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Study of Integrated Corridor Management for San Francisco Bay Area I-880 Corridor

Wei-Bin Zhang, et al.

California PATH Research Report
UCB-ITS-PRR-2008-30

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Final Report for Task Order 6612

November 2008

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Final Report for Task Order 6612

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Abstract

This document summarizes the efforts by the San Francisco Bay Area ICM team to develop the concept of operation, data needs and performance requirements for an Integrated Corridor management System for I-880 Corridor. Although the transportation management systems at the Bay Area are consistent with the regional ITS plans, these management systems are less integrated. It is believed that higher level of integration among freeway and arterial systems, transit systems with considerations of all transportation needs and demands in the region will greatly enhance and improve the efficiency and productivity of all individual systems. ICM benefits include, to name a few, enhanced ability of the partner agencies to provide true integration of multiple operational components of the corridor, better management of non-recurrent congestion caused by major incidents, unexpected weather events, unexpectedly high travel demand, and major construction and maintenance activities by allowing the full capacity of the corridor to be utilized through improved integration, and improved capabilities to manage daily recurrent congestion in the corridor.

Keywords

Integrated Corridor Management, ITS

Table of Contents

Executive Summary

Under the Integrated Corridor Management (ICM) program sponsored by the United States Department of Transportation, the San Francisco Bay Area I-880 corridor ICM team has developed the Concept of Operations, data report and system requirements, documented in three reports:

1. I-880 ICM Concept of Operation
2. I-880 ICM Sampla Data for Analysis, Modeling and Simulation
3. I-880 ICM System Requirements

This report summarizes the findings in these three reports.

<u>Existing Conditions:</u>
The I-880 corridor in Alameda County is a long and densely populated urban corridor connecting a major employment center (Silicon Valley in the south) with the Port of Oakland, Oakland International Airport, and major population centers including the Cities of Oakland, Alameda, San Leandro, Hayward, Fremont, and Union City. It is a truly multimodal corridor, including a robust freeway network, major arterials which carry high volumes of local traffic as well as absorb diversion from the freeway networks, a transit network which includes the Bay Area Rapid Transit (BART) rail system and multiple AC Transit bus transit lines, and heavy freight movements with trucks comprising between 4% and 11% of the average annual daily traffic in the corridor.
Transportation management systems (TMS) have been widely deployed in the corridor for many years including: a) ramp metering on I-880; b) HOV lanes and HOV bypass lanes for ramp meters; c) incident and emergency management systems on all freeways; d) changeable message signs on freeways; e) electronic toll collection systems (FasTrak); f) coordinated traffic signal systems on major arterials; g) BART transit management system; h) bus transit with signal priority capabilities and AVL; and i) transportation management centers for freeways, arterials, BART, bus transit and the Port of Oakland.
The transportation management systems are consistent with the regional ITS plan, the national ITS architecture, and the Caltrans strategic plan for TMS. These management systems are semi-integrated, with higher levels of integration at freeway and arterial systems, and lower integration levels at BART and bus transit systems.
An institutional integration/coordination setting is already in place: the Metropolitan Transportation Commission (MTC), California DOT (Caltrans), Alameda County Congestion Management Agency (ACCMA), BART, Alameda-Contra Costa Transit District (AC Transit), and cities in the corridor have a history of cooperation.

<u>Concept of Operations:</u>
The I-880 corridor team has defined this Concept of Operations (ConOps) based on two primary principles: (1) it must improve overall corridor performance by meeting the needs of the local stakeholder agencies, within their practical operational, institutional and financial constraints; and (2) it must focus on integration of pre-existing systems rather than

on implementation of new equipment or infrastructure. Considering that the individual transportation networks within the corridor are already generally well equipped with ITS systems, this is not as serious a limitation. A set of strategies were developed, each representing a high level of stakeholder interest in maximizing the opportunities for corridor integration. These strategies are summarized in the Table below.

