San Francisco County Transportation Authority
Geary BRT Rail-Ready Analysis

BACKGROUND AND INTRODUCTION

The purpose of this analysis is to evaluate the cost and engineering implications related to achieving a rail-ready status for the Geary Corridor Bus Rapid Transit (BRT) Project, independent of the work that has been performed in the current feasibility study for the corridor. The County's Proposition K specifically envisions a "fast, frequent, and reliable Bus Rapid Transit Service, with exclusive lanes and dedicated stations, on Geary Boulevard (designed and built to rail-ready standards)." During the development of Prop K's language, the Authority concluded, and the Expenditure Plan Advisory Committee acknowledged, that light rail was not financially possible within the provisions of the referendum's 30-year Expenditure Plan. Consequently, the Expenditure Plan required that potential center-running BRT design alternatives chosen be "rail-ready."

The Geary Corridor BRT Study evaluated three prototypical full-featured design alternatives, two center-running alignments and one that incorporated side-running exclusive lanes, along with an exclusive lane during the peak-hour in the peak direction only. In accordance with the voter mandate, the Authority has asked Parsons Brinckerhoff to evaluate the center-running alternatives for rail-ready strategies beyond that which has already been performed by the feasibility study currently underway in the corridor. For the purposes of evaluating rail-readiness strategies, treatment of the two center-running alternatives is regarded as the same.

Based on feedback from the Geary Citizens Advisory Committee (GCAC), the Study team has chosen to evaluate two definitions of rail-readiness. The first is a package of design guidelines that would produce an alignment that does not preclude potential conversion to light rail in the future. The second goes beyond this approach, to comprise a series of investments that enable future light rail conversion much more quickly, with less additional expenditure and more reduced impact to nearby businesses and transit riders. These two definitions are described in more detail and form the basis for this analysis. This report includes a spreadsheet that summarizes this analysis, an electronic version of which has been transmitted to the Study team.

This report consists of five sections. The first is an analysis of the Geary Corridor studies performed to date, namely the Needs Assessment Report prepared in 2005 and the conceptual design work performed as part of the feasibility study. In addition, the conceptual designs—in particular, the design criteria approved by the GCAC in November 2006—are reviewed and analyzed.

The second section is a summary and analysis of various BRT projects in development or already in revenue service, particularly the Guided Rapid Transit network contemplated for Houston. In addition, other relevant industry projects will be discussed, particularly Seattle's Downtown Transit Tunnel, Pittsburgh's Martin Luther King Busway, and Los Angeles County's Orange Line in the San Fernando Valley. These projects incorporated many design elements—such as shared platforms, LRV-supportable bridges and roadways and signaling technologies—that could be used for future LRT operation.

The third section evaluates the methodologies and conclusions of cost estimates for the two definitions of rail-readiness outlined by this project's scope of work. The first of these definitions entails design of the BRT alignment so as to not preclude LRT. The second definition entails provision of significant surface and subsurface elements of a light rail system in the BRT design. Intermediate modular steps between the two extreme definitions are also evaluated.

The fourth section discusses the constructability implications of these two alternatives and the steps that may be required to bring each alternative definition of rail-readiness to revenue status light rail. This section includes whether and when such systems as traction power, trackwork, train control systems, station modifications are to be preinstalled in either scenario of rail-readiness.

The final section summarizes these findings and discusses any recommendations for preliminary engineering and final design criteria. As part of this report, the Study team has been provided with an electronic copy of this spreadsheet to help enable staff evaluation of various issues and elements associated with converting the BRT service on Geary to LRT operation.

This study is neither meant as a conclusive or prescriptive policy position nor a replacement for detailed final design. However, it is meant to give the Study team and its stakeholders a useful tool toward those next steps, by providing policy-makers with the necessary information to determine the most cost-effective balance between the benefits of more near-term BRT with a "readiness" for a potential rail project on Geary. In short, it is designed to help fulfill the mandate of Proposition K to the most practical extent.

1. Review of Studies to Date

A 2005 memo to the Geary Citizens Advisory Committee (GCAC) (attached as Appendix I) built on the conceptual designs and the Needs Assessment Report by the Study team. These documents began to define the "rail-readiness" mandate of Prop K by providing two alternative definitions. Option A, the baseline definition evaluated in this report, defines rail-ready as a set of elements to be incorporated into BRT design so as to not preclude future light rail conversion. Option A requires BRT geometric design—i.e., horizontal and vertical clearances, grades, adjacent tangents, and turning radii–to meet light rail standards. On Geary, the Needs Assessment Report noted that this definition will introduce the most constraints at Fillmore and Masonic, where automobile lanes become a limited access expressway. Grades also are steeper in these blocks of Geary.

Option A requires that stations be sited at locations that can accommodate a light rail platform (typically 180 feet), which is longer than a BRT platform (typically 120 feet). This definition allows for future conversion to light rail without redesign of either station platforms or the street. Construction-related disruption would occur if track and related infrastructure were installed during a conversion to light rail. Option A focuses on features that "prioritize resources for development of a more full-fledged bus rapid transit system," (GCAC memo, 2005). In reality, the approach's primary effect on BRT project delivery is less upfront cost than Option B. These cost savings could be used for the purchase of additional, larger, or more expensive BRT vehicles to achieve a more frequent and/or higher-capacity operation than what is contemplated in the Study team's Geary BRT service assumptions to date, or they might be applied to a project in another corridor.

Under Option B, rail-readiness is defined by designs that minimize the construction of additional major facilities at the time of conversion, particularly for subsurface infrastructure. As the staff memorandum to the GCAC mentioned, this design approach would not "dig up the street more than once in an effort to minimize construction impacts."

This definition includes all the construction and installation associated with Option A, as well as all surface and subsurface infrastructure. Option B would also include all trackwork (rail, fasteners, and concrete supportive slab); ductbanks for all electrical and communications; manholes; pole (for an overhead system) and substation foundations for traction power cables and train control wiring; ductbanks and concrete boxes for stray-current protection against corrosion; any necessary drainage work; and needed utility relocation, including work to preserve access to minimize interruptions to BRT/LRT service during utility maintenance activities. This definition considerably narrows the differences between this version of BRT and the cost and construction considerations for light rail.

