SPUR SAN FRANCISCO PLANNING + URBAN RESEARCH ASSOCIATION

AFTER THE DISASTER:
REBUILDING OUR TRANSPORTATION INFRASTRUCTURE

SPUR REPORT

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INTRODUCTION

The next major earthquake that hits the Bay Area will wreak havoc on our transportation systems. Transit lines will collapse and rail tracks will be broken. Transbay road, rail and public transit links will be disrupted. Highways and surface streets will be closed by the failure of pavement and the accumulation of debris. Power system failures will immobilize electric-powered transit, including BART and Muni. Maintenance facilities such as yards and garages will be damaged. Airport runways will be rendered unusable. Even worse, damage to the transportation network will limit the ability of firefighters, public safety officers, utility workers, debris removal teams and medical personnel to travel where they are needed.

This paper is part of SPUR's *After the Disaster* work. It focuses on one essential component of our infrastructure – transportation – and proposes a plan to rebuild quickly and effectively after the disaster, while increasing our resiliency in the process.

The scope of this paper is limited in the following four important ways:

1. It only addresses the physical infrastructure of our transportation system – it does not address the human resources needed to operate and manage our transportation infrastructure.
2. It does not include a financial analysis of what it would cost to both retrofit our transportation infrastructure before the disaster and rebuilding our transportation infrastructure after the disaster.
3. It does not include a socio-economic analysis to determine where the most vulnerable populations are within our region and how to serve those populations in both the near and long term rebuilding process.
4. It does not address freight movement.

Much depends on getting the transportation aspects of our disaster planning work right. Failure to plan for the recovery of our transportation systems after an earthquake likely will create a number of problems:

- out-migration of workforce and jobs
- delays in the restoration of infrastructure caused by lengthy regulatory and contractual processes
- debate over the allocation of recovery funds
- protracted fuel and water shortages and increased delivery costs
- constrained transportation access to and from the region
- loss of overall regional competitiveness
- politicization of restoration projects

SPUR believes that San Francisco's resiliency relies on the redundancy of our transportation network. When one piece of infrastructure in a transportation corridor fails, there must be another way to get people and goods where they need to go. This paper focuses on the transportation network – the bridges, tunnels, rails, vessels and roadways – that serve San Francisco. We analyze the corridors that connect the city to the surrounding region, as well as the transportation network within San Francisco.

SPUR'S RESILIENT CITY INITIATIVE

Before the Disaster
Our Before the Disaster work has focused on key questions related to disaster planning. What do we need to be doing now to make sure that our built environment can recover quickly from a major earthquake? Which existing buildings need to be retrofitted, and to what standard of performance? How do we encourage better performance from new buildings? How do we strengthen our lifelines so that our buildings are serviceable after an earthquake? SPUR addresses these and other questions in four Before the Disaster papers published in the February 2009 edition of the *Urbanist*.

Disaster Response
Disaster Response focuses on activities during the days and weeks following a catastrophic event, including damage assessment, ensuring the safety of responders, communications and control, evacuation, public health and safety and restoration of vital systems. SPUR has recently completed a paper on the culture of preparedness, which focuses on disaster planning and preparedness in San Francisco's neighborhoods.

After the Disaster
Our After the Disaster task force is asking several key questions: After a catastrophe, are we prepared to rebuild our city to a state even better than it was before? What plans and systems of governance does San Francisco need if it is to be effectively positioned to rebuild? What lessons can be learned from recovery experiences in lower Manhattan, New Orleans, Haiti, Chile, China and beyond? This task force will be working to complete major papers on long-term recovery, covering the topics of transportation, governance, planning and housing.

SAN FRANCISCO'S TRANSPORTATION INFRASTRUCTURE AND ITS VULNERABILITIES

The City of San Francisco and the entire San Francisco Bay Area are vulnerable to natural disasters, particularly earthquakes. While other disasters, such as fires, industrial accidents, landslides, tsunamis and acts of terrorism are also possible, a major earthquake is the most likely event for which our regional emergency planning prepares.

Among the many faults that cleave Northern California, the Hayward and San Andreas faults pose the greatest threats. The 1906 earthquake and fire was the "Big One" of the 20th century, caused by movement on the San Andreas Fault and exacerbated by the vulnerabilities of the City's utility infrastructure and buildings. The 1906 earthquake is estimated to have measured 7.9 on the moment magnitude scale – a scale seismologists use to measure the energy released by an earthquake, instead of the Richter scale more commonly known among the general public. Together, the earthquake and the consequent fire destroyed three-quarters of the city[1] – more than 500 square blocks – and are estimated to have claimed 3,000 lives. The 1989 Loma Prieta earthquake was also caused by movement along the San Andreas Fault measuring 6.9 on the moment magnitude scale. While effects on transportation facilities were localized, some of the necessary restoration has yet to be completed[2] – more than two decades after the event.

It is assumed that the next big earthquake will be more intense than the 1989 Loma Prieta event, and could easily sever transportation links to the north, east or south. It is impossible to predict which links will break, but it is possible to envision a break in each link and to prepare for those events.

DESIGNING LIFELINES TO PERFORM IN THE EXPECTED EARTHQUAKE, PLANNING TO RECOVER FROM THE EXTREME EARTHQUAKE.

SPUR's Resilient City effort pegs performance goals for all the major "lifelines" (vital transportation systems and other infrastructure) to the "expected earthquake"– that is, the seismic event that is likely to happen within the lifetime of the infrastructure. SPUR's "Before the Disaster" seismic performance goals are stated in terms of general states of damage and repair over an extended recovery period, under the assumption that an expected earthquake has occurred. We chose the expected quake rather than the extreme earthquake because it is a major event that can reasonably be expected to occur once during the useful life of a structure or lifeline system. However, for purposes of planning for actions that should be taken restore transportation systems following an earthquake, a more extreme earthquake should be considered to ensure that preparations are sufficient for San Francisco to recover from a potentially much greater earthquake. Additionally, because earthquakes on different faults will likely have different effects on transportation systems around the region, the effects of different earthquakes should be considered.

In our Before the Disaster work, in which we examined the performance of buildings in San Francisco, we defined the expected earthquake as one measuring 7.2 on the moment magnitude scale, occurring on the San Andreas Fault somewhere on the San Francisco Peninsula. We also defined the extreme earthquake for San Francisco as one of magnitude 7.9 on the San Andreas Fault, also on the Peninsula (i.e., a reprise of the 1906 earthquake). While this earthquake would have a severe impact on transportation systems in San Francisco and on the Peninsula, a similar event on the Hayward Fault could more severely debilitate transportation for the entire Bay Area. Some of the region's most important transportation features – including BART, Interstates 80 and 580, and State Route 24, all of which are vital links within the region and to neighboring regions – cross or lie immediately adjacent to the Hayward Fault.[3] The extreme earthquake on the Hayward Fault would rupture both the northern and southern segments of the fault in a seismic event measuring 7.0 on the moment magnitude scale.[4] This report considers extreme events on both the San Andreas and Hayward faults, each of which would severely compromise our regional transportation infrastructure.

THE EFFECTS OF THE 1989 LOMA PRIETA EARTHQUAKE ON THE BAY AREA'S TRANSPORTATION SYSTEM

While the effects of the Loma Prieta earthquake were minor in comparison with those of recent earthquakes (for example, the 2010 earthquakes in Haiti, Chile, China and the Baja California region of Mexico), it still had a substantial impact on the Bay Area's transportation system.

- **Bay Area Rapid Transit:** The BART rail system, including the Transbay Tube, was virtually undamaged and closed only for post-earthquake inspection. As one of the few means of transbay access into San Francisco in the days following the earthquake, daily ridership increased by 90,000, a roughly 50 percent jump, in the week after the earthquake (from 218,000 to 342,000). Today, ridership is at the post - Loma Prieta level of 342,000[5] passengers per day, which means there is less flexibility in the system to accommodate the spike in trips that would occur after a major disaster. If transbay demand increased by a similar proportion, the BART ridership would spike from 342,000 to over 500,000 daily riders. If gas prices and transit ridership both continue to rise, daily BART ridership will likely exceed the high of 374,000 average daily riders that was reached in July to September 2008 prior to the economic contraction.
- **San Francisco-Oakland Bay Bridge, Interstate 80:** The Bay Bridge was repaired and reopened to traffic in just one month. However, the earthquake made it clear that the Bay Bridge, like many of California's toll bridges, required major repair or replacement, for long-term viability and safety. The replacement of the eastern span of the Bay Bridge has been in planning, design and construction for two decades, and still is not complete.
- **Cypress Structure, Interstate Freeway 880:** The Cypress Structure, a 1.6-mile long, bi-level elevated freeway constructed of reinforced concrete with four lanes on each deck, collapsed

between the MacArthur Maze (the convergence of Interstate Highways 80, 580 and 880 east of the San Francisco-Oakland Bay Bridge) and 16th Street in Oakland, claiming 42 lives. Completed in 1997, a single-level elevated freeway structure around West Oakland replaced the Cypress Structure, enabling the neighborhood previously divided by the freeway to be re-unified.

