

**CORE CAPACITY
TRANSIT STUDY**



MEMORANDUM

To: Matt Maloney (MTC)

CC: Aidan Hughes

From: Lauren Dong

Date: November 6, 2015

Title: Core Capacity Transit Study Task 4 – Initial Engineering Studies

1 Introduction

This memorandum presents the initial engineering study that supports the Core Capacity Transit Study (CCTS). This memorandum delivers the scope of services identified in Task Order #2 (dated May 2015), Task 4, Initial Engineering Studies. The studies are focused on the following:

- review of potential tunnel crossing landing locations and corridors for a second transit crossing of San Francisco Bay
- review of potential tunneling techniques and technologies to evaluate the following
 - risk profiles of each technology including construction impacts, constructability, permitting and regulatory environment and geotechnical conditions
 - opportunity to combine modes in a single tunnel technology versus constructing separate tunnels for transit and rail services

The engineering studies are intended to inform the CCTS recommendations. In particular, they will help in identifying “red flags” or constraints associated with proposed Bay crossings. They will also provide a guide to assist in the evaluation of the CCTS alternative packages of improvements. The engineering studies do not include conclusions or make recommendations on where, whether and/or when a second crossing should be constructed.

For the purposes of this analysis, the studies include an assessment of the implications of crossing configurations that could accommodate either a BART crossing or a passenger rail service, or both. This memorandum primarily looks at the physical landing sites and Bay crossing engineering considerations with limited consideration of system operational issues as noted.

2 Memorandum Outline

After this introduction section, this technical memorandum presents the following:

- Summary of the outreach efforts in Section 4
- Evaluation of potential corridor alignments and landing zones in Section 5
- Evaluation of the tunneling technologies available for a Bay crossing in Section 6

Appendix A contains the following study analysis details:

- Alignment design
- Geology, seismicity, and geotechnical conditions
- Permitting and regulatory environment
- Environmental engineering concerns
- References used in development of the analyses

3 Assumptions and Limitations

The data review, engineering studies, cost estimates, and permitting risk evaluation are preliminary and examine a large review area encompassing over 30 square miles. The evaluation is not a feasibility study level of any specific alignment. It is meant to provide qualitative information that can be used by planners and stakeholder agencies to make considerations for future studies of more specific corridors and alignments.

Other clarifications and exclusions are as follow:

- Environmental screening: These high-level studies are focused on major risks associated with known contaminated materials, permitting, and potential disposal costs. They do not include a level of environmental screening associated with a CEQA/NEPA screening assessment.
- System connections: Only the Bay crossing segment of any rail or BART crossing is considered. BART or passenger rail operational and network issues associated with various landings are not analyzed, nor related issues of vehicle storage or maintenance. System connections will be considered in later tasks as appropriate.
- Building foundations: Known foundation depths in downtown San Francisco, along the San Francisco Seawall, in Mission Bay, and under AT&T Park were considered as major limitations of rail landing points and geometry. In general, it was assumed that most modern mid- or high-rise construction in downtown San Francisco and Mission Bay are on piles of variable depth; and up to 200 feet in Mission Bay.
- Existing utilities: Major combined sewer collection systems and outfalls were considered as constraints as these are difficult or impractical to relocate. Other smaller utilities, including water mains, gas mains, fire water, auxiliary water storage systems, electrical and communications were not analyzed in detail.
- Tunnel cross-sections: The main purpose of developing cross-sections in this Task was to develop the differential costs associated with immersed tube tunnel (ITT) or mined tunnel technologies. Interior configurations of two-track/four-track ITTs and mined tunnels are schematic only and don't indicate all of the egress, utility, maintenance, and ventilation corridors in detail that may be required in detailed design.
- Alignments: The alignments presented in this memorandum were drawn as potential alignments that connect landings and facilitate a cost comparison of tunnel technology. The alignments do not represent the only possible alignments between landings.

4 Agency Outreach

4.1 BART

The CCTS team was briefed by BART engineering and operational staff about the performance and conditions of the existing Transbay Tube. In addition, as noted above, the team received detailed notes from BART on their concerns and observations on mined tunnel and immersed tube potential crossings, as well as rough sketches of potential crossing scenarios.

4.2 Caltrain

The CCTS team met with Caltrain staff to discuss the study and the consideration of a passenger rail crossing of the transbay corridor. It was noted by Caltrain staff that this service would need to be compatible with the Downtown Extension (DTX) connection and serve the Transbay Transit Center (TTC). [GJ1][MW2]The Peninsula Corridor Joint Powers Board does not have any current plans or the authority to operate transbay rail service outside of their current three county jurisdictional limits.