Due to these higher average unit costs, which are discussed below in more detail, adoption of Option B could force the Study team into one or more difficult choices, including seeking additional funding to offset these costs, project delay, a shorter BRT operating segment, less frequent service, or fewer passenger features and amenities, etc. Although Option B's substantial up-front investment will obviate some construction costs if the decision is made to convert to LRT, construction of additional light rail infrastructure will lead to increased time and construction impacts during BRT implementation. The fourth section of this report will discuss how delay and disruption compare between options, but in either approach, these delays and impacts could create additional stress on neighborhood businesses or residents, or decrease or delay benefits to transit riders and neighbors in some segments of the corridor.

In sum, this analysis will illustrate how these two definitions basically represent extremes on a continuum of BRT project delivery strategies; other combinations of delivering packages of high quality BRT service elements while preserving the option of future rail conversion along this continuum between these two will also be addressed.

Rail-readiness Design Criteria

To date, the Study team has developed a set of design principles and guidelines derived from the project study goals, which were adopted by the GCAC in its November 2005 meeting. These principles and guidelines include minimum design standards for stations, vehicle and running-way image criteria, service planning parameters, traffic signal requirements, environmental sustainability objectives, neighborhood access guidelines, and pedestrian safety protections. The criteria imply a prepaid fare with proof-of-payment by use of ticket vending machines in BRT stations and enforcement with roving inspectors.

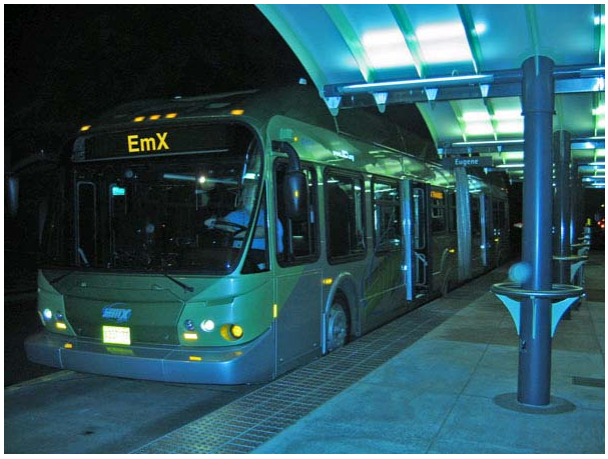
These design principles support both BRT and LRT operations. Some, however, would require further refinement in final design, based on an evaluation of the range of options that can comply with these criteria.

The GCAC memo further defined the term "rail-convertible" for the BRT running-way for Geary. The running-way must be separated from other vehicular traffic with "self-enforcing" features such as a colored pavement or island separation, and, in conjunction with station access, features such as minimal walking distances and street crossings from the neighborhoods served, as well as between connecting transit routes (e.g., BART/Muni services). It also stipulated

that the infrastructure should be designed for easy maintenance. These design criteria neither facilitate nor preclude potential conversion to light rail in future; they enhance effectiveness of both modes by designating and helping to enforce priority of the transit service in the traffic corridor.

Running-way and station designs are to "facilitate efficient transit loading and unloading," according to the GCAC November 2005 memo. This would imply platforms whose widths (stipulated at least 8 feet) and lengths (at least 125 feet) are long enough to accommodate at least a single articulated LRV), along with heights that match the floor heights and capacities of both BRT and light rail vehicle (LRV) floors.

However, the BRT vehicle interfaces that were adopted in the GCAC memo from staff differ from LRVs currently operating in San Francisco in an important way. Currently available U.S.-built BRT vehicles have a partial low floor (at 13-14 inches without kneeling, they are similar to the low-floor buses that MUNI has already begun to purchase) and multiple, wide doors. Some include doors on both sides of the vehicle to allow boarding from center platforms as indicated in one of the design alternatives for a center-running BRT on Geary. The photos below show the two U.S.-manufactured vehicles currently available with doors on both sides of the vehicle.



New Flyer Industries' vehicle for the EmX Green Liner Project, Eugene, Oregon's BRT starter segment.



North American Bus Industries' (NABI) vehicle for Los Angeles Orange Line and Metro Rapid services.

However, LRVs in the city employ the older standard floor design, with a floor height of 33 inches. The photos below illustrate this disparity. Thus, in order to accommodate eventual use in the Muni light rail system, BRT platforms ideally should be designed so that they can be raised with minimal reconstruction and/or related traffic disruption.

The Study team could overcome the disparity of these floor heights with one of three strategies. First, final designers could devise a "raisable platform," which would initially accommodate low-floor BRT vehicles. It could then be raised to accommodate the higher-floor LRVs sometime in the future. Another option might be to procure vehicle fleets that could use the same platforms. However, this would involve a major investment to retrofit one or more existing rail maintenance shops.





Example of typical modern low-floor U.S. BRT application (Los Angeles) vs. typical Muni higher floor LRT design.

Because of the greater expense of LRVs and the likely desire of the operator to preserve its existing investment as much as possible, and because Muni still operates many standard-floor buses in the city, procuring standard-floor buses for the BRT service might be an attractive option. This option also has limitations, however. All of the more stylized BRT vehicles currently available in the market employ at least a partial low-floor design. Indeed, only one U.S. manufacturer continues to build standard-floor articulated buses (NABI), but this model is a traditional "shoebox" exterior design. Thus, any potential contractor would need to be incentivized to a) redesign its vehicle for BRT application; b) resurrect an obsolete articulated bus model—and redesign it accordingly—or c) serve this project with vehicles produced outside the U.S., an option limited by federal procurement (Buy America) regulations.

In addition, standard floor BRT vehicles would forego the advantages of low-floor operation, including eliminating need for more complicated lifts for ADA compliance as well as reduced dwell times with low-floor vehicles at stations.

The final option is to construct separate platforms or sections of the same platform, one with a higher floor boarding section and another with the lower-floor section. This is also the approach many LRT systems use to comply with ADA, including Muni's; the lower section is joined to the higher section by a ramp. Platform lengths and corridor constraints might make this approach infeasible, especially given the additional costs associated with a design that in effect require twice as many platforms for the corridor.

The final chapter will discuss the constructability implications of these three options further.