- **Central Freeway, U.S. Highway 101:** San Francisco's Central Freeway (part of U.S. Highway 101 and a link to the Bay Bridge skyway) was another concrete double-deck structure. It did not collapse, but was ultimately torn down. Originally terminating at Franklin Street and Golden Gate Avenue near San Francisco's Civic Center, the section past Fell Street was demolished first, followed by the section between Mission and Fell streets. The section from Mission Street to Market Street was rebuilt (completed September 2005) as a single-deck elevated freeway. The remainder was replaced as a surface boulevard on Octavia Street.
- **Transbay ferries:** Ferry service between San Francisco and various points in the East Bay (Oakland, Richmond, Berkeley, Alameda, etc.), was expanded and invigorated during the month-long closure of the Bay Bridge, as an alternative to the overcrowded BART transbay services. The Vallejo Baylink ferry service, started in 1986, saw a big increase in ridership during Loma Prieta earthquake recovery. Within one week after the earthquake, three vessels were put into operation between Vallejo and San Francisco. The passenger-only ferry services maintained their popularity after the earthquake and are a mainstay of the North Bay commute market.
- In the immediate aftermath of the 1989 San Francisco earthquake, Red and White Fleet provided free transportation to 15,000 stranded commuters and initiated new services to Richmond and Oakland with an expanded fleet of ferries borrowed from operations outside the Bay Area.
- **Embarcadero Freeway, state Route 480:** The earthquake forced the closure of San Francisco's largely unloved Embarcadero Freeway (state Route 480). It was replaced with a surface boulevard with a dedicated right of way for Muni, opening up San Francisco's eastern waterfront to public access.
- **Southern Embarcadero Freeway, Interstate 280:** Seismic damage also led to the long-term closure of Interstate Highway 280 in San Francisco (north of Highway 101), another concrete freeway. The highway, which has double-deck segments, remained closed for seven years as restoration plans were debated, delayed and finally implemented. The City is considering, as part of the high-speed rail system, pulling the freeway south to Cesar Chavez and replacing it with a surface boulevard. In that event, the seismic considerations would be greatly reduced.

The Loma Prieta earthquake was a watershed event. While lives were lost in the Bay Area, the earthquake's epicenter was located 60 miles south of the city. The main shock lasted less than 20 seconds, a short duration that mitigated what could have been much more serious damage.

Loma Prieta made transbay travel between the East Bay and San Francisco completely rail- and water-dependent. During the one-month Bay Bridge closure, transit use from the East Bay peaked and automobile use dropped. The Bay Area improvised, since there was no regional plan to deal with the emergency. BART ran additional trains, and ferries were brought in from other cities to support the recovery phase.

Figure 1 provides comparative ridership data before and after of the Loma Prieta earthquake.

Figure 1: LOMA PRIETA EARTHQUAKE TRANSBAY CORRIDOR				
	Pre-Quake (October 17, 1989)	**Post Quake (Tuesday-Thursday Average)**	**Change**	**Change (percent)**
BART Transbay (All Day)	102,000	219,000	117,000	115%
BART System (All Day)	218,000	342,667	124,667	57%
Caltrain (AM Peak)	3,560	4,443	883	25%
Alameda Ferry (AM Peak)	N/A	632		N/A
Oakland Ferry (AM Peak)	N/A	1,830		N/A[6]
Berkeley Ferry (AM Peak)	N/A	528	N/A	N/A
Richmond Ferry (AM Peak)	N/A	453	N/A	N/A
Vallejo Ferry (AM Peak)	N/A	506	N/A	N/A
Golden Gate Ferry (AM Peak)	1,510	2763	1,253	83%
Bay Bridge (All day)	243,000	0	-243,000	N/A
Bay Bridge (AM Peak)	59,000	0	-59,000	N/A
Golden Gate Bridge (AM Peak)	25,000	28,655	3,655	15%
Richmond Bridge (AM Peak)	6,500	11,102	4,602	71%
San Mateo Bridge (AM Peak)	13,500	18,430	4,930	37%
Dumbarton Bridge (AM Peak)	14,200	15,013	813	6%

Source: RIDES for Bay Area Commuters (S. Beraldo) 1989

These data indicate that almost 40 percent of automobile users switched to transit during this period (this underestimates the impact on transit however, because it counts Richmond Bridge users as highway users when in fact many of them crossed the bridge only to get to the Larkspur Ferry). In addition, other surveys conducted by the University of California, Berkeley estimate the switch to be about 50 percent. When we model potential scenarios after an earthquake, SPUR assumes that about half of automobile users (both single occupant and carpoolers) will switch to transit if the Bay Bridge is damaged. In addition, we assume that about 35 percent will change arrival and departure times.

The emergency closure of the Bay Bridge from October 27 to November 2, 2009 demonstrated how BART might perform in the days following a major disaster were the Bay Bridge to be closed. As shown in Figure 2, BART's three all-time high ridership days occurred during the closure while the bridge was being repaired, with a peak of 442,000 daily riders on Thursday, Oct. 29, 2009. The previous all-time daily high did not occur during an emergency or a Bay Bridge closure, but when the Oakland Raiders and San Francisco Giants both played home-field day games on September 8, 2009, where ridership was 405,000.

The BART system performed well during the Bay Bridge closure, with crowded trains and stations, and some minor delays. However, with daily ridership projected to increase, BART's capacity challenges must be addressed sooner rather than later.

Figure 2: BART RIDERSHIP DURING EMERGENCY CLOSURE AS COMPARED TO OTHER HIGH USAGE DATES

Ridership	Day	Date	Events
442,000	Thursday	Oct. 29, 2009	Emergency Closure Bay Bridge – Day 2
437,400	Friday	30 Oct 2009	Emergency Closure Bay Bridge – Day 3
437,200	Wednesday	28 Oct 2009	Emergency Closure Bay Bridge – Day 1
405,400	Monday	8 Sep 2009	Raiders vs. Broncos, Giants vs. Arizona
395,300	Friday	4 Sep 2009	Planned Bay Bridge Closure (24 hr service)
394,400	Thursday	19 Jun 2008	Spare the Air Day
393,200	Monday	2 Nov 2009	Emergency Closure Bay Bridge – Day 6 – Bridge Reopened at 9 AM after morning commute
391,900	Wednesday	9 Apr 2008	Olympic Torch Relay; Giants vs. San Diego
389,400	Friday	31 Aug 2007	Day before Planned Bay Bridge Closure
381,200	Wednesday	13 June 2007	Police Concert, Giants vs. Toronto
375,200	Tuesday	1 May 2007	MacArthur Maze Meltdown – Day 3
376,000	Wednesday	4 October 2000	Baseball Playoffs, Giants vs. NY Mets, A's vs. NY Yankees
374,200	Thursday	3 May 2007	MacArthur Maze Meltdown – Day 5
366,800	Tuesday	3 October 2000	Baseball Playoffs: A's vs. NY Yankees
357,100	Thursday	16 November 1989	Post Loma Prieta Earthquake – Bay Bridge Closed – Day 29

Source: http://articles.sfgate.com/2000-10-06/news/17664253_1_bart-patrons-bart-spokesman-mike-healy-trains,

Ridership peaks compiled from BART news reports 5/08/2007, 5/25/2007, 6/14/2007, 8/31/2007, 4/10/2008, 9/9/2008, 10/29/2009, 11/03/2009, and BART History page http://www.bart.gov/docs/BARThistory.pdf

SAN FRANCISCO AS A REGIONAL HUB: TRANSPORTATION CORRIDORS INTO AND OUT OF SAN FRANCISCO

San Francisco depends on its transportation infrastructure for its livelihood: for delivery of goods, tourism, shopping and getting people to work. After a disaster, especially a major earthquake, many vital transportation links may well be broken. The economy of the city, on the tip of the Peninsula, depends on restoring those links quickly. To maintain the viability of San Francisco as a major employment center, temporary links must be established as soon as possible. If businesses realize they cannot function in San Francisco, within as little as weeks they will likely relocate to other cities, whether in the Bay Area or beyond. If they believe that rebuilding will hamper normal operations for years, firms with multiple locations in the world will be especially likely to shift work to other offices.

Our resiliency depends in part on the ability of transportation systems to withstand an earthquake, and on the speed and efficiency with which they are restored. In San Francisco, the transportation network includes the public transit and surface street networks administered by the Municipal Transportation Agency, and the waterfront, administered by the Port of San Francisco – all wholly under the auspices of the City and County of San Francisco. However, as San Francisco is a focal point of the Bay Area, other transportation systems that are part of the regional network are vital to the city's recovery, including BART, AC Transit, Golden Gate Transit, SamTrans, Caltrain, Amtrak, the Port of Oakland, San Francisco International Airport, the Transbay Joint Powers Authority, Water Emergency Transportation Authority, and Caltrans. The failure or debilitation of any of these regional systems could paralyze San Francisco or a wider area.

A majority of jobs in San Francisco are located in the city's Central Business District, in the northeast corner of the city. We can divide commute origins into four zones: North Bay (Marin and Sonoma Counties), East Bay (Solano, Contra Costa and Alameda Counties), South Bay (San Mateo and Santa Clara Counties) and from within San Francisco itself. Some of these zones, such as the South Bay and East Bay, have a number of links to San Francisco in the form of freeways and rail access. The presence of more than one link among various transportation modes increases redundancy, capacity and passenger options, and decreases the likelihood that all links in these corridors will fail. On the other hand, other zones, such as the North Bay, have very few links. Because most North Bay traffic can only use the Golden Gate Bridge or ferries with relatively low capacity, this corridor lacks redundancy.

Today, there are approximately 350,000 employees[7] in greater downtown San Francisco. Of these commuters, about 148,000 arrive at work on transit, about 40,000 arrive via walking or biking, and the remaining 158,000 (45 percent) arrive by car.[8] This makes downtown San Francisco the least car-oriented job center in the entire region.