(A) Influencing Travelers' Decisions & Choices and Traveler Information Strategies	
	A corridor-based advanced traveler information system (ATIS) database that provides information to travelers for pre-trip and en-route decisions, across all networks.
	Promote route shifts between roadways via en-route traveler information devices (e.g. DMS, HAR, "511") advising motorists of congestion ahead, directing them to adjacent freeways or arterials.
	Promote modal shifts from roadways to transit via en-route traveler information devices (e.g. DMS, HAR, "511") advising motorists of congestion ahead, directing them to high capacity transit networks and providing real-time information on the number of parking spaces available in the park and ride facility.
	Promote shifts between transit facilities via en-route traveler information devices (e.g. station message signs and public announcements) advising riders of service outages and directing them to adjacent rail or bus services.
(B) Facilitating Collaboration among Agencies for Operational Improvement	
Integrated Freeway/Arterial Operations	
	Coordinated operation between freeway ramp meters and arterial traffic signals to accommodate traffic shifts in both directions.
	Enhance arterial signal timing with advance information about special events at Coliseum.
Coordinated Roadway/Transit Operations	
	Signal priority for transit (e.g. extended green times to buses that are operating behind schedule).
	Adjustment of AC Transit bus operations based on real-time information about highway traffic and special events.
Integrated Transit Operations)	
	Transit hub connection protection for incidents and emergencies
Collaboration between Freeway Operations and Port of Oakland)	
	Port of Oakland advises trucks travel time based on real-time traffic information.
Coordination with Emergency Services)	
	Signal pre-emption or "best route" for emergency vehicles.
Coordination for Incident Response)	
	Multi-agency or multi-network incident response teams and service patrols and training exercises.
(C) Facilitating Collaboration among Agencies for Event Planning	
	Coordinate scheduled maintenance and construction activities among networks.
	Guidelines for construction work hours during emergencies or special events.

Data Summary:

Transportation facilities in the corridor are highly instrumented with real-time data collection systems. Real-time data collection capabilities include: a) the freeway Performance Monitoring System (PeMS); b) the Smart Corridor system focusing on arterials; and the rail and bus transit operations systems. Furthermore, through the California Model Corridor Study high-quality data have been collected and used in modeling and

microsimulation of all networks in the I-880 corridor; these data and models are readily available for use in the analysis of ICM opportunities in the corridor. Specifically for 880 ICM Field of Operational Tests, the primary operation agencies along 880 have all agreed to add additional instrumentation and communication to facilitate high quality real-time traffic and transit data to support quantitative before-and-after evaluation.
As the I-880 corridor is both operational and institutionally complex compared to most corridors in the U.S., the experience gained and lessons learned from deployment of ICM along I-880 can help other regions in the U.S learn how to deploy ICM in less complex environments.

System Requirements: The I-880 ICM team developed the system requirements for the I-880 Integrated Corridor Management System (ICMS). It describes the approach that the I-880 team took in defining the ICMS and in developing ICMS requirements:

- General requirements (non-functional requirements)
- Functional requirements
- Data requirements
- Interface requirements

The functional requirements provide a complete description of the behavior of the ICM system to be developed. The general requirements contain non-functional requirements which impose constraints on the design or implementation (such as performance requirements, quality standards, or design constraints). Data requirements define the information needed to perform the desired functions. Interface requirements specify the requirements imposed on one or more ICMS subsystems, Hardware Configuration Items (HWCIs), Computer Software Configuration Items (CSCIs), manual operations, or other system components to achieve one or more interfaces among these entities.
These requirements were developed using the systems engineering approach, under the guidance of USDOT and the IEEE 1233 Guide for System Requirements Specifications. As per DOT requirements, this document adopted some contents from the I-880 ICM Concept of Operations document in order to make it a stand-alone document so that readers can understand the context of the ICMS requirement without needing to read the ICM ConOps document.

1. Existing Corridor Scope and Operational Characteristics

1.1 Corridor Boundaries and Networks

The San Francisco Bay Area is the fifth most populated metropolitan area in the United States, and the I-880 corridor is centrally located within the region. The I-880 corridor starts from the connector of freeways I-880, I-80 and I-580 and ends at SR237. A number of parallel arterial highways, including Highway 185 (International Blvd./E14 blvd. Fremont Blvd) and San Leandro St., are part of the I-880 ICM corridor. I-880 ICM corridor provides connectivity between densely populated residential areas and many major commercial and industrial centers. The corridor also plays a key role in freight and goods movement, directly serving the Port of Oakland, the fourth busiest port in the United States. Thus, the efficient operation of I-880 is of critical economic importance to the region the state, and the entire nation. The I-880 corridor is truly a multi-modal, multi-use urban freeway corridor.