4.3 California High-Speed Rail Authority

The CCTS team met with the California High-Speed Rail Authority staff from the Northern California region to discuss the study and the consideration of a passenger rail crossing of the transbay corridor. The California High-Speed Rail Authority noted that they are supporting a blended use concept for the peninsula, the current electrification project, and DTX as environmentally cleared.

4.4 Transbay Joint Powers Authority

The CCTS team met with Transbay Joint Powers Authority (TJPA) staff to discuss the study and the consideration of a passenger rail crossing of the transbay corridor. The TJPA noted that they are supporting a blended use concept for the peninsula, the current electrification project, and DTX as environmentally cleared. The latest sketches of East Bay extensions done in 2014 by the TJPA's DTX consultants were discussed. The sketches indicate the need for alignments to follow Steuart Street southward to the Embarcadero to make a practical East Bay extension, acknowledging the significant associated right-of-way acquisition.

5 Landings, Corridors, and Alignments Evaluation

5.1 Landings

5.1.1 Evaluation Criteria

Five qualitative landing criteria have been used to evaluate the potential landing sites in San Francisco and the East Bay. These criteria were selected from a list of over ten categories relating to alignment geometry, alignment depth, transition structure location, and environmental, constructability, and utility conflict risks. The major evaluation terms are as follows:

- Rail geometry and connectivity (BART/rail): This criterion reflects the ability of the landing site to accommodate and meet BART or rail horizontal or vertical alignment requirements. Geometric constraints restrict the viability of some landing sites for rail connections to the Downtown Extension (DTX) at 4th and Townsend/King or alternate DTX alignments in Mission Bay. Vertical geometry also limits the ability of some connections to be made to the east end of the TTC rail box.

- **Geotechnical conditions:** These were reviewed extensively by the team based on available data and risks associated with conditions noted. Poor conditions can be mitigated but generally add to constructability risks and costs. Liquefaction hazard zones in areas of fill and steep profiles of young Bay mud are considered poor conditions. All San Francisco landing sites considered fall within the Maher Zone, indicating the potential for encountering environmental contamination during excavation activities.
- **Environmental risks:** This criterion considers broad risks associated with environmental hazards, permitting risks, and some typical risks considered as part of a CEQA/NEPA process (4f parklands, cultural, biological). Note that this evaluation was a high-level evaluation of known environmental hazards, not a full environmental screening. Parklands on the San Francisco and East Bay shorelines are considered and noted. Other known environmental constraints such as tern nesting and wetlands at Alameda Point are considered in landing selections shown. Known contamination sites requiring special treatment, handling, or disposals are noted. Legacy contamination issues in San Francisco, including Maher Zones, and in the East Bay shoreline areas dictate that these risks have a minimum level of “moderate” for all landings on the developed Bay shoreline.
- **Constructability risks:** These are often related to and driven by the geotechnical conditions and tunneling technology used; however, some sites have deeper bay mud and more adjacent structures that could be impacted by settlement or ground movement due to tunnel, shaft, or transition structure construction. This criterion also considers the risks/suitability of construction of an offshore or near-shore transition structure.
- **Construction impacts:** The impacts of building major launching/receiving shafts, transition structures, hauling extensive spoils or other required activities at the landing location are considered based on the impacts to existing residential, commercial, or industrial use. Specifically, narrow landside right-of-way corridors, extensive utilities, and sensitive adjacent structures add to these risks.

5.1.2 San Francisco Landings

San Francisco landings include sites from Pier 33 to Pier 70. One feature common to each landing site is the presence of the San Francisco Seawall, which must be considered for depth of alignment and construction impacts. In detail, the San Francisco landings considered in this study for a BART and/or standard passenger rail are as follows:

- **Northern Waterfront:** Pier 33 to the Ferry Building. Rail geometry restrictions through street grid of the Financial District reduce the potential for many landings in this area. The Pier 23 location was considered most viable for a north-south BART connection through the Financial District; however, the adjacent cruise ship terminal at Pier 27 would have to be avoided and this could make an immersed tube tunnel impractical. North-south rail alignments will not be able to tie-into the TTC, so are not considered.
The landing in this area is SF-1.
- **Ferry Building to Pier 14:** The primary SOMA streets (Mission, Howard, Folsom) running east-west through the southern downtown core have been considered in numerous planning studies and conceptual layouts. These landings involve poor geotechnical conditions, high construction impacts, and constructability risks. Muni Metro Turnback, historic buildings, major sewers, Central Subway, and future DTX tunnels are other challenges of these landings and corridors. New BART tunnels could be constructed below the Bay Mud, but would be approximately 150 feet deep at their approach. Any east-west rail alignment directly to the TTC would likely require construction of mined tunnels in the young bay mud layer, which adds significantly to construction risks.
Landings in this area are SF-2, SF-3, and SF-4.