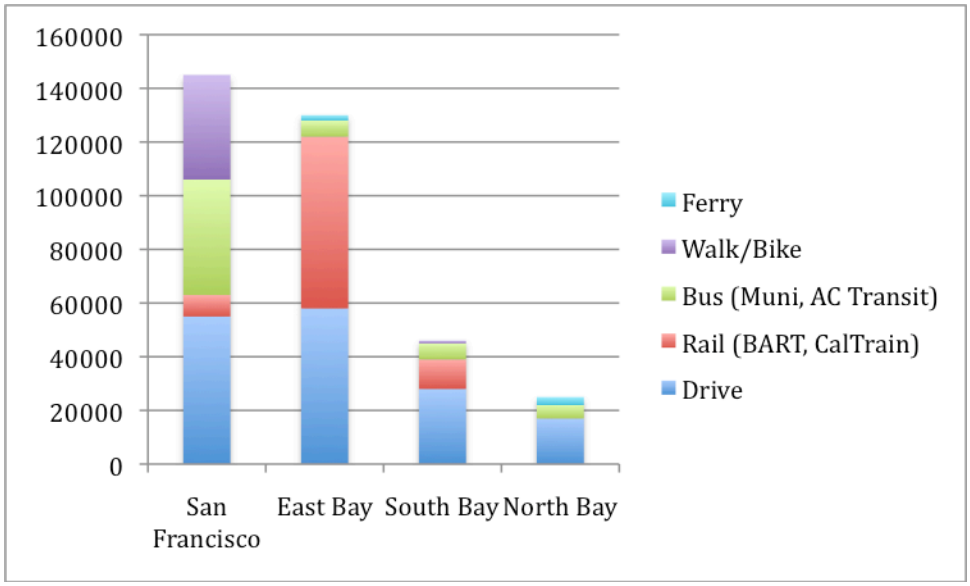
Among all the people who work in downtown San Francisco, 42 percent live in San Francisco, 38 percent live in the East Bay counties (Contra Costa and Alameda), 13 percent live on the Peninsula (San Mateo County) or in the South Bay (Santa Clara County) and 7 percent live in the North Bay (Marin, Sonoma and Solano counties). Figure 3 shows the breakdown of commute patterns by origin location and by mode. [9]

There are other job centers beyond downtown that need to be taken into account when planning for disaster recovery. San Francisco job centers outside of downtown include Mission Bay, San Francisco State University; the University of California, San Francisco, Parnassas; and San Francisco's many hospitals such as San Francisco General Hospital and the Geary/Divisadero medical district. Hospitals are a critical link in the emergency response system. Their emergency medical and health functions are debilitated if hospital employees are unable to get to work.

San Francisco's major hospitals are in Metropolitan Transportation Commission superdistricts 2 and 3 (the Richmond and the Mission, which includes UCSF facilities). The MTC identifies about 47,000 health, education or recreation employees in each of those superdistricts. A review of the job distribution reveals that about 40 percent to 45 percent of the employees in those superdistricts commute to jobs from

outside of San Francisco.[10] Assuming that medical jobs represent about half of the employment category, about 30,000 medical workers thus commute from outside of San Francisco. Planning for transportation redundancy to these other San Francisco locations is critical to facilitating the city's recovery.

Figure 3: Commute patterns into downtown San Francisco, by mode and subregion, 2005



Source: "Caltrain Downtown Extension and Transbay Ridership Analysis" prepared by Cambridge Systematics, Inc. for the Transbay Joint Powers Authority. Final Report, November 2008 and "Transbay Ridership Analysis: Draft Report" prepared for Alameda-Contra Costa Transit, Transbay Joint Powers Authority, Metropolitan Transportation Commission, San Francisco Water Transit Authority, August 2007. Data derived from both draft and final reports and analyzed in SPUR's "Future of Downtown" Report, January 2009, page 34. Additional analysis prepared by Cambridge Systematics, Inc and Arup.

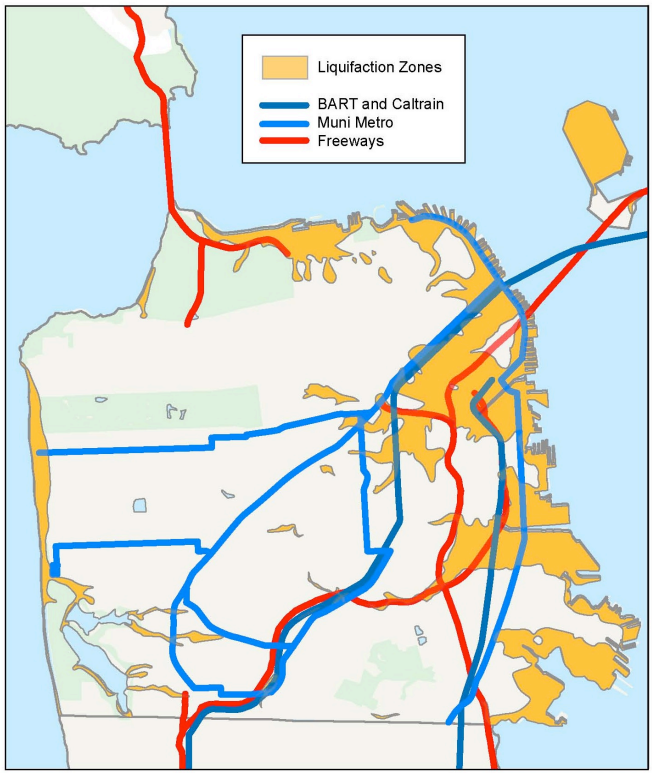
TRANSPORTATION SYSTEM VULNERABILITIES

When considering the expected earthquake, plans should address the likelihood of vital transportation system failures:

- **Liquefaction** of poorly consolidated soils may cause tremendous damage to both the highway and street systems vital to San Francisco (**see Figure 4.).** The principal areas of concern are the Bay Bridge toll plaza in Oakland and northbound Highway 101 in San Francisco. Liquefaction may also affect I-80 between Emeryville and Vallejo, a very important lifeline connecting East Bay communities to employment in San Francisco. The Embarcadero, South of Market and Mission Bay areas are all constructed on soils that may liquefy.
- **Power outages,** continuing or sporadic**,** may immobilize the San Francisco Municipal Railway's electrically powered lines, at least temporarily. These lines include trolley coach, light rail, cable car and streetcar lines. Diesel or hybrid buses may be the only means available to provide emergency or basic mobility.
- **Road damage and debris** may constrain movement for transit or personal vehicles. Damage should be anticipated in such areas as the Embarcadero, South of Market, the Marina and China Basin, and in general on surface streets on poor soils. This is a particular concern in the SOMA neighborhoods (as it was in 1906), as well as throughout the financial district. On Market Street the pavement may be disrupted and power lines may be down. Mobility in the Tenderloin may be limited by both debris and displaced people. Chinatown and parts of the Mission District may also face serious problems with debris removal and displacement of vulnerable populations such as the elderly.

- **Transit access to San Francisco** will be constrained, at least temporarily. The Transbay Tube is vulnerable, as BART has not yet completed its seismic retrofitting. After an earthquake, the tube will be closed temporarily for inspection even if the tube does not fail. Damage to approaches and surface streets at either end of the Bay Bridge may limit bus access to San Francisco.
- **Fixed facilities**, including offices, stations, depots, yards and garages for transit systems likely will suffer damage that could affect operations. In the recent Chilean earthquake, even as structures generally performed well, non-structural damage did occur and resulted in some loss of services. In the Bay Area, fueling systems may be damaged and unusable for several days, pavements and soils may fail, and lighting and power systems may not function even if there has been little structural damage.
- **Ferry service** demand may vastly exceed supply. Temporary ferry terminals may need to be created, to transport passengers particularly between San Francisco and the East Bay cities. Vessels may have to be procured under mutual aid agreements to provide the requisite system capacity.

Figure 4 - Liquefaction Zones in San Francisco



Source: California Department of Conservation, Division of Mines and Geology, final edition February 2003
http://gmw.consrv.ca.gov/shmp/download/pdf/ozn_sf.pdf

CORRIDOR FAILURE ANALYSIS

How much redundancy do we have in our transportation system? What do we do when our major transportation links fail? SPUR has begun to analyze this issue by looking at redundancy on a corridor-by-corridor basis. We analyzed the four major corridors serving San Francisco. We also examined what happens if all our fixed corridors fail and we must rely on ferries for all our passenger transportation needs.

East Bay: Transbay Tube, Bay Bridge

North Bay: Golden Gate Bridge, ferries
South Bay: BART, Caltrain, I-280, Highway 101
Intra San Francisco: Roads and rail
Regional: Failure of all systems, leaving ferries only

For each corridor, we describe what types of transportation failures could occur, the effects of those failures on transportation capacity within the corridor, and what should be done in the short, medium and long term if one or several transportation links are severed.

1. EAST BAY – TRANSBAY TUBE, BAY BRIDGE

There are three possible scenarios for transportation failures in this corridor:

A. Bay Bridge intact, Transbay Tube closed
B. Transbay Tube intact, Bay Bridge closed
C. Both Bay Bridge and Transbay Tube closed

SPUR does not disregard the enormous efforts made to "earthquake harden" these systems and facilities[11]. These efforts are vital, and must continue in order to increase the likelihood that the Bay Bridge and the Transbay Tube will perform well in a major earthquake. We also must be prepared for something in the system to fail in a way that denies normal service, however.

There are several sub-scenarios for these scenarios. For example, some portions of the BART system may survive and remain operable, but not other parts. The Bay Bridge itself may survive, but its approaches may be damaged due to liquefaction or ground subsidence. As a result, some transit vehicles may be able to use the bridge, but no other access may be provided.

For this part of the exercise, we assume that the San Mateo Bridge and Golden Gate Bridge are undamaged and resume normal operations after temporary closures for inspection.

It is also important to note that the Transbay corridor has less latent capacity available than it did in 1989. BART's train control system is operating close to capacity (although, in theory, the system could accommodate about 30 percent more trains with a new control system). However, the San Francisco downtown stations, as noted in SPUR's "Future of Downtown" study, are already operating close to capacity. It will be necessary to shift some trips from the peaks to the shoulders of the commute periods, when more capacity is available.