Other design criteria adopted in November do not pose either cost or constructability challenges for BRT in the near term or with respect to longer-term conversion to LRT. These criteria include preferred minimum lane width 11.5-12 ft, minimum turning radii of 80 ft, maximum running way grade of 6%, adequate curbside bus stops space for businesses and pedestrians, enhanced security with lighting and clear sightlines to approaching vehicles; inviting stations with adequate weather protection and comfortable seating; easy-to-understand signs and maps; and real-time information systems indicating arrival of the next vehicle. In addition, requirements for multicultural and/or multilingual information appropriate to the neighborhood (e.g. Japanese for stations in Japantown), as well as facilities for bicycles at key BRT stations, do not have an effect on rail-readiness in the corridor.

2. Review of Relevant Industry Experience

This section will evaluate the definitions of rail-ready that were presented to the GCAC with case studies from two industry perspectives. The first is Houston METRO's rail-ready research into alternatives to LRT, which was originally promised to voters. The second is Seattle's experience in designing and retrofitting the Downtown Transit Tunnel.

Houston METRO experience to date

In April 2006, the Harris County (Houston) METRO Board approved five consultant teams for design development and conceptual and preliminary engineering on five corridors, four of which were for "Guided Rapid Transit"—METRO's phrase for BRT—on the North, Southeast, Harrisburg and Uptown corridors and one for light rail on the University corridor.

In May 2006, three consortia were pre-qualified for METRO Solutions Phase 2 work as "Facility Provider." The selected team, which will be decided in early 2007, will be responsible for providing and installing the systems, as well as constructing the civil works for the four Guided Rapid Transit corridors. The selected consortium will also be responsible for operating and maintaining the new light rail and bus rapid transit lines (Houston Metro, 2006).

In addition, the Facility Provider team will serve as a general engineering consultant, overseeing the work of these preliminary engineering consultants and integrating them into a consistent final design for the five-corridor network. However, the agency has repeatedly suggested in several public forums that due to region's inability to afford LRT within its forecasts of future tax revenues each of the four BRT lines must easily be convertible to light rail, and have made representations to the public that the lines can be converted without disruption to service and that rails will be embedded into the corridor along with all light rail systems except for the electric traction system (Railway Age, 2005), despite the potential cost of conversion.

During the project's first phase, which is scheduled to finish preliminary engineering by July 2007, the preliminary engineering firms and Facility Provider will also determine the detailed definition of rail-readiness and how the BRT lines are to be designed, constructed, operated, and maintained with rapid conversion of them to LRT in the future.

Work in this phase will also include the development of innovative financing and funding plans that focus on future convertibility from BRT to light rail, as well as the potential early construction of light rail to be funded by transit-oriented development proceeds. This financing work, along with the final definitions of the technology, systems, and infrastructure in preliminary engineering, will also determine METRO's ultimate definition of rail-readiness. At the end of this phase, the Facility Provider will also lead these firms as a design-build project team that will deliver a fixed-price and guaranteed completion date for the specification, design, and construction of these lines to revenue-ready status. This team will also involve an operations and maintenance contractor as part of the team's fixed-price offer (Houston Metro, 2006).

Phase 2, which will commence immediately thereafter, includes program management, final design, construction, start-up, commissioning, and testing. A turnkey (design-build) project delivery method is being used. However, because so much of the important decisions on this project have yet to be made, the ultimate outcome regarding both the detailed engineering definition, as well as strategies involving rail-readiness of the BRT system under development, remain yet to be determined in Houston.

PB, as a member of one of the three prequalified consortia (the Bayou City Transit Team), has already performed feasibility analysis of Houston's expectations regarding rail-readiness. In order to maintain the desired aggressive design and construction schedule, some design criteria will be needed to oversee configuration management of the five corridor PE consultants. In its work on this project and others, PB estimated that in order to support future light rail operation, the running way structures can be designed so that the additional design costs of this approach exceeds the design costs for BRT running ways by no more than 5-10%.

This work is consistent with rail-ready analyses performed by PB's office in Seattle for that city's Downtown Transit Tunnel. Extracted from this analysis, the following table details the typical design elements for a BRT project where LRT constraints need to be considered and whether BRT or LRT requirements control the design.

Seattle's experience

Many cities have considered conversion from a bus fixed guideway to LRT. Only Seattle has actually undertaken such an endeavor. Conversion has been studied and debated elsewhere in North America and Australia. Proponents of conversion point to the higher maximum carrying capacity offered by LRT vehicles that can travel in trains of multiple cars, as well as the theoretically lower operating costs associated with fewer vehicles and drivers. Proponents discount the huge weekday ridership levels posted by many BRT systems around the world and the relatively high maintenance costs of LRVs. Critics of conversion assert that the capital costs associated with the conversion process outweigh any

savings derived from lower operating costs; further, demand must be extremely high in order to realize operating cost savings. Perhaps most importantly, system owners have not elected to disrupt streets and the built environment in order to avoid impacts on businesses and existing transit riders associated with conversion to light rail. Additional challenges include integration with other rail or bus systems within a larger regional network, transfers between different modes, and the effects of converted lines on nearby land uses. The planning agency in Curitiba, Brazil has studied replacement of two lines of its famed BRT system with "electric tramcars" but to date has not begun the project.

Given the above considerations, particularly the cost, disruption, and uncertain marginal benefits associated with such a conversion, no BRT facility in the U.S. other than Seattle's Downtown Transit Tunnel (DSTT) has ever been converted



to joint bus and LRT use. PB is responsible for much of the industry and research literature regarding this issue (Wood et al). The findings summarized below were compiled from a study of selected existing BRT systems and analysis of the DSTT conducted by PB. The Seattle project will be the primary focus of this part of the analysis.

Plans to convert the DSTT from initial bus operations to future rail transit use began during design in the mid-1980s. Several important rail transit design elements were incorporated at that time, many of which are pertinent to this discussion. These elements include rail-compatible horizontal and vertical geometry, tunnel clearances for LRVs, station platform lengths to accommodate four-car LRV trains, appropriate station widths, capacity provisions for accommodation of projected higher LRT ridership, and design of structural elements to support LRV loads.