1.1.1 I-880 Freeway

As one of the main arteries of the freeway system in the Bay Area, I-880 consists of 45 miles of freeway connecting Silicon Valley with the East Bay. Major interchanges in the corridor include junctions at SR-112 (Davis Street in San Leandro), I-238 (connecting I-880 in San Leandro to I-580), SR-92 (from Hayward, west to the San Mateo-Hayward Bridge), SR-84 (from Fremont, west to the Dumbarton Bridge), and SR-262 (Mission Blvd. in Fremont, east to I-680).

I-880 serves the Port of Oakland, Oakland International Airport, and the Oakland Intermodal Gateway Terminal (the Joint Intermodal Terminal), the Oakland Coliseum, as well as a major concentration of industrial and warehouse land uses. I-880 serves as both an access route for major inter-regional and international shippers and a primary intraregional goods-movement corridor.

The I-880 ICM team has selected the segment of the I-880 corridor between the cities of Oakland and Fremont in Alameda County, with the I-580/I-80 interchange as the northern boundary and SR-237 as the southern boundary (a distance of about 38 miles and 250+ lane miles). This is a logical segment for the Integrated Corridor Management project as it matches the existing institutional agreements in place for the corridor management plan. In addition, the necessary infrastructure is already in place to support the integrated corridor management functionality, without major additional investments.