A. BAY BRIDGE INTACT, TRANSBAY TUBE CLOSED

Under this scenario, BART's current demand of about 150,000 to 175,000 daily transbay trips would be diverted to other modes of transportation. About 14,000 of those trips are in the peak hour (approximately 7:30 a.m. to 8:30 a.m.) from the East Bay into San Francisco. The peak hour is important from a transit planning perspective because it is the time of day when the transportation system is most utilized. Therefore, transportation plans need to be able to accommodate the number of trips taken during the peak hour. The 14,000 peak hour trips from the East Bay into San Francisco would be accommodated by additional Transbay buses. We assume that with work shift changes, about two-thirds of the 14,000 would be accommodated in the peak hour. [12] The other 4,600 would be accommodated in the off peak period. A number of tools could be used to meet this demand:

- **Additional bus service:** An increase of 10,000 bus passengers hourly would require about 200 additional buses (assuming that most buses could do a round trip in one hour from the East Bay), in addition to the 100 buses currently scheduled. The new Transbay Transit Center will accommodate this demand.
- **Bay Bridge use restrictions**: Similar to the requirements that New York City put into effect in Lower Manhattan after September 11th, 2001, the bridge could be restricted to occupancy of not

less than four per vehicle. In addition, contraflow lanes should be established on the lower deck for buses entering the city in the morning.

- **East Bay park-and-ride locations**: In addition to using BART stations, cities would need to provide additional locations as park-and-ride areas for express buses operating into San Francisco.
- **HOV restrictions**: Caltrans could increase all high occupancy vehicle occupancy requirements to not less than four per vehicle, to ensure that express buses can operate effectively.
- **Bridge access**: Caltrans could designate special bus-only access to the Bay Bridge from locations such as West Grand Avenue.

B. TRANSBAY TUBE INTACT, BAY BRIDGE CLOSED

Under this scenario, the current demand of about 270,000 daily vehicular transbay trips via the Bay Bridge (about 325,000 person-trips) would either be curtailed or diverted. About 23,000 of those person-trips are in the peak hour (approximately 7:30 a.m. to 8:30 a.m.) In addition, about 3,000 bus passenger-trips would be affected. [13]

BART has capacity in the peak hour for another 10,000 to 15,000 passengers in its downtown stations, or about half the demand diverted from the Bridge. Loma Prieta numbers indicated that about half the automobile person-trips moved to transit. However, BART has rolling stock limitations, access constraints and other capacity constraints. While BART plans to expand its fleet and upgrade train control systems to accommodate more trains, a disaster that occurs before these projects are completed will compel BART to make the best use of its existing resources:

- **Adapted service**: BART could concentrate operations in the areas of its densest demand, and limit services to the furthest edges of the system. This would make equipment available to satisfy BART's greatest demand, on the core of the system.
- **Additional bus service**: As part of the realignment of BART service, the Fremont to San Francisco service could be suspended and trains could be turned at Bay Fair or other closer-in locations (fewer trains could also serve Pittsburg, for example, with trains turning at Pleasant Hill). East Bay buses could provide express bus service from these stations to San Francisco via the San Mateo Bridge. This approach would optimize BART resources and make effective use of available buses.
- **High-Occupancy Vehicle (HOV) restrictions**: Caltrans could increase HOV occupancy requirements on Highway 101 to not less than four people per vehicle, to ensure that express buses can operate effectively.
- **Bridge access**: Caltrans could designate special bus-only access to the San Mateo and Dumbarton Bridges.

C. TRANSBAY TUBE AND BAY BRIDGE CLOSED

In this scenario, the frequency and distribution of ferry service from the East Bay would need to increase. In addition, extra vessels, possibly larger ones, would help carry a portion of people who currently use either BART or the Bay Bridge. In fulfillment of its mandate, the Water Emergency Transportation Authority would manage the increase in existing services, including augmenting service with vessels brought in from other locations.

The East Bay ferry routes (Alameda-Oakland and Harbor Bay routes) currently carry about 2,000 passengers per day. Using all available boats in all Bay Area corridors (i.e., maximizing usage on the North Bay and East Bay corridors), ferries in the East Bay corridor could carry about 2,000 passengers per hour, regardless of the three scenarios discussed in this section.

This means that in emergencies, ferries would be able to transport 2,000 passengers per hour – or 48,000 passengers in 24 hours or 32,000 passengers during two eight-hour shifts. The Alameda/Oakland and Harbor Bay routes take approximately 30 minutes each way. Based on Water Emergency Transportation Authority estimates, approximately 228,000 people would need to get back to the East Bay from San Francisco after a major disaster that would disrupt both the Transbay Tube and the Bay Bridge. It would take approximately 114 hours to evacuate 228,000 people if WETA maxed out on both of these East Bay routes.[14]

What can be done to augment ferry service in response to a major emergency? The limiting factor for increasing ferry service is not the number of vessels, but instead the number, location and type of landings and terminals suitable for ferry service. WETA could double East Bay service capacity to 4,000 passengers per hour if one additional terminal were added at the San Francisco ferry terminal. This would allow WETA to use the three terminals in the east bay (Jack London Square in Oakland, Main Street in Alameda and Harbor Bay in Alameda) to their maximum capacities.

Relatively few vessels suitable for ferry service are available from outside the region. A few high-speed vessels could come from Southern California (Catalina and Channel Islands ferries), as well as some military air-cushion vessels (hovercraft). The only automobile ferries in the western United States are those operated by the State of Washington. However, these are in short supply and require dedicated landing facilities, so WETA cannot realistically rely on that option.

The suitability of vessels for emergency ferry service is a function of their design. Most of the Bay is quite shallow, and routes to potential emergency ferry terminal locations may be navigable only at high tides. Vessels serving terminals outside the central Bay must therefore be of shallow draught (the depth that the vessel projects below the waterline). Furthermore, a vessel's freeboard (the height of the deck above the waterline) must be compatible with the landing and passenger boarding structures. Similarly, vessels designed for boarding over both bow and stern, or strictly from alongside, may not be compatible with existing and emergency ferry terminals. Certain landings and routes may only be compatible with reversible, double-ended ferries, while others may be compatible only with conventional single-ended vessels.

If both the Transbay Tube and the Bay Bridge are closed, WETA will be able to provide sufficient transportation evacuation for the commuters and visitors stranded either in San Francisco or in East or North Bay (Vallejo). WETA will also be able to become a key transit link between San Francisco and East Bay by adding additional vessels and by increasing frequency of ferry service. However ferries will not be able to meet the total demand for trips in the months and years following a major disaster. One of the key deterrents for the ferry service augmentation could become the limited number of ferry terminals in San Francisco and the unsuitability of these ferry terminals to certain type of vessels.

EAST BAY / TRANSBAY LINK: SOLUTIONS BY TIMEFRAME	
Action Item	**Responsible Agencies**
BEFORE THE DISASTER: PLANNING	
Create a plan to coordinate bus bridges across the Bay Bridge in the event BART service is disrupted. Such a plan would include routing, stops and schedules of new bus lines created for an emergency event.	AC Transit, BART and Caltrans
Create permanent bus-only lanes on approaching freeways to the Bay Bridge (I-80, I-580 and I-880). Consider contraflow lanes on these freeways, in addition to the Bay Bridge.	Caltrans and AC Transit

Develop a restricted vehicle plan. Identify the locations of the HOV system where occupancy limits would be increased, along with pre-designation of dedicated bus access ramps on the freeway and bridge access system. Pre-printed signs should be fabricated and stored.	Caltrans
Develop contraflow bus system, including a morning-only westbound contraflow lane to improve bus access into San Francisco. This system would be vital during a BART emergency.	Caltrans, MTC and the Bay Area Toll Authority.
Identify emergency park-and-ride locations, and have maps and draft websites available for their dissemination.	MTC and local government
Develop emergency transit plans. Agencies should develop plans for Bay Bridge failure which assign trains and buses to their most productive use. Plans should be coordinated across agencies.	MTC, BART and AC Transit
Establish an emergency reserve fleet. About 100 buses should be maintained in the East Bay.	AC Transit
Establish mutual aid agreements with other bus agencies. The Bay Area should enter into mutual aid agreements with other agencies to ensure that 100 buses can be quickly requisitioned, along with drivers from other operators.	AC Transit, MTC
Complete BART system improvements. BART is pursuing several capital improvement projects that would be of benefit after a disaster since they increase capacity within the system core. These include three-door cars that allow passengers to board faster and reduce the time trains spend in the stations. In addition, BART should begin the process of adding side platforms at critical center platform stations, such as Embarcadero and Montgomery.	BART
Ensure ferry vessel/terminal compatibility. Compile and maintain a register of existing and potential emergency ferry terminals, their characteristics and the requirements for vessels that would serve them after an emergency.	Water Emergency Transportation Authority
Identify critical docks and piers throughout the Bay Area that could be used after an earthquake. Develop a plan to create the necessary contingency infrastructure and procedures.	WETA
Develop a strategy for critical goods movement in both the response and recovery periods to ensure that food, water and construction materials can be delivered as required.	WETA
AFTER THE DISASTER: MANAGING THE MID-TERM	
Implement Bay Bridge restricted vehicle plan	Caltrans, MTC
Implement bus bridging in the event of a BART shutdown. Bus bridging uses buses to fill in a gap in rail service or highway facilities. As an example, if BART has a disabled train at Lake Merritt, buses can be used to transfer passengers between Fruitvale and 12th Street.	BART, AC Transit
Create contraflow bus lanes on Bay Bridge	Caltrans, AC Transit, MTC
Create bus only lanes on Bay Bridge and on approaching freeways.	Caltrans, AC Transit, MTC
Require all BART cars running into and out of San Francisco to be at full capacity—this would require significant management of the BART platforms	BART

at strategic locations.	
Implement mutual aid actions	MTC, AC Transit
Utilize excursion boats to enhance ferry service.	WETA
ONGOING (LONG-TERM): PROJECTS THAT CREATE REDUNDANCY	
A second transbay tube would create a critical redundancy in the rail network between Oakland and San Francisco. Although this project would take years of planning and require a major financial investment, it would also ensure the region's economic viability in the event of a disaster. In addition, Caltrain and high-speed rail should be extended under the Bay to Oakland. A new tunnel would be built to current seismic standards, and it would provide increased capacity to the transportation system.	BART to lead, in consultation with Muni, AC Transit and cities that would receive new BART service.