- Pier 30-32: The southern SOMA waterfront offers some possible shoreline staging areas, especially at Pier 30-32. Construction could be coordinated with existing pier and piling removal and restoration could integrate vent structures. The geotechnical conditions are mixed, but generally more favorable than the SF-2 to SF-4 landings. North-South rail alignments along the Embarcadero and Stuart could attain sufficient depth at this point to be below the young Bay mud layer. *The landing in this area is SF-5.*
- Mission Creek/Pier 48: The Mission Creek area is a possible landing site for BART service that runs north-south up 2nd or 3rd Street. 2nd Street is not a practical corridor if the DTX three-track tunnels are built from 2nd and Folsom to 3rd and Townsend. Construction and cost risk are higher for tunneling onshore beneath the heavily developed Transbay District, especially with the planned DTX alignments, piles under AT&T Park and the new development planned for Mission Rock.
The landing in this area is SF-6.
- Pier 50: Northern Mission Bay: Northern Mission Bay landings have challenges of variable ground conditions, constrained ROW/corridors to the East, and interface with the Mission Rock Development. There is also the existing seawall structure.
Landings in this area are SF-7 and SF-8.
- Pier 54/Central Mission Bay: The central Mission Bay area offers wider east-west corridors and more consistent ground conditions, although construction impacts and shoreline parks. The new Warriors development could be integrated with the Mission Bay Commons and 16th Street options.
The landings in this area are SF-9 and SF-10.
- Pier 70: The Pier 70 area has known hazardous sediments that would increase construction and permitting risks, as well as material handling and disposal costs. The coastal young Bay mud deposits transition to more competent hard clays and rocks westward of the shoreline, so TBM mining could continue for shoreline transition structures. The area would support immersed tunnel or mined tunnel landings. Nearby environmental contaminant plume makes this landing less favorable.
The landing in this area is SF-11.

5.1.3 East Bay Landings

The landings considered in the East Bay are in the Port of Oakland and Alameda Naval Air Station shoreline. In detail, the East Bay landings considered are as follow:

- Port of Oakland: These sites are on Port of Oakland property located in the Outer Harbor and Middle Harbor. These areas could require ground improvement of the hydraulically placed fill and Bay mud layers.
The landings in this area are OAK-1 and OAK-2.
- Alameda Point: These landings are at the west end of Alameda Point are the site of the former Naval Air Station. These areas could require ground improvement of the hydraulically placed fill and Bay mud layers
The landings in this area are ALA-A, ALA-B, and ALA-C.
- Emeryville: An additional landing was considered at Emeryville Marina as it has been shown as a potential landing area in concepts by BART.
The landing in this area is identified as EMY-1.

5.1.4 Evaluation Findings

Figure 1 shows the landings described above. Table 1 presents the evaluation for each landing. The evaluation shows the most promising landings in San Francisco are SF-3, SF-5, SF-8, and

SF-10. In the East Bay, the promising landings are OAK-2, ALA-B, and ALA-C. In summary, the evaluation findings are as follow:

- The BART and rail, horizontal and vertical alignment geometric requirements reduce the viability of some landings by depth or tight curves.
- Many landing sites are possible on both sides of the Bay, though some show clear advantages for construction impacts and conflicts with existing or planned infrastructure.
- Geotechnical conditions vary in San Francisco with young Bay mud requiring ground improvement for transition structures, or good founding conditions on rock.
- Young Bay mud is generally a thinner stratum in the East Bay and landing structures can be founded in more competent soil below; however, near-surface fill soils are problematic in seismic conditions.
- The San Francisco Seawall must be considered for all landings in San Francisco.
- The Alameda Naval Air Station landings have significant construction staging advantages over the Port of Oakland or Emeryville landings.
- Environmental impact and environmental contamination considerations are deemed moderate for all landings locations in San Francisco and the East Bay, with the exception of Pier 70, which is deemed a high risk for its known history of contamination.
- Landing sites at the Port of Oakland Outer Harbor or Middle Harbor would provide for BART to tie-in to the existing system west of the Oakland Wye. Rail alignments that tie-in to the Union Pacific mainline and Amtrak/Capitol Corridor between Jack London Square and Emeryville are favorable with these locations.
- Port of Oakland landings would be constrained by existing Port of Oakland operations, especially in the Middle Harbor area. The impacts would be limited to port operations and industrial activities only, and have a small or no effect on residential or commercial stakeholders. Environmental mitigation could be necessary for the impacts of middle harbor landing sites on existing shoreline parks.
- The Alameda Point landings must consider the potential for reuse and development of some of the lands east of the existing tarmacs and runways.