FIGURE 1.1a CORRIDOR MAP

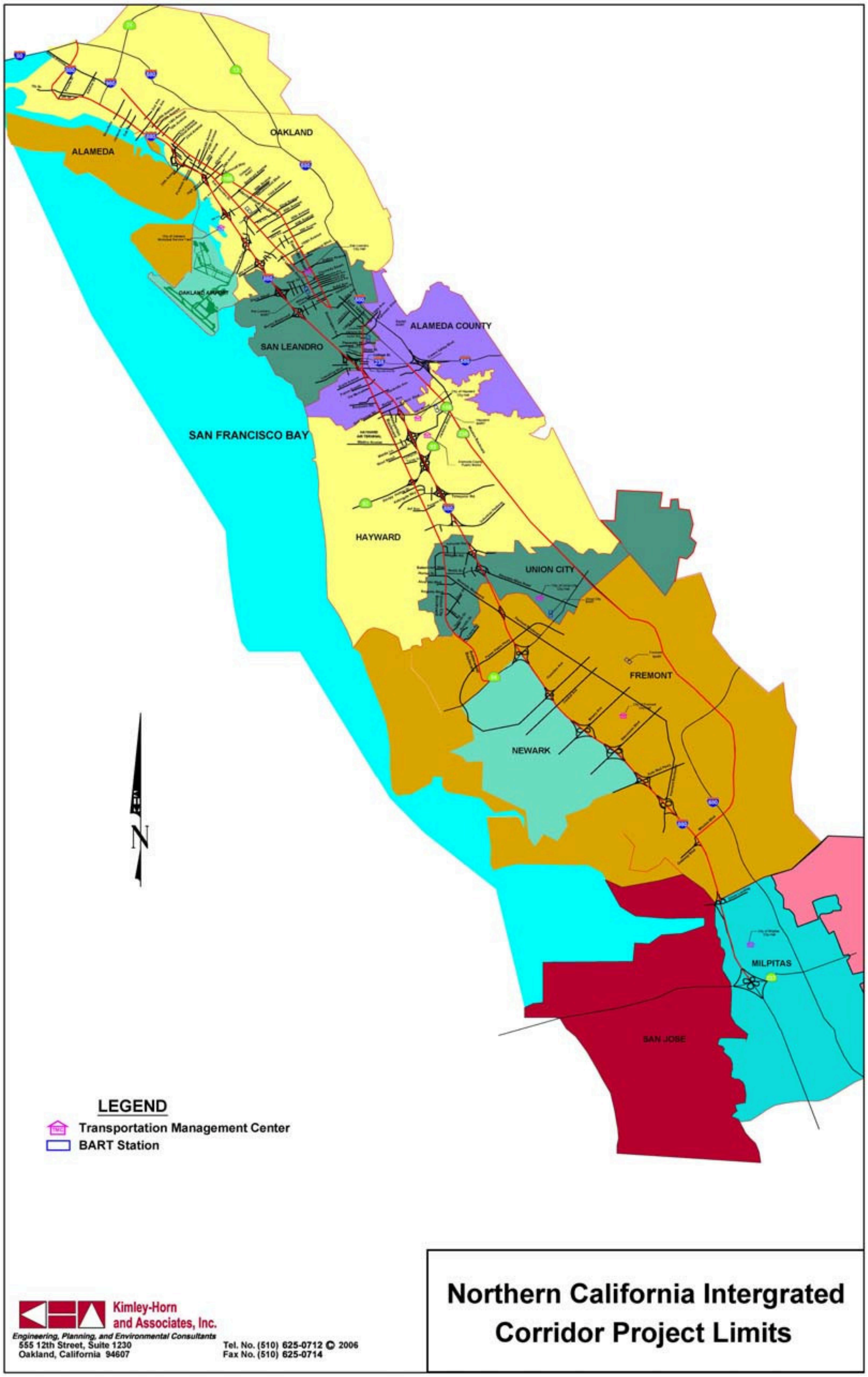
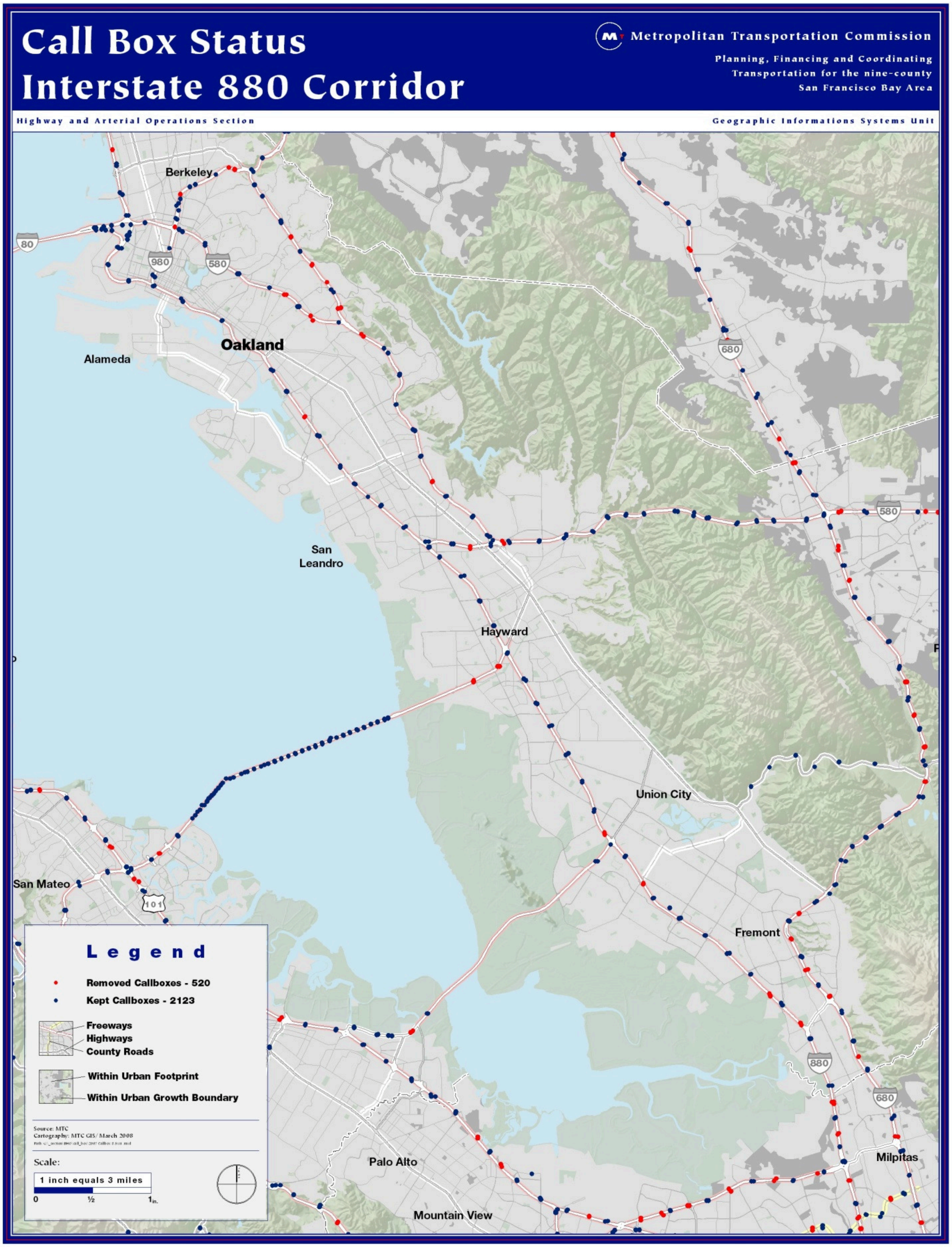


