehicles (sec/vehicle)</td>
<td>30 sec</td>
<td>37 sec</td>
<td>48 sec</td>
</tr>
<tr>
<td>Average Intersection Delay All Vehicles (sec/vehicle)</td>
<td>14 sec</td>
<td>16 sec</td>
<td>20 sec</td>
</tr>
<tr>
<td>Average Person Delay (sec/person)</td>
<td>15 sec</td>
<td>13 sec</td>
<td>15 sec</td>
</tr>
</tbody>
</table>

NOTE: Intersection delay for Alt. 2: Basic Plus Transit Priority would be similar to Alt 3.

### Reliability Improvements:

The information presented above is based on average in-vehicle travel times only, which is part but not all of the transit travel time components. When a person starts to make a bus trip, he or she allocates enough time to walk to the bus and wait for the bus. In addition, since many people cannot be late to their destinations, they add in additional time to account for unreliable travel times and wait times.

With BRT, transit passengers can reduce the amount of travel time padding because both wait time and in vehicle times are more reliable. For the limited service, waiting times are also reduced because of more frequent headways. The reliability improvements for the Center BRT alternatives are significantly higher than for the Side BRT and Basic Plus Transit Priority alternatives, because conflicts with cars are completely eliminated. The Side BRT alternative has some reliability improvements because conflicts with cars are reduced; however, parking, turning and double parked vehicles will continue to slow some buses down, causing gaps in service. The Basic Plus Transit
Priority alternative faces similar challenges to the side alternative, but will also have improved reliability, especially when the bus lane is in effect. More research is needed to determine if the lack of a colored lane and the changing regulations by time of day will impact driver compliance and understanding.

From both the travel time and intersection delays, we can conclude that the BRT alternatives deliver significant transit benefits, while minimizing impacts to autos. Transit travel times decrease as much as 9 minutes for transit riders, while auto times increase by 2 minutes or less. The Basic Plus Transit Priority Alternative (Alt. 2), also delivers travel time benefits when the dedicated lane is in effect. The center-running alternatives have the most aggregate hours of savings for transit riders (5,500 per day). Transit travel times are reduced even further when one considers the reliability improvements and estimates showing that about one third of passengers shift from the local to the limited bus. The network benefits lead to even more substantial savings, as many people would use the Geary buses to transfer to other rapid transit lines, such as the proposed Van Ness BRT line. The time they save on Geary is magnified by the time they save on other rapid routes in the network. The information presented here is based on average in-vehicle travel times; however, if we consider the additional time people pad their trip to account for unreliable wait times and longer than average trips, the total travel time savings from using BRT increases even further.

We are seeking a Committee action to accept the evaluation of transit performance and traffic impacts for the Geary Corridor Bus Rapid Transit Study.

ALTERNATIVES
1. Adopt a motion to accept the evaluation of transit performance and traffic impacts for the Geary Corridor BRT Study.
2. Adopt a motion to accept the evaluation of transit performance and traffic impacts for the Geary Corridor BRT Study with modifications.
3. Defer action, pending additional information or further staff analysis.

RECOMMENDATION
Adopt a motion to accept the evaluation of transit performance and traffic impacts for the Geary Corridor BRT Study.