Figure 1. Potential landings considered in San Francisco, Emeryville, Oakland, and Alameda.

5.2 Corridor Summary

The most promising landings can be grouped into north, central, and south corridors connecting San Francisco and Oakland as shown on Figure 2. When considered by corridor, further findings from the landings evaluation include the following:

- Considering the geometry needed to connect to the environmentally cleared DTX alignments, landings for rail crossings are possible only in the central corridor.
- In the central corridor in Alameda, the southerly landing is more promising as it provides more alignment options for BART and rail connections to existing infrastructure
- A second BART crossing in the northern corridor connecting into the Market Street Core would use less promising landings.
- The south corridor provides more promising landings for BART via SF-8 and SF-10 than the central (SF-5) and north (SF-3) corridor landings.
- The south corridor landings in Alameda Point create some of the shortest water crossings of the Bay, allow for low-impact construction staging, and have adequate landside space to construct necessary crossovers underground. There may be lower costs of dredge spoils disposal because of the thinner deposits of young Bay mud in this corridor.

5.3 Alignments Summary

From the promising landing locations, six alignments were drawn as shown on Figure 2 for the purposes of comparing the tunnel technologies. For most alignments, a mined tunnel and an immersed tube tunnel option were considered viable, unless noted. The following bullets summarize the alignments' key characteristics:

- BART 1: This alignment alternative is a BART-only connecting landing SF-3 (Mission Street) meeting the Port of Oakland Middle Harbor landing OAK-2.
- BART 2: This alignment alternative was considered to avoid deep deposits of young Bay mud and uses larger curve radii to connect landing SF-5 with ALA-B.
- BART 3: This alternative connects landing SF-8 in Mission Bay with ALA-B. SF-8 is in close proximity to Mission Bay development and AT&T Park.
- BART 4: This alternative connects landing SF-10 with ALA-C. While the SF-10 landing is in close proximity to the proposed sporting facilities and the UCSF Children's Hospital, onshore construction impacts could be significant.
- Rail 1: This alternative connects the downtown TTC via landing SF-5 and ALA-B. It facilitates rail connections to the Oakland rail infrastructure and DTX.
- BART & Rail Combined: These alignments connect SF-5 to ALA-B.

Further detail regarding the design of these alignments, including vertical alignment cross-sections, is included in Appendix A.