Incorporating these elements in the DSTT's original construction to some degree minimized the demolition and reconstruction required to convert the tunnel to LRT use. However, LRT technology has changed significantly since the tunnel was designed roughly two decades ago. These changes were not anticipated during the original design process and have significantly affected the conversion project currently underway (since autumn 2005), which is due to be completed next year. A major part of the DSTT conversion is the incorporation of a new LRT traction power system, with attendant retrofit of grounding and other corrosion protection. Low-floor LRVs were not available in North America at the time the tunnel was designed. Thus, track and platform modifications are also necessary in Seattle. Fire/life safety systems are also being upgraded, and train control and communications systems are being improved to support integrated joint bus and rail operations.

Of particular interest to the San Francisco case is Seattle's decision to lower the tunnel bed to accommodate both low-floor LRVs and buses. Before the retrofit, King County Metro operated standard floor buses in the tunnel, and standard-floor LRVs were planned for future LRT operation. When the DSTT conversion is completed next year, both low-floor buses and low-floor LRVs will operate jointly in the tunnel.

When to Convert – Issues to Consider from Seattle's Experience

The amount of disruption to the operating BRT system during conversion varies greatly depending on decisions made during the BRT design stage, particularly the following:

- The extent to which LRT geometries and elements (as discussed above) are included in BRT design and construction;
- Whether or not the system is at-grade or on an elevated structure and ease of access to the guideway;
- Availability and access to the work sites, which will influence manner of installation of rail and supporting infrastructure and rerouting of precursor BRT service during conversion; and
- Whether and to what extent access to the guideway is maintained during LRT conversion.

In Seattle, all bus service that had previously used the DSTT was rerouted to surface streets during LRT construction. In addition, Third Street through downtown has become a transit-priority corridor, with new restrictions on other traffic during peak hours. Extra Seattle Police Department officers have been assigned to enforce traffic restrictions and aid pedestrians at several affected intersections. This reassignment was in excess of the police, janitorial, and security personnel that were previously assigned to tunnel operations, who were also reassigned to surface duty during the temporary tunnel closure. In addition, as part of Mayor Greg Nickels' "Seattle Moving" initiative, the police department and the city's Department of Transportation have undertaken a public information campaign, entitled "Don't Block the Box," to bolster the enforcement efforts.

Much of this has already been anticipated by the Study team to date. For example, design elements can be categorized into several key areas:

- Horizontal geometry (alignment with minimal curvatures and appropriate cross sectional widths to support LRT operation, and static and dynamic envelopes at design speeds for both BRT and LRT);
- Vertical geometry (grades and clearances that can accommodate LRVs, typically 7% maximum grades) and;
- Structural elements (proper loading and pavements for LRV weights and vibration, and stray current protection);
- Utility accommodation (relocation, new services, and drainage);
- Other guideway construction details to facilitate later removal and replacement with rail; and
- Proposed future construction sequencing provisions, to accommodate continuation of existing BRT service during construction.

Table I. Controlling Design Elements BRT and LRT

Design Element	BRT Controlling	LRT Controlling
Design Speed (based on Geary alignment)		√
Horizontal Geometry		√
Vertical Geometry		√
Gradients		√
Superelevation (above adjacent streetscape)		√
Horizontal Clearances		√
Vertical Clearances		√
Platform (based on Geary assumptions of heights)	√	√
Pavement		√
Stray Current Protection		√
Utility Accommodation		√
Cross Section (based on the vehicle type used in SF)		√

These are discussed in further detail below.

Horizontal and Vertical Geometry: Horizontal and vertical geometries should be driven by the LRT requirements because they are more stringent than for BRT. For example, the horizontal and vertical curves should generally be calculated based on stopping sight distance requirements for light rail vehicles on the basis of the LRT service braking rate. Approach curves to station platform areas should also consider the LRT vehicle. For both LRT and BRT vehicles, it is preferable that station areas do not include curves. Tighter constraints on the super-elevation criteria exist for LRT alignment than for BRT alignment; super-elevation parameters should be assessed in terms of "balance," "comfort," or "limit" design criteria for LRT vehicles. These criteria are more robust for in-road vehicles such as buses, including BRT vehicles. Thus, overall design of the super-elevation now and in the future should be to the stricter levels of LRT rider comfort, with proper rates of horizontal and vertical transition for LRVs. These vehicles are also wider than buses and thus require a wider static and dynamic envelope for operation, issues that are summarized in the table below. For example, the static envelope gap between the platform edge to the vehicle door threshold is approximately 1.5 inches (40 mm). Regarding vertical envelopes, vehicle clearances required for LRT from the top of finished rail to contact system fixing must allow for passages under the overpass at Masonic. Based on the preliminary conceptual design work completed to date, these geometric constraints should not be issues for future light rail operations on Geary, which is essentially a straight alignment, with sufficient clearance at Masonic and sufficient horizontal clearances being designed for both buses and LRVs.

Table II. Comparison of BRT and LRT Vehicles and Running Ways

Dimension (typical for U.S. industry)	BRT	LRT
Top operational speed	65 mph	55 mph
Vehicle length	30-60 ft.	55-95 ft.
Vehicle width	96-102 in.	96-121 in.
Vehicle height	9.5-11.5 ft.	Approx. 12.5 ft.
Vehicle axle ratings	6.6-13 MT	13 MT
Running way min. width (two lanes)	23 ft.	23.5 ft.

Structural considerations: All structures should be designed to support the additional weight of LRVs, which at 13 tons per axle are rated as heavier than articulated buses (although the rear axles are rated the same). Thus, the additional load bearing on the pavements and supporting subsurfaces for LRVs are used in these analyses and cost calculations. A more serious issue is platform design. Platforms for BRT and LRT should be compatible in order to save substantial future costs in providing a station suitable for the LRT vehicle. As mentioned above, vehicle heights contemplated for BRT along Geary are quite different than the heights for LRVs in use currently in San Francisco. Widths and lengths that have been approved by the GCAC are satisfactory for both modes. Platform height to suit LRT vehicle level loading access could be provided later by raising the end of the platforms to suit. In general, the Study team's preliminary engineering or final design consultant should determine a platform adjustment concept. Further**,** concrete pavements constructed for BRT must accommodate the heavier LRV axle loads, location and nature of rail installation, and consideration of stray current protection. There are two possible options for BRT concrete pavement levels that will provide for future LRT conversion. The first is to allow for the future rail pockets to be cut into the pavement. The second is for a slab to be overlaid to allow for the formation of the rail slots. Rail drainage also should be considered in all concrete pavements that are constructed for dual BRT and LRT use. To prevent electrolytic corrosion of adjacent structures, foundations and services, stray current protection will be necessary. If LRT is pursued on Geary using an overhead contact system comparable to the city's other LRT and trolleybus services, preliminary identification of traction power substations sites would be more desirable (though not essential) at this design phase than waiting for a future LRT conversion. These substation sites and foundations also become the location for the grounding mat for stray current corrosion protection.