2. SOUTH BAY/PENINSULA – BART, CALTRAIN, I-280 AND HIGHWAY 101 FREEWAYS

Of the corridors serving San Francisco, this is among those with the greatest redundancy. Because there are multiple links from the South Bay to San Francisco, if one or two of the links are disrupted, there are other links that can allow continuous access to San Francisco. The key links are two freeways – Highway 101/Bayshore Freeway and I-280/Junipero Serra Freeway – and the Caltrain and BART rail lines. There are also several main street connections: Bayshore Boulevard, Geneva Avenue, Mission Street, Junipero Serra Boulevard, Lake Merced Boulevard and Skyline Boulevard.

SPUR examined two scenarios for an earthquake affecting this corridor:

A. CALTRAIN AND BART INTACT, BOTH FREEWAYS CLOSED

Under this scenario, neither of the two freeways from the South Bay – U.S. Highway 101 and I-280 – would be able provide access into San Francisco from south of the city. The two highways' current demand of about 330,000 daily vehicular trips (192,000 for Highway 101 and 138,000 for I-280), or about 390,000 person trips,[15] could not simply transfer to Caltrain or BART. About 29,200[16] of those trips taken by people in cars are in the peak hour (from roughly 7:30 a.m. to 8:30 a.m.) In addition there are about 800 people taking the bus into San Francisco in the peak hour.

We assume that with work shift changes, about two-thirds of the 29,900 trips taken by people in private cars and 800 bus passenger trips would be accommodated in the peak hour, or about 20,700 additional rail passengers per hour.[17]

While the many commuters travel from the South Bay to jobs in San Francisco, many, if not more, commute from San Francisco to work in San Mateo and Santa Clara counties. In fact, many technology companies offer free shuttle bus service from San Francisco to Silicon Valley so their employees can get to work without driving in the traffic. In the event of a major earthquake, if one or both freeways to the South Bay were disrupted, then many residents in San Francisco would either switch to driving street highways such as El Camino Real or commuting during off-peak hours.

A number of tools could help minimize the effect of freeway disruptions in this corridor:

- **Adapted and Enhanced Caltrain and BART Service.** Adding train cars would be the principal way to increase capacity, especially for Caltrain. In addition, timed transfers between BART and Caltrain at Millbrae Station would also facilitate the increased demand.
- **Make Operational improvements to improve system performance and add rail capacity** Caltrain service other than the Baby Bullet trains would be restricted to limited service between

San Mateo and San Jose. Trains would not make stops at 22nd Street, Bayshore, South San Francisco, San Bruno and Burlingame. Running Baby Bullets to and from San Francisco, Millbrae, San Mateo and other Baby Bullet stations would add capacity. In addition to the existing two BART trains to San Francisco International Airport and Millbrae, the Green and Blue lines would be temporarily extended to Millbrae

- **Additional Bus Service:** With some Caltrain stations not receiving service, bus service between closed stations and Baby Bullet stations should be implemented.
- **Park and Ride Locations:** In addition to using Caltrain and BART stations, cities would need to provide locations such as shopping centers and fairgrounds to use as park and ride areas for feeder buses to Caltrain stations.
- **HOV Restrictions:** Caltrans should increase all HOV occupancy requirements to not less than four per vehicle on open sections of Highway 101 and I-280.
- **Make use of the old Highway Network:** Manage auto demand by utilizing El Camino Real, Alemany Boulevard and Bayshore Boulevard

B. ONE OR BOTH FREEWAYS INTACT, CALTRAIN AND BART CLOSED

Under this scenario, neither Caltrain nor BART would be able to operate into San Francisco from south of the City. This would affect about 40,000 BART trips into and out of San Francisco, and about 15,000 Caltrain trips.

About 3,100 BART trips are taken in the peak hour and about 2,300 Caltrain trips occur in the peak hour, for a total of about 5,500 peak hour transit trips. We assume that with work shift changes, about two-thirds of the 5,500 would be accommodated in the peak hour, or about 4,000 additional bus passengers per hour.[18] The impact of rail-service disruptions could be mitigated in several ways:

- **Additional Bus Service:** An additional 4,000 hourly bus passengers would require about 100 additional buses (assuming that most buses could do a round trip in 90 minutes from the Peninsula), in addition to the dozen buses currently scheduled. The new Transbay Transit Center will accommodate this demand.
- **Peninsula Park and Ride Locations:** In addition to using Caltrain and BART stations, cities would need to provide additional locations as park and ride areas for express buses operating into San Francisco.
- **HOV Restrictions:** Caltrans could increase all HOV occupancy requirements to not less than four per vehicle to ensure that express buses can operate effectively. In addition, meter facilities should allow only vehicles with at least four passengers to bypass them.

SOUTH BAY: STRATEGIES BY TIME FRAME	
Action Item	**Responsible Agencies**
BEFORE THE DISASTER: PLANNING	
Establish plan for managing roadway capacity in the event of an emergency. Coordinate between agencies to plan for bus bridges and park-and-ride facilities. Create plans for emergency services in case of disaster, especially if freeways are disrupted.	BART, Caltrans
Strengthen and retrofit Caltrain tracks as necessary and tunnels on the	Caltrain

peninsula and within San Francisco.	
Develop a restricted vehicle plan. Identify the locations of the HOV system where occupancy limits would be increased, along with pre-designation of dedicated bus access ramps on the freeway and bridge access system. Pre-printed signs should be fabricated and stored.	Caltrans
Develop emergency park and ride locations. Identify various emergency park and ride locations and have maps and draft websites available for their dissemination.	MTC, local governments
Establish an emergency reserve bus fleet. Should BART and Caltrain fail, at least 100 additional buses would be required in Peninsula service. Build a reserve fleet of about 50 buses, located in San Mateo and northern Santa Clara Counties. Additionally, create a locomotive and passenger car fleet. Due to the higher cost of purchasing and storing rail cars, a very small fleet is recommended.	Caltrain, Santa Clara Valley Transportation Authority
Enter into mutual aid agreements with other bus agencies to ensure that the other 50 buses required for service can be quickly requisitioned, along with drivers from other operators. In addition, agreements with rail providers (e.g. Amtrak, Metrolink, ACE) would ensure that additional rail cars could also be requisitioned quickly.	VTA, MTC
AFTER THE DISASTER: MANAGING THE MID-TERM	
Create bus bridges to manage roads with carpool lanes, bus prioritization and park and rides.	Caltrans, VTA
Allow for transit-only lanes on Highway 101 and I-280.	Caltrans
Employ old highway system, by making use of El Camino Real, Alemany and Bayshore.	Caltrans, MTC, local government
Require carpooling for private automobiles	Caltrans
Require Caltrain and BART cars to be full.	Caltrain, BART
Use diesel locomotives on Caltrain lines if electricity is down.	Caltrain
Require valet parking at lots and garages. If existing parking facilities have assisted parking (aka valet parking), more cars can be parked.	Local government
ONGOING (LONG-TERM): PROJECTS THAT CREATE REDUNDANCY	
Complete the California high-speed rail project.	California High Speed Rail Authority
Electrify Caltrain.	Caltrain
Expand Caltrain to a four-track, completely grade-separated system	Caltrain

3. NORTH BAY – GOLDEN GATE BRIDGE, FERRIES

Although the Golden Gate Bridge and North Bay ferries accommodate only moderate traffic to San Francisco in comparison with the Bay Bridge and BART, these links are very vulnerable. The Golden Gate Bridge, with one deck of six narrow lanes, provides the only road access between the North Bay and San Francisco. There is no rail access, and ferries from multiple cities provide the only other access. Due to ferries' limited service levels and vessel sizes, ferries provide only a small portion of the access to San Francisco from the North Bay.

There is one North Bay scenario:

A. FERRY TERMINALS INTACT, GOLDEN GATE BRIDGE CLOSED

There are several factors to consider in this scenario. For example, the Golden Gate Bridge itself may survive, but its approaches may be damaged due to liquefaction, landslides or other ground subsidence. In such a situation, some transit vehicles would use the bridge, but no other access would be provided. Ferry landings also could be damaged. Ferry solutions are discussed in more detail for all scenarios later.

In this scenario we assume that both the Richmond-San Rafael Bridge and the San Francisco-Oakland Bay Bridge survive, as do the ferry landings. The Golden Gate Bridge's current demand of about 118,000 daily vehicular trips (about 141,500 person trips[19]) would be unable to use the bridge. About 10,000 of these vehicular trips are in the peak hour (approximately 7:30 a.m. to 8:30 a.m.). In addition, about 1,400 peak-hour bus passengers would be affected. Under this scenario, commuters (both auto and transit) would be diverted to ferries and the Richmond-San Rafael Bridge. We assume that with work-shift changes, about two thirds of the 10,000 would be accommodated in the peak hour by a combination of bus and ferry service, or about 6,700 additional bus and ferry passengers per hour.[20]

Golden Gate Ferry services typically carry 3,500 passengers per day, and Vallejo Baylink 1,500 per day. In an emergency, Golden Gate Ferry could carry about 2,300 passengers per hour and Vallejo Baylink could carry about 600 passengers per hour, for a total of 2,900 passengers per hour for the North Bay corridor.

The Golden Gate Ferry Larkspur service takes 30 minutes and the Sausalito service 25 minutes one-way between those terminals and San Francisco[21]. The Water Emergency Transportation Authority estimates that 75,000 people will need to return to Marin County from San Francisco after a disaster. With increased, emergency ferry service, it would take as long as 33 hours to carry those people to Marin County. The Vallejo Baylink service takes 60 minutes one way. WETA estimates that 22,000 people would need to return from San Francisco to Solano County, which means that emergency ferry service would need as long as 37 hours to get these people back to Vallejo.[22]

Although ferry capacity would be increased, not all of the demand could be met through ferries. Due to the need for more than ferries, we assume rerouted buses would carry at least 75 percent of the 6,700 commuters via the Richmond-San Rafael Bridge, or about 5,000 additional bus passengers per hour.