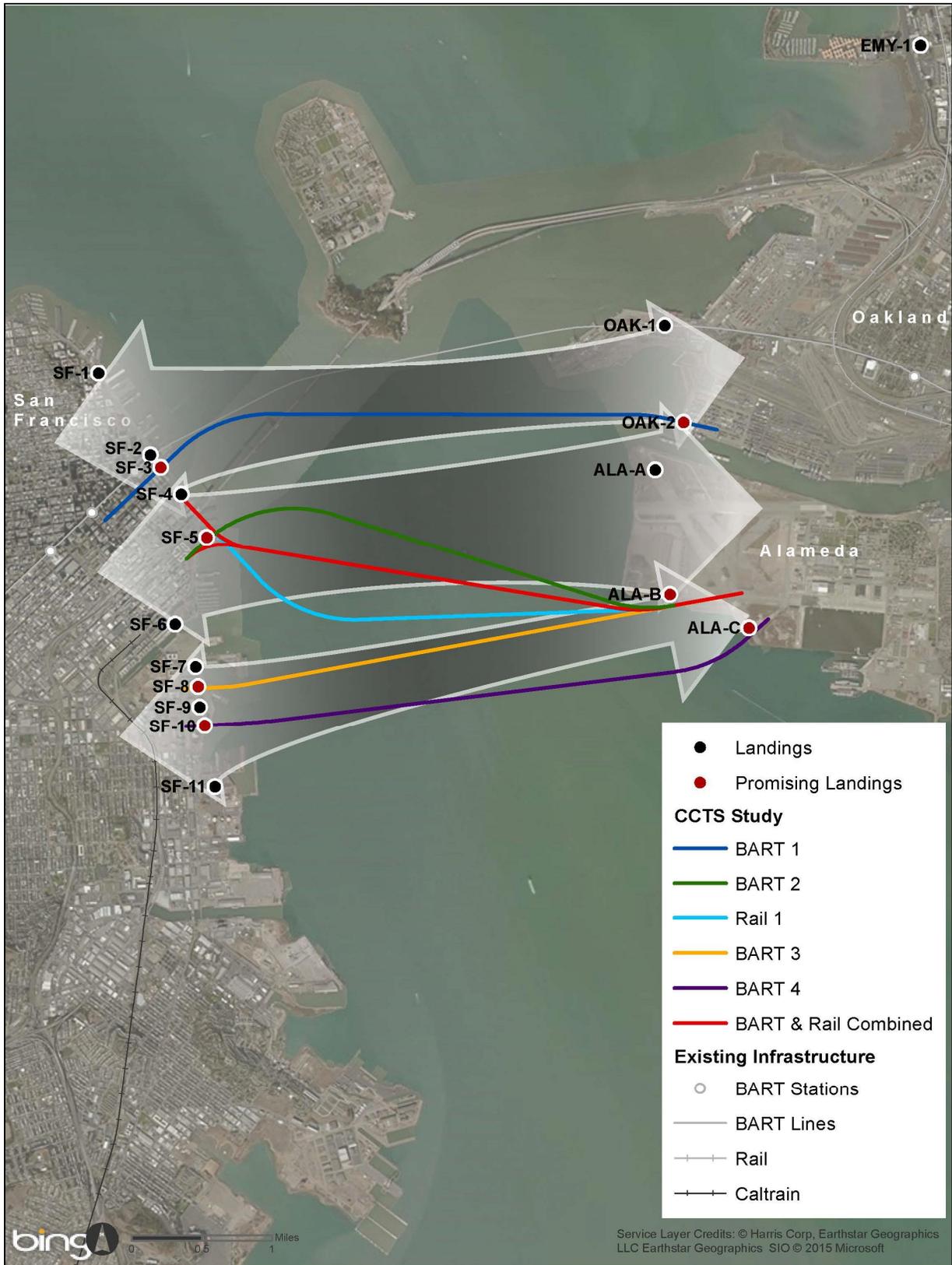


Figure 2. North, central, and south corridors with considered alignments connecting promising landings.

6 Tunnel Technology

For the length of the Bay crossing and depth of the Bay, two tunnel technologies are feasible described herein as a mined tunnel and an immersed tube tunnel (ITT).

A mined tunnel Bay crossing would employ a tunnel boring machine (TBM) that is launched on land from an excavated launch pit (likely in the East Bay) and remains deep below the Bay floor. A TBM can mine through varying stratigraphy, though it requires between one and two tunnel diameters of soil coverage to provide sufficient confinement and reduce tunneling risk. The TBM is typically retrieved on land in an excavated retrieval pit. Because of the diameter of tunnel required to house both BART and conventional rail in one tunnel, and the required alignment depth for TBM coverage, two tunnels (one for each mode) are more practical than one large tunnel.

Modern ITTs are often cost-effective for shorter crossings of shallow water bodies as they are constructed on-land and can be either steel or concrete (frequently with steel connections). The current BART crossing is an immersed tube. Dredging would be required for a new Bay crossing via ITT. Excavated near- or onshore transition structures would receive the ITT and provide launch locations for onshore alignments constructed by mined tunnel machinery. While greater environmental and permitting risks are associated with the ITT, the structure can house both BART and rail tracks without significant alignment modifications.

Appendix A documents the engineering considerations of both technologies, including the regulatory environment associated with construction. The engineering considerations support a cost comparison, which focused only on the relative cost of the tunnel technologies.

6.1 Tunnel Technology Findings

This study has used engineering and planning methods to identify landings and corridors for a new transbay crossing of BART or rail employing either an ITT or mined tunnel construction. North, central, and south corridors were defined from groups of potential landing sites on each side of San Francisco Bay. The promising landings were used as endpoints for alignments, and their subsequent engineering evaluation. The alignments represent examples of potential crossings within corridors that could serve areas within San Francisco and the East Bay.