Other structural issues: In addition to running-way design, maintenance facility design and location for future rail operations must be considered. In Houston, expansion of METRO's existing rail facility with a spur to enable transit between the line and the maintenance yard is one possible option; a similar spur will be necessary in San Francisco to the most appropriate existing Muni LRT line near Geary. Conversion of a nearby bus facility to LRV maintenance use is another option. Should this be the option chosen, and if use of standard-floor LRVs continues, the need for underfloor pits must be accommodated. LRVs are also typically longer than 60-foot articulated BRTVs; thus, pit or catwalk lengths as well as in-floor jacks installed for work on buses, would then likely have to be modified to accommodate LRVs. Moreover, because the existing BRT facility(ies) would still likely be needed for all or part of the fleet after an LRV upgrade (because BRT vehicles could then be redeployed as feeder service), any BRT maintenance facility would either be expanded to accommodate LRT maintenance, or Muni's existing LRV and traditional bus fleet maintenance facilities would be expanded to accommodated these new operations.

Utility Accommodations: To comply with the minimum definition of rail-readiness outlined by the GCAC staff memo, all relocation of existing utilities must consider future LRT infrastructure. Accordingly, the proposed BRT drainage system should consider how the future LRT infrastructure is to be accommodated. Rail drainage, point drainage, and drainage of underground LRT infrastructure should be considered during the BRT design phase. As is discussed below, these drainage provisions, on their own, should not significantly add to the civil works costs of BRT construction. However, if no such provisions for LRT are included in BRT design and construction, the cost of conversion can be significantly higher.

Construction sequencing issues: Rail-readiness affects the order and timing of both short-term BRT construction and future LRT construction if pursued. For example, in the near term, because there is no appropriate interface standard at present, the chosen precision docking technology of BRT vehicles at a station should take into consideration the widest possible range of BRT vehicles available, particularly available vehicles' wheelbases and steering turn angles. In addition, sufficient clearance in the curb and platform configuration of the station to accommodate the maximum range of available vehicles to approach, dock and depart without undue constraint must be provided in the horizontal geometries of the alignment.

While these issues arise in any BRT design, they are complicated by rail-readiness considerations. For example, additional right-of-way must be identified for the locations of future special trackwork such as rail turnouts and crossovers. If not preinstalled as part of the BRT construction, then clearance, footings, conduits and/or space should be provided in order to satisfy the following future LRT elements:

- Pole foundations for an overhead contact system
- Duct banks and conduits for traction power and communications infrastructure
- Pull and / or junction boxes and conduits for vehicle tracking system and track circuit embedded loops
- Subbase, base, drainage, track slab, and track pavement to accommodate rail
- Rail and fasteners / space for any preinstalled / future trackwork (e.g., crossovers, turnouts, etc.)
- Electrical bonding, and embedded switch mechanisms and machines
- Stray current protection infrastructure

BRT roadway curb and gutter should be designed and constructed so as not to interfere with future LRT operation, or for removal prior to LRT operation. They should include the future LRT surface and subsurface LRT infrastructure drainage, or at least not preclude it. There are two possible options for BRT concrete pavement levels that will still provide for future LRT conversion. The first is to allow for the future rail pockets to be cut into the pavement; the second is for a slab to be overlaid to allow for the formation of the rail slots. Rail drainage should thus be constructed in the BRT phase for all concrete pavements with dual BRT and LRT usage. For segments that would be for LRT systems only, the LRT-specific space and drainage provisions should be preserved for these future needs. These constructability issues and their cost implications are elaborated upon below.

Comparisons with Geary rail-readiness definitions

Other BRT systems have included some rail-ready features, though most fall far short of the measures taken in Seattle or those contemplated in Geary's Option B. In Pittsburgh, PA, for example, structures, geometries, and some utility relocation were employed to support future LRT operation, though features for future electric traction power and LRT signaling systems were not designed on any of the city's busways. The new Los Angeles Orange Line BRT includes stations that could be used for LRT operation. In Los Angeles, electric traction was considered for BRT operation (as a noise abatement measure), but was eventually deemed too expensive for the project. Design requirements specified that the BRT vehicles be 40% quieter than the agency's newest buses (at a cost of an additional 5% built into the contract as an incentive payment). Instead, BRT vehicles powered by CNG (clean natural gas) are used. Cleveland's Euclid Corridor and Eugene, Oregon's BRT lines under construction have even fewer rail-ready features. As such, they would require much more extensive retrofit work than either Seattle's tunnel or the Los Angeles Orange Line. Similarly, busways in Hartford, CT and Miami are of little relevance to this analysis.

Significant community and operational resources are required to maintain existing transit service and minimize disruption during the conversion to light rail. This is true even when the agency has prepared for future conversion in BRT design—e.g., appropriate clearances for envisioned future equipment, utility relocation, etc. Even if technology does not advance in the decades subsequent to Geary BRT deployment to the degree it did in the Seattle case, Muni should assume that a successful conversion (even from a "rail-ready" BRT system) will require additional money and time, as well as attendant disruptions to existing bus service and impacts on surrounding businesses and residents.

3. Cost Estimates: Methodologies and Conclusions

This section discusses the methodologies and results of cost estimates contained in the existing studies of the corridor as well as for the two definitions of rail-readiness outlined by the Authority in the November 2005 GCAC memo.

Analysis of Existing Cost Estimates

The analysis assumes additional design fees to ensure that the horizontal, vertical and dynamic envelopes allow future implementation of light rail in the corridor. Accordingly, the design fees associated with the three alternative definitions described below reflect these considerations.