While there are plans to improve the ferry fleet, if an earthquake or other disaster occurs before those projects are completed, the Golden Gate Bridge, Highway and Transportation District will need to concentrate its bus and ferry resources effectively. It has a number of tools it could use to meet the demand:

- **Additional bus service**: An additional 5,000 hourly bus passengers would require about 150 additional buses (assuming that most buses could do a round trip in one and a half hours from Marin County to El Cerrito Del Norte and Richmond BART Stations), in addition to the two buses currently scheduled. The two BART stations would have to be temporarily redesigned to accommodate the higher demand. If the Bay Bridge were open, some buses could take the full journey to San Francisco, although such a route would require more buses due to the longer trip

time.

- **Richmond-San Rafael Bridge use restrictions**: Similar to the requirements recommended earlier for the Bay Bridge, the bridge should be restricted to occupancy of not less than four per vehicle. In addition, the wide shoulder lanes should be made into contraflow lanes for buses on both decks.
- **Marin and Sonoma park-and-ride locations**: Cities would need to provide additional locations as park and ride areas for express buses operating over the Richmond-San Rafael Bridge.

NORTH BAY LINK: SOLUTIONS BY TIME FRAME	
Action Item	**Responsible Agencies**
BEFORE THE DISASTER: PLANNING	
Develop a restricted vehicle plan. Identify the locations of the HOV system where occupancy limits would be increased and identify locations that could be designated dedicated bus access ramps on the freeway and bridge access system. Signs should be fabricated and stored.	Caltrans
Develop emergency park-and-ride locations. Identify various emergency park-and-ride locations and have maps and draft websites available for their dissemination.	MTC, local governments
Establish an emergency reserve fleet. Should the Golden Gate Bridge fail, at least 150 additional buses would be required in service (due to using the Richmond Bridge and additional feeder services to the Larkspur Ferry). This will require several acres of parking, probably by expanding existing Golden Gate Transit bus yards in Marin.	Golden Gate Transit
Establish mutual aid agreements with other bus agencies. Enter into mutual aid agreements with other agencies to ensure that the additional buses required for service can be quickly requisitioned, along with drivers from other operators.	Golden Gate Transit, MTC
Develop a contraflow bus system. Caltrans, along with the Metropolitan Transportation Commission and the Bay Area Toll Authority, should develop emergency-only Bay Bridge and Richmond-San Rafael contraflow lanes to improve bus access after a disaster in the event that access across the Golden Gate Bridge is disrupted.	MTC, BATA
Develop emergency transit plans for Golden Gate Transit and Golden Gate Ferry, as well as BART. Each agency should develop a plan that assumes Golden Gate Bridge failure and assigns ferries and buses to their most productive use. Plans should be coordinated across agencies.	Golden Gate Transit, WETA, BART
Create a plan to coordinate bus bridges from Marin to San Francisco across the Richmond-San Rafael Bridge to East Bay BART stations or into San Francisco via the Bay Bridge. Such plans would include routing, stops and schedules of rerouted Golden Gate Bridge bus lines created for an emergency event.	Golden Gate Transit, MTC
AFTER THE DISASTER: MANAGING THE MID-TERM	
Require carpooling for private vehicles on the Richmond-San Rafael Bridge.	Caltrans, MTC

Implement the bus bridge plan to East Bay BART stations, or into San Francisco via the Bay Bridge.	Golden Gate Transit, BART, Caltrans
Create contraflow bus lanes on both decks of the Richmond-San Rafael Bridge.	Caltrans, MTC
Increase ferry service through borrowing ferry vehicles from tour operations and ferry operators from the West Coast.	WETA
LONG TERM PROJECTS THAT CREATE REDUNDANCY	
Add ferry landings in appropriate locations.	WETA, Local Ports
Coordinate Sonoma Marin Area Rail Transit train service to access Larkspur Landing.	SMART, WETA
Replace Doyle Drive in San Francisco to ensure that its approach to the Golden Gate Bridge functions after an earthquake.	San Francisco County Transportation Authority

- **HOV restrictions**: Caltrans could increase all HOV occupancy requirements on Highway 101, I-580 and I-80 to not less than four per vehicle to ensure that express buses can operate effectively.
- **Adapted ferry service**: Golden Gate Ferries could dedicate its entire fleet to peak demand periods, while acquiring temporary use of other ferries from other ferry providers based on prearranged agreements. This would ensure that it has adequate equipment to meet the high demand on the core of the system.

4. FERRIES ONLY

If most or all major rail and highway links were disrupted, especially from the East Bay and the North Bay, a major upgrade in ferry service would be required. All existing and possible temporary landings would be employed on all shores. We would need to:

- Radically increase ferry service (additional docks would be needed, particularly at the downtown San Francisco Ferry Building).
- Add new routes of service. Some options include Richmond, Benicia and Redwood City to spread the passenger load to new docks along existing San Francisco to Oakland route.
- Reroute bus lines from rail and highway networks to new ferry landings.
- Add non-Bay Area ferry boats to area. (See Section A on adding boats.)

This section explores the possibilities and limitations of using ferries as our worst case scenario regional transit system following a major earthquake.

Ferries: SOLUTIONS BY TIMEFRAME	
Action Item	**Responsible Agencies**
BEFORE THE DISASTER: PLANNING	
Inventory existing ferry fleets, commercial fleets, and ferry fleets at nearby cities (Los Angeles, Seattle, and Vancouver), to assess whether each fleet would be able to	WETA

adapt to current ferry landings. In the inventory, indicate a tier of different boat sizes and capacity.	
Establish official disaster mutual aid agreements with other ferry operators so that the other ferry providers would be ready to offer some of their ferries to relieve the city in case of a disaster. Nearby boat and ferry agencies should be contacted first. Because some ferries may be seaworthy, cities at greater distances that would require an ocean journey for the ferry to reach the Bay Area also should be considered, but using ferries from some of these cities would present additional challenges: • Los Angeles • Seattle (nearby, but most ferries probably too big for docks in San Francisco) • Vancouver (nearby, but some ferries probably too big and others too small for docks in San Francisco) • In case of a catastrophic disaster in which most bridges collapse, other areas should be considered: New York City, Hong Kong, Sydney, Istanbul, Boston, Norway, Long Island Sound, Nova Scotia, Alaska The main challenge with ferry systems outside the Bay Area is that many of their boats are either too small to travel long distances to San Francisco, or are too big for San Francisco and other Bay Area docks. For those with larger ferries, only long-term solutions like building more docks could allow large ferries such as those in Vancouver, Seattle and New York to function in San Francisco.	WETA
Consider preparing docks and ferry landings that could accommodate larger vessels. Many of the San Francisco piers may be able to take a large ferry, including the cruise ship terminal. However, such landings may not exist on other, smaller properties. Consider funding the development of new terminals as long as further ferry fleet development is environmentally smart and economically viable. The Water Emergency Transportation Authority would be in charge.	WETA
Inventory existing Bay Area landings: boat landings at marinas, ports and ramps that could be easily adapted for ferries, should be researched and developed. Some landings could be adapted ahead of time, while others could be altered after a disaster to accommodate water taxis and larger ferry vehicles.	WETA
AFTER THE DISASTER: MANAGING THE MID-TERM	
Increase ferry service where necessary.	Caltrans, VTA
Consider adding water taxi services where possible and economically viable. Ferry landings could be added at sites that may not normally be viable for regular ferry services but would be critical in a disaster.	Caltrans
Reroute bus services to ferry landings if many or most links are disrupted. Ferry landings will also need large parking lots nearby and shuttle service from the parking lots to the ferry landing. Such parking lots include shopping centers, racetracks, empty lots, parks and universities.	Caltrans, MTC, local government

5. INTRA SAN FRANCISCO

A. MARKET STREET SUBWAY CLOSED

Due to the street network and multiple rail lines from San Francisco's many neighborhoods, there are many redundancies. The only link that is critical and has no direct equivalent is the Market Street Subway for both BART and Muni Metro trains.

Under this scenario, Muni's current demand of about 75,000 daily Market Street Subway trips would be diverted to other modes. About 9,500 of those trips are in the peak hour (7:30 a.m. to 8:30 a.m.). Those trips would be diverted onto replacement buses. We assume that with work shift changes, about two-thirds of the 9,500 would be accommodated in the peak hour, or about 6,300 additional bus passengers per hour.[23] If either the Twin Peaks Tunnel or the Sunset Tunnel were compromised in addition to the Market Street Subway, all light rail service would be converted to bus service. If only the Market Street Subway were compromised then most, if not all, Metro service could move to the surface of Market Street. The tools to use to meet this demand include:

- **Reroute Muni Metro Service to Surface of Market Street**: If the Muni's Market Street Subway is not usable, it is possible for the light rail vehicles manufactured by Breda to operate on the surface of Market Street. The Breda cars use a pantograph (a device which maintains electrical contact with Muni's overhead electrical wires) to collect power and transfer it to the Muni car.

  The trolley coaches that run on Market use a different system, with both positive and negative wires. It is possible to rebuild Muni's overhead wires to accommodate the Breda cars, but a less expensive and time consuming approach is to outfit all the Bredas with trolley poles so they can use the wires on Market Street. A reasonable scenario would be to wire the cars to be easily modified and have the poles stored on-site at Muni for an emergency adaptation.
- **Additional Bus Service**: An additional 6,300 hourly bus passengers would require about 250 additional buses (assuming that most buses could do a round trip in one hour from the western and southern parts of San Francisco), in addition to the many buses currently scheduled.
- **Transit Only Market Street.** Market Street already supports many bus routes and a bus lane along much of its length. In the event of a disaster, Muni and the City of San Francisco should plan for Market Street to be closed to general traffic between points where transit is critical.
- **Increase BART service in San Francisco**: If electric buses and roads are incapacitated, a functioning BART should increase service.
- **Employ Diesel and Hybrid Buses on Electric Bus Routes.** Have a plan to deploy diesel buses to the highest ridership electric bus routes if they are incapacitated.