The findings relating to the tunnel technology of those evaluations are summarized as follow:

- The BART & Rail Combined alignment indicates that a combined alignment connecting the DTX infrastructure and providing BART to southern South of Market is geometrically possible.
- Dredging and disposal of potentially contaminated soils is a large cost driver for ITT construction, and this drives related findings:
 - Mined tunnels produce a lower volume of spoils. Mined tunnels also carry lower environmental and regulatory risk provided that multi-agency coordination is not required and the mining spoils are non-hazardous for disposal.
 - Because of the dredging spoils disposal cost, a two-track ITT (carrying BART or rail) is more costly than a mined tunnel crossing.
 - Because of the dredging spoils disposal cost, a four-track ITT (carrying both modes) is more costly than constructing two mined tunnels separately.

Given the uncertainty in future needs for two modes of transit (BART and rail) crossing San Francisco Bay, the construction now of a four-track ITT provides greater expansion flexibility. However, the cost differences suggest that it would be more prudent and overall less costly to consider two mined tunnel crossings, each carrying a separate mode, than to consider a four-track immersed tube tunnel option. In addition, two separate tubes, each with two tracks, would provide more resiliency to extreme events.

Table 1. Landings Evaluation Summary

ID	Landing		Bay Crossing		Opportunities (+)	Constraints (-)	Geometry ¹		Risk and Performance Measures				Overall Rank
	Location	Description	Mined Tunnel	ITT			BART	Rail	Geotechnical Conditions ¹	Environmental Risk ²	Constructability Risks ²	Construction Impacts ²	
SF-1	NW Waterfront Pier 23-27	North of Bay Bridge/TI to Emeryville Pier 23 landing site BART Option 5 "Northern Tube"	✓	N/A	<ul style="list-style-type: none"> New Access for NW waterfront Accommodates N-S alignments through downtown 	<ul style="list-style-type: none"> Bay and bay mud are deep across navigation channel; ITT crossing impractical Station and mined tunnels would be deep Higher construction risks due to long tunnel length to Emeryville Adjacent to cruise terminal 	Poor	N/A	Poor	Moderate	High	Moderate	
SF-2	Market Street/ Parallel Tube	Build tube/tunnels parallel to existing and tie-into existing system under Market Street using mined tunnel	✓	✓	<ul style="list-style-type: none"> Similar/known ground conditions to existing tube Direct redundancy for Market Street Stations 	<ul style="list-style-type: none"> Connection to existing mainline challenging New transition/construction structures near Ferry building Deep construction on Market Street very high risk/cost Vertical circulation and fire code challenges through existing BART/Muni levels 	Fair	N/A	Fair	Moderate	Very High	Prohibitive	
SF-3	Mission Street	Landing near south end of Ferry Building (1991 Bay Crossing Study Alt. 8)	✓	✓	<ul style="list-style-type: none"> Redundant to Market, existing tube and East Bay service Adjacency/Ped connection to TTC Possible connection west/NW service area via Otis/McCoppin 	<ul style="list-style-type: none"> Connection to existing mainline challenging Very high construction impacts Settlement mitigation high Crosses Central Subway at 4th Street Crosses Muni Metro Turnback at Embarcadero Avoidance of sewer on Mission between 2nd/4th 	Good	N/A	Poor	Moderate	High	Very High	Promising
SF-4	Rincon Park-Pier 14 Howard/Folsom Street	Landing near Pier 14; Rincon Park Waterfront/Promenade	✓	✓	<ul style="list-style-type: none"> Redundancy to Market Street Core Adjacency/tie-in to TTC (Howard) New transfer connection to Central Subway at Moscone 	<ul style="list-style-type: none"> Connections to existing system at CC building interferences Deep alignment/stations; crosses Muni Metro, DTX, Central Subway, Sea Wall Building settlement mitigation High Major Sewer on Howard Street; station construction impacts Landing at Rincon Park (4f review) Mahler Zone impacts may be higher 	Good	N/A	Fair	High	High	High	