An initial review of the capital cost estimates for BRT on Geary prompted the following five observations. First, material costs seem somewhat high by industry standards. For example, 10-inch PCC concrete is typically appropriate for the BRT running-way. In fact, the 2.7 foot overall structural depth indicated in the consultant team's cost assumptions may not require additional depth to accommodate light rail.

Earthwork, running way pavement structures and drainage for this project averages $870 per route foot, nearly double the national average. These costs are typically in the range of $450 -$570 per route foot for other planning-level BRT cost estimates nationwide. For this project it was estimated to be $692 per route foot, given San Francisco's higher construction costs.

BRT stations are estimated by the consultant team at $670,000 each. This represents a high level of finish and amenities. However, there is no distinction in the estimate of total station costs between far side split stations and single center platform stations (estimates for the higher-cost scenario were used). Split station costs are usually higher due to the construction of two platforms per BRT or LRT stop. In general, the station cost estimates for Geary to date are at the higher end of the range for BRT stations nationwide. In part, this is due to a higher than normal unit cost used for ticket vending machines.

Second, costs for temporary maintenance of traffic are estimated at approximately 1% of infrastructure cost. These are typically in the range of 2.5 % to 3% of infrastructure costs and a minimum of 3% in San Francisco. Accordingly, we estimate these costs will be $5 million for the Option B definition.

Third, capital outlay support, consisting of project management, design costs, construction administration, and general program administration, was estimated on the low end, at 30% of total infrastructure cost. Our experience has found that the typical range of these so called "soft costs" is actually between 30% and 35% of total infrastructure budgets, and the FTA most recently recognizes 34% as the typical figure.

Fourth, Year of Expenditure (YOE) appears to be based on 2005; thus, escalation to YOE 2008 might be required.

Finally, a contingency of between 30%- 35% is usually applied at this planning level estimate. For the purposes of adding a planning-level contingency to the rail-readiness estimates discussed below, this report will use an industry-average 32%.

Cost Estimates of the Rail-Ready Definitions

The costs of the two definitions articulated in the GCAC memo, as well as a mid-range alternative, are explained here. First, the costs associated with designing the BRT system to a level that does not preclude future light rail operation (Option A) were calculated. These costs include the horizontal and vertical clearances, grades, and turning radii required for LRT operation. Because the Study team is contemplating a different platform height for BRT (for low-floor vehicles) than the LRT platforms used to achieve level boarding elsewhere in the city, Option A does not assume conversion of the platforms or pre-installation of trackwork or supportive slabs. Instead, it contemplates potential modular design of station platforms to ease the conversion to LRT if pursued. The rationale for this is that while use of low-floor platforms is not part of San Francisco's experience it is possible to use them with industry-available equipment; thus the design adheres to the "does not preclude LRT" paradigm. Option A is estimated to cost approximately $2.7 million more than the center-running BRT design that has been identified by the consultant team.

In all three alternative definitions, the unit construction and materials cost estimates performed for the recent light rail projects PB has performed for Muni are used. This database represents the most accurate costs available for transit infrastructure and is specific to the city and region.

As shown in the spreadsheet attached as Appendix II, this "does not preclude LRT" definition of rail-readiness will total $2.8 million, or less than 3% more than the estimated cost of a BRT system with the center-running features established in the consultant team's needs assessment.

From this baseline estimate, the cost of Option B was determined by adding the costs associated with of each of the discrete elements needed to bring the system's design to this more extensive rail-ready definition. Option B includes all

surface and subsurface infrastructure, such as trackwork (rail, fasteners, and concrete supportive slab); electrical and communications duct banks; manholes; contact system pole foundations and traction power substation foundations; duct banks and concrete boxes for stray-current protection against corrosion; related drainage work; and needed utility relocation, including access to utilities so BRT/LRT service will not be interrupted.

As shown in the spreadsheet in Appendix II, this second definition of rail-readiness would increase total project's cost by more than $114 million in current dollars, or nearly as much as the estimated cost of the most expensive center-running BRT design with the features established in the needs assessment.

By presenting these costs in separate line items in the attached spreadsheet, incremental steps between these definitions can then be analyzed by the Study team individually. In this manner, a third definition of rail-readiness is illustrated. This intermediate alternative is estimated to cost $22.2 million. The logical sequence of the construction of these systems and structures is discussed in the next section, which will help the Study team consider such a scenario.

Several costs are not included in this analysis. For example, vehicles, commissioning and testing costs, and retrofit of maintenance facilities to accommodate low-floor LRVs are not included here, primarily because actual technology choices in a future LRT conversion remain undefined. In addition, ticket vending machines for fare collection are assumed to be reused by the LRT design. Contact system and substation installations are also excluded, again because exact LRT technology is unclear. Inclusion of these and other costs would drive the price of the eventual LRT conversion much higher than the most expensive design definition indicated above.

4. Constructability Implications

This section analyzes the constructability issues related to the two alternative definitions of rail-readiness and the steps that may be required to bring each to revenue status light rail. This section also addresses when and whether such important systems as traction power, trackwork, station modifications, and train control systems are to be preinstalled or retrofit after commencement of BRT operations.

As the Seattle experience suggests, regardless of the level of rail-readiness, conversion from BRT to LRT should be carried out as a series of steps designed to minimize the impact on the operating transit system and adjacent residents and businesses. For purposes that will become clearer momentarily, this discussion begins with the Option B definition of rail-readiness.

Comparison of Definitions for Construction Sequencing

Option B requires a more detailed examination, because it would result in a conversion to LRT with less disruption of BRT and feeder bus service and less impact on surrounding neighborhoods during the conversion project. However, even with the high level of rail-readiness assumed in Option B, substantial disruption would still occur.

Assuming that a moderate level of BRT service reduction is acceptable and that all LRT design features of the Option B definition of rail-readiness were pre-constructed, the activities associated with conversion to LRT would generally occur as follows:

First, the agency and its construction management team would establish alternative routes (or if possible, procedures for buses to utilize the same transitway with traffic control) for the existing BRT service infrastructure around the required work area for the LRT conversion.