SAN FRANCISCO: SOLUTIONS BY TIMEFRAME	
Action Item	**Responsible Agencies**
BEFORE THE DISASTER: PLANNING	
Complete a performance audit of Muni facilities (yards, stations) and identify deficiencies and retrofit as required. Ensure that facilities will be operable within two days.	MTA
Replace Muni's central control facility, ensuring that it performs as an essential facility.	MTA
Retrofit Forest Hills Muni Metro station	MTA
Develop a plan for deploying diesel and hybrid buses on incapacitated electric bus routes. Make routes with the highest ridership the highest priority.	MTA
Enact mutual aid agreements for buses and bus service with other transit agencies.	MTA

Develop program and stockpile materials to allow Muni Metro light rail vehicles to operate on the surface if the Market Street subway tunnel is damaged.	MTA
Establish an emergency reserve fleet. Should Muni's electrical transit system fail, at least 200 additional buses would be required to partially compensate for the almost 400 trolley coaches and nearly 200 light-rail vehicles. While Muni has maintained a small reserve fleet for minor events, it is not sufficient. On the other hand, it would be unwise to simply store 200 old buses for possible use. They need to be maintained, occasionally cleaned and garaged. However, in conjunction with other reserve fleets (such as the East Bay fleet) Muni should maintain a reserve fleet of about 100 buses, located in San Francisco. This will require a total of about three acres of parking, which could require the expansion of an existing or planned Muni diesel yard.	MTA
Plan for bicycle transportation as part of the immediate, medium and long-term recovery period.	MTA
AFTER THE DISASTER: MANAGING THE MID-TERM	
Activate reserve fleet as necessary.	MTA
Deploy diesel buses on incapacitated electric bus routes.	MTA
Run Muni light rail vehicles on Market Street surface—likely would require temporary retrofit of LRVs with trolley poles.	MTA
Create temporary transit-only streets to allow for more high volume usage.	MTA
Ensure that the bicycle network is usable during recovery period and that the network is enhanced and expanded as part of long-term recovery.	MTA
ONGOING (LONG-TERM): PROJECTS THAT CREATE REDUNDANCY	
Build San Francisco's Bus Rapid Transit Network, including Bus Rapid Transit lines on Geary and Van Ness.	SFCTA, MTA
Complete Transbay Terminal.	Transbay Joint Powers Authority
Build out the Bicycle Network	MTA
Build a new BART line serving San Francisco to ensure redundancy after a disaster.	BART

BICYCLES AND DISASTER RECOVERY

Bicycles can play a key role in disaster response and recovery. Bicycles need little road/path infrastructure to travel efficiently, are very flexible, can carry substantial loads and do not require fuel for operation. Since the advent of Kevlar and comparable belting materials, flat tires are very rare. Given that bicycles are slow relative to transit or auto travel, their use is generally limited to a radius of less than 10 miles.

After a disaster, bicycles offer efficient transportation alternatives when other options may be unavailable. Bicycles can be used by engineers and inspectors performing building triage for tagging damaged buildings and transportation infrastructure, for personal use by residents for commuting, and as an option for evacuation post earthquake, given the limited likely road and rail alternatives available to the nearly one million people in the city during a peak period in the day.

Although only a small segment of the population ride bikes for utility purposes, there is anecdotal evidence that San Francisco could have several hundreds of thousands of bicycles, kept in garages, sheds, and storage facilities. However, many are neglected and are not street-worthy. There are additional tens of thousands in the inventory of the city's many bike shops and rental companies.

Our plans for immediate response to a disaster should include the creation of a Bicycle Emergency Response Team, made up of volunteers and paid professionals who can be reached and activated, much like a NERT team. With 11,000 members, the San Francisco Bicycle Coalition, plus other local coalitions and clubs in the Bay area could help this team.

Other elements of a bicycle response plan should include:

- Shared Bikes for short-term check-in-check-out, tracked via existing open source systems.
- "Below Market Rate" Bikes for longer-term use during the disaster-recovery period, sold for highly discounted rates.
- "Loaner" bikes at no cost, but with registration and agreement for return after the disaster. These bikes will require discounted purchase of a U-lock, and have locking skewers to prevent wheel removal built-in.
- Key locations storage for bicycle pickup and check in.
- Use of volunteers and professionals to pick up donated and low-end purchase, to sell/lease/lend/, provide valet services modeled on the system used at AT&T Park, perform "triage" services in sorting donations/purchases for classification, and 'tune-up' teams.
- Media plan for calling for bike donation/delivery to bicycle stations
- Communication and inventory tracking system for people and bicycles.

III. ADDITIONAL RECOMMENDATIONS

SPUR has three recommendations not specific to any corridor that would enable San Francisco and its associated transportation systems recover quickly and effectively from a disaster.

1. **Develop a recovery organization** for the San Francisco Bay Area**.**
2. **Complete a performance audit** of our existing transportation infrastructure**.**
3. **Engage in hazard mitigation strategies** that shore up our existing transit infrastructure and add redundancy on our core transportation lines.

Recommendation #1: Do a "gap analysis" to determine what types of authority should be housed within a recovery organization for the San Francisco Bay Area, focused specifically on transportation.

No single entity, task force or organization in the San Francisco Bay Area is responsible for the region's recovery after a disaster. The Metropolitan Transportation Commission, in coordination with the Association of Bay Area Governments, needs to assess the need for the creation a transportation recovery entity that will function as the Bay Area's command center for transportation. Specifically, the MTC should determine what powers a regional recovery organization would need to facilitate coordination among the various transit operators and to help balance competing priorities. The MTC should conduct this analysis through its Transit Sustainability program.

In the short term, ABAG and the MTC should convene a group of high level public and private stakeholders to focus specifically on transportation recovery planning. This group should define plans and criteria for recovery before an event, and may be positioned to begin recovery very soon after the event. The group should study and form plans take action in a number of key areas:

- Organizational form, structure, roles and responsibilities of a recovery authority after a catastrophe
- Criteria and processes for transition from response to recovery
- Criteria for determining and setting priorities for investments in restoration, removal or improved rebuilding of damaged transportation facilities
- Features, facilities and services that are preferred for investment in restoration or rebuilding differently
- Desirable alternative states of transportation infrastructure, service and administration
- Reconfiguration of transportation infrastructure in response to observed damage after earthquake
- Compiling knowledge of best practices throughout the world for recovery and restoration of transportation systems

It addition to defining the criteria and processes for restoring and rebuilding transportation infrastructure, this group could also develop scenarios assuming various types, distributions and levels of severity of catastrophic events, and could use these scenarios as case studies for planning and executing the recovery and rebuilding of transportation systems.

Recommendation #2: Complete a performance audit of our existing transportation infrastructure.

SPUR's work on lifelines as part of its Before the Disaster efforts revealed that, for the most part, we don't know how our lifelines will perform during a disaster. We recommended that a lifelines audit be conducted, using the performance during both the "expected" and the "extreme" earthquakes as standards. Information on the extreme event is needed for immediate response planning, and information on the performance under the expected event is need for non-critical transportation infrastructure that will be needed during the recover phase. This recommendation should be extended to the Bay Area's transportation systems. The MTC should assess the performance of our existing transportation infrastructure, and report its findings within a year.

PERFORMANCE CATEGORIES FOR LIFELINES

Category I Resume 100 percent of service levels within four hours

Critical response facilities — including fire stations, hospitals, and facilities used for evacuation — need

to be supported by transportation systems critical to their operation. This level of performance assures that these facilities will be available within four hours of the disaster. It requires streets and roads that provide access to critical facilities and waterfront and airport facilities used for evacuations to resist significant damage; provisions for removing debris and making immediate repairs as needed; and establishment of alternative routes that allow troubled spots to be avoided.

Category II Resume 90 percent service within 72 hours, 95 percent within 30 days, 100 percent within four months

Residential neighborhoods and key commercial areas require that transportation systems be restored quickly so that these areas can be brought back to livable conditions. This category includes the Bay Bridge and Golden Gate Bridge, which should be re-opened to traffic immediately after post-earthquake inspections are complete; the main arteries of the US 101, I-80, and I-280 freeways, as well as key on- and off-ramps; the BART transbay tube and San Mateo County line; key MUNI lines; and facilities required for MUNI operation and maintenance. While this level of performance allows for repairs to lightly damaged facilities or establishment of temporary facilities and systems, these systems need to have a higher level of resilience and redundancy than the systems that support the rest of the city.

Category III Resume 90 percent service within 72 hours, 95 percent within 30 days, 100 percent within three years

The balance of the city needs to have its systems restored as buildings are repaired or replaced and returned to operation. There is time to repair and replace facilities with major damage and to replace older vulnerable systems with new systems. This category includes restoration of full service at the airport, all MUNI lines, Caltrain, all ferries and other waterborne transportation, all freeway on- and off-ramps, and less-traveled streets. Temporary systems can be installed as needed while long-term repair/replacement projects are completed. Most existing transportation systems will qualify for Category III performance.