ID	Landing		Bay Crossing		Opportunities (+)	Constraints (-)	Geometry ¹		Risk and Performance Measures				Overall Rank
	Location	Description	Mined Tunnel	ITT			BART	Rail	Geotechnical Conditions ¹	Environmental Risk ²	Constructability Risks ²	Construction Impacts ²	
SF-5A	Pier 30-32	Rail Only: Bored Tunnel to transbay with potential split to the DTX Loop	✓	✓	<ul style="list-style-type: none"> No viable existing uses of Pier 30-32 Transition/Vent Structures could be placed in Pier 30-32 footprint Challenging integration with DTX loop from the TTC via Stuart Potential to combine 2-BART, 2 Rail tracks into one Immersed Tube 	<ul style="list-style-type: none"> Challenging integration with DTX loop from the TTC via Stuart Rail tunnel must pass under Seawall and piles after transition structure Construction impacts on Embarcadero Ground improvement required for transition structure 	N/A	Good	Poor	Moderate	Moderate	Moderate	Promising
SF-5B	Pier 30-32	BART Only: E-W towards Brannan Street - N-S up Spear, Main, or Beale across Market (2002 Bay Crossing Study Alt 2)	✓	✓	<ul style="list-style-type: none"> No viable existing uses of Pier 30-32 Transition/Vent Structures could be placed in Pier 30-32 footprint Brannan corridor captures new BART market/service in SOMA 4th and Townsend/King Caltrain Adjacency offers new connection options 	<ul style="list-style-type: none"> Construction impacts on Embarcadero Any E-W BART alignment crosses deep under DTX BART tunnels must pass under seawall and piles after transition structure Ground improvement required for transition structure 	Good	N/A	Poor	Moderate	Moderate	Moderate	Promising
SF-5C	Pier 30-32	Combined Rail/BART Four-Track Immersed Tube	N/A	✓	<ul style="list-style-type: none"> Construction cost reductions by combining 2-BART, 2 Rail tracks into one Immersed Tube No viable existing uses of Pier 30-32 Transition/Vent Structures could be placed in Pier 30-32 footprint 	<ul style="list-style-type: none"> Geometry of BART/Rail convergence is constrained Construction impacts on Embarcadero Rail tunnel must pass under seawall and piles after transition structure Ground improvement required for transition structure Brannan Street BART crosses deep under DTX 	Fair	Fair	Poor	Moderate	Moderate	Moderate	Promising
SF-6	Pier 48 to 3rd St	Transition to N-S 3rd Street alignment via south Mission Creek and Pier 48	✓	N/A	<ul style="list-style-type: none"> Continuous and deep N-S alignment on 3rd Street 1+ block connection to TTC Known ground conditions on 3rd: sands/clays/weak rock New extension to NW SF across Market Street 	<ul style="list-style-type: none"> Variable ground conditions: deep bay mud near Mission Creek/Rock near Pier 50 Construction impacts on Mission Rock development Deep foundations/piles for AT&T, 3rd Street Bridge/Mission Rock constrains geometry Shoreline parklands along mission creek/Mission Rock development N-S BART alignment on 3rd has single point transfer at Market St to existing system 	Poor	N/A	Poor	Moderate	High	High	

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	Location	Description	Mined Tunnel	ITT			BART	Rail	Geotechnical Conditions ¹	Environmental Risk ²	Constructability Risks ²	Construction Impacts ²	
SF-7	Pier 50	BART E-W continuing along Mission Rock Street	✓	X†	<ul style="list-style-type: none"> Rock and comment materials at landing Transition structure near Pier 50 Existing T-Third Station Adjacent Proximity to Caltrain (4th and King/Townsend); Ballpark 	<ul style="list-style-type: none"> Interferences with Building foundations east of Mission Rock Variable ground conditions (rock nearshore, bay mud offshore) Future Mission Rock development Maritime uses of Pier 50 to continue (Interferences) 2300 space garage proposed for Mission Rock/3rd Streets 	Poor	N/A	Poor	Moderate	High	Moderate	
SF-8	Pier 54 North - Mission Bay Blvd/Commons	E-W BART Along Mission Bay Blvd and Commons	✓	✓	<ul style="list-style-type: none"> Wide construction corridor Fewer Utilities Pier 50 for maritime use Existing T-Third Station Adjacent Ventilation or transition structure founded on rock. 	<ul style="list-style-type: none"> Deep Bay Mud (>100') on land side Mined tunnel conditions proceed from Bay soils to rock and into softer Bay Mud 	Very Good	N/A	Good	Moderate	Moderate	Low - Moderate	Promising
SF-9	Pier 54 South - South Street	E-W BART Along South Street and Gene Friend Way	✓	✓	<ul style="list-style-type: none"> Fewer utilities than 16th St Better anticipated ground conditions (rock/soil) than Mission Bay Commons Central Mission Bay location Existing T-Third Station at surface 	<ul style="list-style-type: none"> Narrow Street ROW (65') Connection to the west has foundation constraints on geometry 	Fair	N/A	Fair	Moderate	Moderate	Moderate	
SF-10	16th Street/Terry Francois Blvd	E-W BART Along 16th St	✓	✓	<ul style="list-style-type: none"> Better and most consistent ground conditions Wide ROW on 16th Street Central Mission Bay location Proximity to UCSF Hospital (links to East Bay hospitals) 	<ul style="list-style-type: none"> Construction impacts; UCSF Children's Hospital Shoreline Parks (4f) Major Utilities on 16th Street Disruption to adjacent UCSF Children's Hospital 	Very Good	N/A	Fair	Moderate	Moderate	Moderate	
SF-11	Pier 70	20th St or 22nd Street E-W	✓	✓	<ul style="list-style-type: none"> Consistent ground conditions bayside/excellent ground conditions landside (hard clays/rock) Could be integrated with Pier 70 development 	<ul style="list-style-type: none"> Known Contamination Issues with Sediment Narrow E-W Street ROW Land transfers from the Port Interferences with ongoing Port Ops 	Fair	N/A	Fair	Very High	Moderate	Moderate	
EMY-1	Northern Tube Landing	BART only; Emeryville Marina landing E-W towards Powell St	✓	X†	<ul style="list-style-type: none"> Shallow Bay landing/transition structure Emeryville Marina staging area has moderate impacts New service to Emeryville and SF 	<ul style="list-style-type: none"> Crosses deeper channel near SF Longer crossing under Bay (2 miles) Poor operational redundancy to core BART system 	Good	N/A	Good	Moderate	Low	Moderate	