Next, maintenance of traffic procedures and alternative transit operations plans would be implemented. This step should also include personnel reassignments, law enforcement and public information campaigns as performed in Seattle. Then, traction power, train control and LRT-specific communications systems would be installed. These systems, particularly the junction boxes and buried cables for these systems, should be installed prior to any modification of station platforms because they are located at least partly below the platforms.

The stations would be next to be modified appropriately to support the chosen LRV technology. The above cost analysis assumes (in both alternatives) that the stations used for the BRT phase of the Geary Corridor would be modified to accommodate higher-floor LRVs at the time of conversion. A less-disruptive approach could be a design that facilitates more rapid modification. For example, removable platform surfaces could be used, such as flagstones with semipermeable subsurface that both enhances drainage as well as removal. Necessary conduits, ductworks, and even cables and wiring that are of appropriate lengths for higher-floor LRVs could be preinstalled and coiled beneath the BRT platform. When ready for the conversion stage, BRT platform flagstones and subsurface would be removed and in their place a precast concrete structure could be lowered in place with cranes. This precast element then becomes the higher LRT platform. Details of either approach must be provided in final design.

The next step in LRT conversion would be the installation of the trackwork and reconstruction of the pavement. This analysis assumes that concrete pavement with direct fixation track will be used on the Geary project.

Finally, once these systems are installed, the civil works are reconstructed, and the new cars for the converted LRT service arrive, the traction power system would be energized and tested with the new vehicles. This testing would then transition to revenue service simulations of all systems together. Testing is typically six months in duration before the new line can be commissioned to revenue-ready status. At that point the operating agency would decide whether to discontinue the rerouted bus service, slightly reconfigure it to interconnect with the new LRT line as feeder service, or continue it as a parallel operation in the network.

The more basic of the Study team's definitions of rail-readiness (Option A) would require several additional construction steps at the time of conversion. For example, prior to the above steps, remaining utility relocation would occur as required. The ductwork, junction boxes, and corrosion protection infrastructure would be installed after utilities relocation but before reconstruction of stations or installation of rail systems.

Utilities Relocation Considerations

The median or center-running BRT with side platforms is the desired BRT configuration, which is centered in the median of the right-of-way. Whether configured with side or center platforms, however, an extensive gravity sanitary sewer main line and large trunk line system is located directly in the center of the alignment, underneath and throughout the entire length of the projected BRT running way. This sewer system is composed of sewer conduit pipes ranging in sizes from 18 inches in diameter to 72 inches. In some areas, an additional parallel sewer of brick lined or concrete

rectangular sewer lines provide additional sewer capacity. The sizes of these ancillary lines vary from 2'-0" wide x 3'-0" high up to 4'-0" wide x 5'-6" high.

So extensive is this sewer infrastructure system that unless future conversion to a rail based fixed guideway is an absolute certainty, relocation of this sewer system would not be recommended as an initial element of BRT construction. This is mainly due to high costs—at $15.9 million, or more than seven times that needed for BRT—and disruption of utility and vehicular service within this corridor. (This estimate does not assume any cost-sharing with other city infrastructure budgets or the possibility of including these costs as part of the utilities' long-term capital plans.)

Should the sewer system not be relocated for BRT operation, access to and maintenance of the sewer system remains an important issue. Several optional operational strategies would be feasible, one or more of which are presumed in the minimal cost estimated in the consultant team's needs assessment ($50 per RF vs. the $753 per RF needed for LRT). First, adjustments to all access manholes could be made with riser adjustments or by rotation with an eccentric cone such that the manhole access cover would surface in only a single lane of the BRT running-way. Thus, maintenance operations would require the temporary closure of a single bus within the area of the manhole being accessed. The other lane would remain operational. BRT vehicles approaching the closed lane area would stop for sight line clearance of opposing BRT traffic and then pass on the opposite lane around the maintenance work area. Driver protocols and operating procedures to adjust the headways would have to be developed, and an agreement with the local utility would need to be negotiated.

As a second strategy, the sewer utility could remain in place and center median and center stations employed. This configuration would place the planted median and stations directly over the sewer system with a running way lane on either side of the 14'-0" wide median. Although this configuration does not preclude LRT conversion, access and maintenance to the sewer and riser manholes would likely require that a utility service vehicle occupy an adjacent BRT running-way, effectively closing the affected lane for a block. During maintenance activities, the BRT vehicle in the blocked running-way could only cross over to the reverse lane at an intersection. In doing so, the vehicle would be faced with priority traffic signals pointed in the opposite direction, which would render the prioritization strategy ineffective for the duration of the lane closure. To avoid this scenario, operational protocol could require the BRT vehicle to merge into the adjacent mixed traffic lane and merge back into its dedicated running lane beyond the work area.





A final option would be to locate the BRT running way along the curb lanes, which is outside the scope of the rail-ready analysis at this stage. The disruption caused by utility relocation should prompt very careful consideration of the trade-offs between fast, lower-cost deployment of BRT against the likelihood of LRT conversion at some time in the next several decades.

Constructability Priorities

Because these systems and infrastructure needed for LRT operation must be constructed and installed in the sequence described above in order to minimize negative impacts during conversion, the priority of construction packages for earliest preinstallation are roughly the same order. In other words, utilities relocation and systems installation are the highest priorities, because they must be installed first. They are followed by station modifications, then aerial structures and, lastly, trackwork.

Even if the additional cost and time needed to convert a running-way that was designed for BRT operations to LRT are merited given the benefits of implementing a rail system, the disruptive effects on affected neighborhoods and the

significant expenditures could jeopardize the project, particularly in urban areas such as San Francisco. These factors should not be underestimated and help explain why no city other than Seattle has ever converted bus infrastructure to light rail operation. Even in Seattle's case—where LRT was long seen as a likely future service— the conversion project has had substantial construction impacts and unforeseen costs, due to rapid technological change.