Recommendation #3: Engage in hazard mitigation strategies that shore up our existing transit infrastructure and add redundancy on our core transportation lines

Some links are more important than others. Some links carry more traffic, or have more capacity, or have a higher risk of failing in an earthquake. How should we determine which projects are the most important to complete now – before the disaster – to help facilitate a rapid recovery after the disaster? SPUR believes that several hazard mitigation strategies are the most important to pursue:

- Complete ongoing or planned retrofits of regional systems, including Bay crossings, other freeway bridges and important links (e.g. the replacement of Doyle Drive), and the BART retrofit program
- Retrofit existing piers that are or can be used for ferry landings, and establish additional ferry landing sites
- Increase the resilience of fuel storage and distribution systems to promote rapid restoration of the fuel supply for transit providers, businesses and commuters
- Increase the resilience of facilities that support mass transportation (such as power supplies and maintenance facilities)

APPENDIX I: COORDINATION WITH OTHER REGIONAL LEVEL TRANSPORTATION EMERGENCY PLANS

SAN FRANCISCO BAY AREA TRANSIT OPERATORS MUTUAL AID AGREEMENT

The 10 largest Bay Area transit operators have entered into a mutual aid agreement to streamline the provision of voluntary mutual assistance among those operators to help ensure that public transportation services continue during emergencies to the maximum practical extent. This agreement facilitates multijurisdictional transit response during an emergency, if such a response is necessary. The following organizations are part of the mutual aid agreement:

- Alameda – Contra Costa Transit District
- Altamont Commuter Express Rail
- San Francisco Bay Area Rapid Transit District
- Contra Costa County Transportation Authority
- Golden Gate Bridge, Highway and Transportation District
- Livermore-Amador Valley Transit Authority
- San Francisco Municipal Transportation Agency
- San Mateo County Transit District
- Santa Clara County Transit District
- City of Vallejo

Assistance generally will be in the form of resources, such as equipment, supplies and personnel. Assistance will be given only when the lender determines that its own needs can be met before releasing its resources in support of the agreement.

The agreement provides necessary tools for the regional transit agencies to cooperate in an emergency and share resources and personnel. During a major catastrophic incident, most of these transit agencies would be severely affected, and aid from outside of the region would be necessary. The agreement is more useful for a smaller-scale local incident, which would not affect the entire San Francisco Bay Area region.

SAN FRANCISCO BAY AREA REGIONAL TRANSPORTATION EMERGENCY MANAGEMENT PLAN

The Metropolitan Transportation Commission developed and maintains the San Francisco Bay Area Regional Transportation Emergency Management Plan, the purpose of which is to improve the ability of Bay Area public transportation agencies to resume operations and deliver basic transportation services after a significant regional disaster. The Regional Transportation Emergency Management Plan is intended to provide guidance to the MTC, the California Department of Transportation and the largest Bay Area transit operators for coordinating response and recovery efforts, and for allocating assets to restore basic regional mobility.

The RTEMP is a regional plan and is not specific to San Francisco. It covers the nine San Francisco Bay Area counties under the jurisdiction of the MTC. This can be regarded as both a strength and weakness. For example, the RTEMP is not an operational document, but rather an emergency management document. One of the key strengths of the RTEMP is that it is linked to the SF Bay Area Transit Operators Mutual Aid Agreement through the MTC's Trans Response Plan, which translates to greater degree of collaboration among regional transportation entities[24].

SAN FRANCISCO BAY AREA REGIONAL EMERGENCY COORDINATION PLAN

The Regional Emergency Coordination Plan[25] was prepared for the California Emergency Management Agency, Coastal Region. It comprises a base plan and nine subsidiary plans that address specific disciplines and operational activities, such as care and shelter, hazardous waste, fire and rescue, transportation, and recovery. The RECP provides a framework for collaboration among responsible entities and for coordination during emergencies in the Bay Area. The RECP also defines procedures for regional coordination, collaboration and resource sharing among Bay Area emergency response agencies.

The RECP Recovery Subsidiary Plan provides the necessary framework around which to formulate regional mechanisms for the recovery of transportation infrastructure.

One of the imperative issues for the planning process is to designate a Transportation Recovery Task Force that would essentially coordinate the recovery effort after a major earthquake. The RECP Recovery Subsidiary Plan describes such a process whereby the governor would convene a Regional Recovery Task Force. This task force would engage representatives from the local government, private organizations, and government or nonprofit agencies active in recovery operations. The task force would incorporate the rebuilding plans of individual interests as well as larger regional restoration plans defined or mandated by public policy into a long range recovery vision. The City of San Francisco's involvement in such a task force would ensure that the state makes decisions that promote the recovery not just of the region, but also of San Francisco. According to the RECP Regional Recovery Plan, additional functions and structures are defined for the task force:

- Provide a community leadership forum for recovery issues that are regional in scope
- Encourage and oversee appropriate planning and analysis in support of recovery
- Develop regional solutions to issues involving multiple jurisdictions and counties
- Facilitate the establishment of priorities for activities if there is competition for recovery resources
- Represent the region's interests in discussions with the state and federal governments, particularly with regard to long term recovery planning under Emergency Support Function 14 (defined by Federal Emergency Management Agency) and disaster-specific initiatives at the state and federal levels
- Efficiently applies state and federal resources to regional recovery issues

Working groups may be established to manage regional issues associated with specific recovery issues. These working groups may include a number of topics and participants:

- Debris management – Integrated Waste Management Board, local public works departments, local waste management authorities and the California Environmental Protection Agency
- Transportation – local transportation agencies, the Metropolitan Transportation Commission and Caltrans
- Housing – local housing authorities and community development departments, the California Department of Housing and Community Development, private real estate firms and local planning organizations

Similar to the RTEMP, the RECP and its nine subsidiary plans are Cal EMA (California Emergency Management Agency) regional-level documents and not specific to San Francisco. Furthermore, the RECP does not incorporate the San Francisco Bay Area Transit Operators Mutual Aid Agreement**.**

[1] George Cooper Pardee papers: Speeches & Articles: "California, with over one hundred..." http://content.cdlib.org/xtf/view?docId=hb4f59n907&query=percent%20destroyed&brand=eqf

[2] George Cooper Pardee papers: Speeches & Articles: "California, with over one hundred..."http://content.cdlib.org/xtf/view?docId=hb4f59n907&query=percent%20destroyed&brand=eqf

[3] The Hayward Fault is also regarded as more dangerous due to the likelihood of the next major earthquake occurring on that fault. The Working Group on California Earthquake Probabilities has estimated there is 31 percent probability that a magnitude 6.7 or greater earthquake will occur on the Hayward Fault in the next 30 years. Working Group on California Earthquake Probabilities, 2007. *Uniform California Earthquake Rupture Forecast, Version 2.* United States Geological Survey Open File Report 2007-1437.

[4] Risk Management Solutions, Inc. 2008. *1868 Hayward Earthquake: 140-Year Retrospective.* RMS Special Report.

[5] BART Quarterly Daily Station Exits (October – December 2009) http://bart.gov/docs/Quarterly_Exits_Q22010.pdf

[6] Metropolitan Transportation Commission, *San Francisco Central Business District Analysis*, "Table 1: Total Employment in Downtown San Francisco 1980-2035 based on ABAG Projections 2000, 2005, 2007", June 2007

[7] Metropolitan Transportation Commission, *San Francisco Central Business District Analysis*, "Table 1: Total Employment in Downtown San Francisco 1980-2035 based on ABAG Projections 2000, 2005, 2007", June 2007

[8] "Caltrain Downtown Extension and Transbay Ridership Analysis" prepared by Cambridge Systematics, Inc. for the Transbay Joint Powers Authority. Final Report, November 2008. Data derived from both draft and final reports. Additional analysis prepared by Cambridge Systematics, Inc and Arup.

[9] Ibid.

[10] Metropolitan Transportation Commission, San Francisco Central Business District Analysis "Travel_Forecast_Data_Summary_Jan2005.xls";June 2007

[11] BART's Earthquake Safety Program is scheduled for completion in 2014, while the Transbay Tube seismic work will be finished in 2011. http://www.bart.gov/about/projects/eqs/updates.aspx http://www.bart.gov/docs/eqs/ESP%20General%20Presentation.pdf, accessed June 15th, 2010

[12] "Caltrain Downtown Extension and Transbay Ridership Analysis" prepared by Cambridge Systematics, Inc. for the Transbay Joint Powers Authority. Final Report, November 2008 and "Transbay Ridership Analysis: Draft Report" prepared for Alameda-Contra Costa Transit, Transbay Joint Powers Authority, Metropolitan Transportation Commission, San Francisco Water Transit Authority, August 2007. Data derived from both draft and final reports. Aditional analysis prepared by Cambridge Systematics, Inc and Arup.

[13] Ibid.

[14] Email correspondence with Lauren Duran, Administrative/Policy Analyst at Water Emergency Transportation Authority, December 16, 2009.

[15] Person trips assumes 1.2 passengers per vehicle.

[16] Caltrans: 10,600 vehicles enter and exit San Francisco on the two freeways during the peak hour.

[17] Caltrans 2007 Traffic Volumes on California State Highways and SamTrans ridership data per conversation with Ted Yurek (May 2009) and SamTransSFRidershipMay2009.pdf

[18] "Caltrain Downtown Extension and Transbay Ridership Analysis" prepared by Cambridge Systematics, Inc. for the Transbay Joint Powers Authority. Final Report, November 2008 and "Transbay Ridership Analysis: Draft Report" prepared for Alameda-Contra Costa Transit, Transbay Joint Powers Authority, Metropolitan Transportation Commission, San Francisco Water Transit Authority, August 2007. Additional analysis prepared by Cambridge Systematics, Inc and Arup.

[19] Assumes an average of 1.2 passengers per vehicle.

[20] Golden Gate Bridge, Highway and Transportation District

[21] Golden Gate Bridge, Highway and Transportation District, Golden Gate Ferry Schedules - from http://goldengateferry.org/schedules/

[22] Email from Lauren Duran, Administrative/Policy Analyst at Water Emergency Transportation Authority, December 16, 2009

[23] Data from the San Francisco Municipal Transportation Authority's Transit Effectiveness Project: http://www.sfmta.com/cms/rtep/tepdataindx.htm (Accessed on June 16th, 2010)

[24] Trans Response Plan is the transportation plan that Bay Area transportation agencies are using for all emergencies, including evacuations. It was first developed in 1997, and has been tested every year since then. There has not been an actual emergency situation that has activated the Trans Response Plan.

[25] The full version of the plans can be accessed at the governor's Office of Emergency Services Web site at http://www.oes.ca.gov/WebPage/oeswebsite.nsf/content/F39818FB706ECED68825743D00738C6A?OpenDocument