ID	Landing		Bay Crossing		Opportunities (+)	Constraints (-)	Geometry ¹		Risk and Performance Measures				Overall Rank
	Location	Description	Mined Tunnel	ITT			BART	Rail	Geotechnical Conditions ¹	Environmental Risk ²	Constructability Risks ²	Construction Impacts ²	
OAK-1	Outer Harbor	Port of Oakland (near existing BART Portal) - possible Mission Street corridor	✓	N/A	<ul style="list-style-type: none"> potential East Bay landing for 'paralle' alignments to Market-Mission-Howard Streets 	<ul style="list-style-type: none"> access through Port limited Immersed Tube likely not feasible Relies on BART capacity through wye structure in downtown Oakland 	Good	Poor	Poor	High	Moderate	High	
OAK-2	Middle Harbor	Port of Oakland, near Shoreline Park	✓	X†	<ul style="list-style-type: none"> potential landing for redundant alignments to Market-Folsom Streets proximity to a potential connection to rail 	<ul style="list-style-type: none"> access through Port limited Existing parklands at landings Immersed Tube Transition structure locations limited transition structures/crossover area limited within port operations 	Fair	Good	Poor	High	Moderate	High	
ALA-A	NW Corner Alameda NAS	Similar to Oak-2, but on north side of Naval Air Station, allows for immersed tube.	✓	✓	<ul style="list-style-type: none"> Best alignment for Rail towards Emeryville 	<ul style="list-style-type: none"> requires tightest BART curves to transition to downtown Oakland or I-980 alignments Alameda NAS soils are potentially liquefiable and compressible 	Fair	Good	Poor	Moderate	Low	Moderate	
ALA-B	West/SW Alameda NAS	Potential landing facilitating alignments through Naval Air Station	✓	✓	<ul style="list-style-type: none"> Allows for transition crossovers to be excavated in existing NAS airfield footprint Best geometry to Oakland (I-980, downtown, south) 	<ul style="list-style-type: none"> Adjacent to identified biological resources (Tern nesting) Alameda NAS soils are potentially liquefiable and compressible 	Very Good	Fair	Poor	Moderate	Low	Low	
ALA-C	South Central/Alameda NAS	Potential landing facilitating alignments through Naval Air Station	✓	✓	<ul style="list-style-type: none"> Shallow bay muds reduce disposal costs for ITT adjacent to Seaplane basin that could be used for muck disposal transport Good geometry to Oakland (I-980, downtown, south) 	<ul style="list-style-type: none"> Wetlands Adjacent contaminated sediment disposal less vacant land available for junction/crossovers to Oakland Alameda NAS soils are potentially liquefiable and compressible 	Good	Fair	Fair	Moderate	Low	Low	

¹ Geometry and geotechnical conditions were rated qualitatively poor, fair, good, and very good. Poor is the worst rank, and very good is the best rank.
² Environmental risk, constructability risk, and construction impacts were rated qualitatively prohibitive, very high, high, moderate, and low. Prohibitive is the worst rank and low is the best rank.
† Determined to be infeasible from the constraints.

Appendix A – Engineering Methodology, Environmental Engineering, and Permitting