5. Summary and Findings

A review of other cities' experiences, as well as the Geary-related studies and decisions made to date, indicate that while the consideration BRT to LRT conversion is common, it is rarely realized in practice. No BRT projects have yet been converted to LRT, largely because it remains a new mode of transit service, particularly in the U.S. Though existing operations were not full-featured BRT, the Downtown Seattle Transit Tunnel project currently in progress is illustrative, as it represents the first conversion of a bus transitway to rail service. LRT requirements incorporated into design and construction of BRT projects should, at a minimum, incorporate the structural (loading) and horizontal and vertical geometric needs of LRT. Beyond this and a few other investments, however, the marginal benefits of preinstalling and/or preconstructing additional structures and systems for future LRT alignments are minimal unless all such systems are installed. With this most elaborate level of rail-ready BRT design, however, the project cost would be nearly double the estimates of the needs assessment and the Client's consulting team. These higher costs result in a considerable narrowing of the marginal savings associated with a BRT deployment over an immediate LRT construction on Geary. Further, the more substantial rail-readiness option (Option B) does not include all costs of a conversion. These additional costs include the installation of substations and overhead contact system, signaling, and other systems, as well as the vehicles themselves, which can take three years or more to procure and deliver.

Light rail vehicle type must also be considered. Muni should consider similar floor heights in their BRTVs and LRVs. Vehicles should be chosen so as to minimize the retrofit requirements of the stations. If congruent floor heights are considered, however, other issues would arise, such as the retrofit of maintenance facilities to accommodate these vehicles.

Perhaps even more significant than additional costs and time associated with future LRT conversion, the political and neighborhood effects of such a conversion would be significant, particularly in as cosmopolitan and varied a corridor as Geary. This analysis also a scenario of rail-readiness that is intermediate to the staff GCAC memo's two definitions. This middle approach would entail more than $22 million in additional expenditure over the most expensive center-running BRT design and could be performed with minimal additional disruption of traffic over the Option A definition. The Option B definition, however, would entail $114 million in additional expenditure over the most expensive center-running BRT design and would add perhaps another year to the construction schedule, largely due to utility relocation.

Because of these issues, as well as the desire to realize the significant transit service improvements, ridership gains, and neighborhood benefits associated with BRT alone, this analysis recommends that the Study team opt for the less extensive definition of rail-readiness (Option A as adopted by the GCAC) in its design approach.

Appendix I. Rail Ready/Convertibility Cost Comparisons

Description of Incremental Improvement	Option A	Mid-Range	Option B
Design for Horz and vertical geometry	$500,000	$750,000	$750,000
Additional pavement structural section depth	0	$3,000,000	$15,000,000
Utility relocation under Transitway (see detail next tab)	$0	$0	$15,903,360
Related maintenance of traffic	$0	$0	$5,000,000
Duct Bank	$0	$5,808,000	$5,808,000
Manholes	$0	$89,872	$89,872
Hand holes, Junction Boxes, Pull boxes	$0	$168,960	$168,960
Rail installation	0	0	$11,616,000
Special trackwork (turnouts etc.)		0	$2,800,000
Track Drainage (underdrains 10" dia)	0	$1,500,000	$3,590,400
Corrosion protection bonding/grounding	0	$0	$1,056,000
TWC loops and system	0	$0	$1,028,000
Modification of traffic signals, recon of side streets for rail upgrade	0	$0	$2,800,000
Contact system Pole foundations only	$0	$1,000,000	$0
Contact system Poles and OCS	$0	$0	$2,956,800
Substations and TES	0	0	$0
Add'l foundation to support LRV Station platform height, 150 ft length	$1,200,000	$1,200,000	$1,200,000
Subtotal	$1,700,000	$13,516,832	$69,767,392
Engineering and Administrative costs (above rail-ready design effort)	$544,000	$4,325,386	$22,325,566
Project Contingency	$544,000	$4,325,386	$22,325,566
Total Additional Cost for Alternative	$2,788,000	$22,167,605	$114,418,523
Pct. Above baseline cost estimate	2.4%	19.1%	98.6%

Appendix II. Rail Ready/Convertibility Decision Matrix

Description of Incremental Improvement	BRT	LRT	DMU```````
Design for horizontal and vertical geometries	23' -0" width / 12% max grade	26'-0" width / 5% max grade	26'-0" width / 5% max grade
Additional pavement structural section depth	20 inches (8-inch PCC over 12-inch Agg base)	26 inches	26 inches
Utility relocation under running-way	$50 per route ft. (RF)	$340 per RF SS	$340 per RF SS
Duct Bank	none	$140 per RF	$0
Handholes, junction boxes, pull boxes	none	pending	pending
Embedded Rail, special trackwork &rail fastening system	none	$275 per RF	$275 per RF
Track Drainage (underdrains 10" dia)	N/A	$85 per RF	$85 per RF
Corrosion protection bonding/grounding	none	$25 per RF	
TWC loops and system	pending	pending	Pending
Contact system pole foundations only	none	$52 per RF	
Contact system poles and OCS	None	$140 per RF	
Substations and TES (1.5 meg every route mile includes architecture)	N/A	$10-15 million	
Additional Station platform height (33 in) and length (180 ft)	N/A as currently designed	$20,000 per RF	$20,000 per RF

Appendix III. References

"Convertible Transit," Railway Age, August 2005.

Kirschbaum J through Chang T, "ACTION – Adopt a Motion to Approve the Proposed Approach to the Concept of Rail-Ready Design in the Geary BRT Study and the Proposed Q&A Language," memorandum to the Geary Citizens Advisory Committee, February 18, 2005.

Metropolitan Transit Authority of Harris County (Houston Metro), FY2006 Quarterly Financial & Management Report, Third Quarter Ending June 30, 2006

Metropolitan Transit Authority of Harris County (Houston Metro), Request for Proposals, Industry Review draft, for Package No. 1 – Guided Rapid Transit (GRT) Corridors Facility Provider, Book 1: Instructions to Proposers (RFP No. RP0600029), July 2007.

Parsons Brinckerhoff Quade & Douglas, Inc., Sound Transit Long-Range Plan Update, Issue Paper No.5: Convertibility of BRT to Light Rail, prepared for Sound Transit, March 2005

Sallee R., "Metro Told Using Buses Over Rail Hurts Credibility," Houston Chronicle, June 28, 2005.

San Francisco County Transportation Authority, Geary Corridor Bus Rapid Transit Design Principles & Guidelines, Approved by Geary Citizens Advisory Committee, December 1, 2006

Wood E., Shelton D.S. and Shelden M., Designing BRT for LRT Convertability: An Introduction for Planners and Decision-Makers," presented at the Annual Meeting of the Transportation Research Board, Washington DC, final version November 2005.