FIGURE 1.1b CORRIDOR CALL BOX MAP



1.1.2 Arterial Highways

There are a number of major north-south arterials along the entire project corridor on both sides parallel to I-880, with connecting arterials to the freeway segment. On the east side of the I-880 corridor, Mission Blvd (SR-238) and E.14th Street/International Blvd (SR-185) forms a continuous corridor from the southern limit of the project corridor to the northern limit.

On the west side of the I-880 corridor, the major north-south parallel arterials form a continuous segment from the southern limit of the project corridor, starting at the Ardenwood Blvd, Union City Boulevard and Hesperian Blvd, crossing I-880 in San Leandro and joining the E. 14th Street. On the east side of the I-880 corridor, Doolittle Drive (SR-61) serves the Port of Oakland and Oakland Airport and is connected to the I-880 corridor via Davis Street (SR-112), 98th Avenue and Hegenberger Road.

These major arterials link to a number of other key arterials that connect to the I-880 freeway. These connections include:

- 29th Avenue (Oakland)
- 42nd Avenue (SR-77) (Oakland)
- Hegenberger Road (Oakland)
- 98th Avenue (Oakland)
- Davis Street (SR-112) (San Leandro)
- West A Street (Hayward)
- West Winton Avenue (Hayward)
- Tennyson Road (Hayward)
- Industrial Parkway (Hayward)
- Alvarado Niles Road (Union City)
- Alvarado Blvd (Union City)
- Paseo Padre (Fremont)
- Fremont Blvd. (Fremont)

Within downtown Oakland, the major arterials include 14th Street, Broadway and Grand Avenue, where it joins the I-880 corridor at the northern limits of the project corridor.

Major portions of these arterial networks are currently included in the East Bay SMART Corridors program. The East Bay SMART Corridors program includes East 14th/International Boulevard, East 14th Street, San Leandro Boulevard/Street, Hesperian Boulevard, and Union City Boulevard; this arterial corridor is approximately 18 miles long and parallels I-880 from downtown Oakland to Union City.

1.1.3 AC Transit Bus Routes

AC Transit operates a number of Regional Express Bus routes and dozens of local bus lines in the proximity of the I-880 corridor. This includes Route 82/82L, a key high-ridership trunk line along the I-880. This route operates 24 hours a day from the Hayward BART station (Bay Fair BART for 82L) to downtown Oakland via E.14th Street and International Boulevard. Figure 3.2 is the AC Transit route map for most of the East Bay, which includes Route 82/82L. Regional Express Bus lines using I-880 include Line S (South Hayward to San Francisco), Line SA (San Lorenzo to San Francisco), Line SB (Newark to San Francisco), Line OX (Harbor Bay / Alameda to San Francisco), Line O (Alameda to San Francisco), and Line W (West Alameda to San Francisco). The following table is a summary of transit service along East 14th/International Blvd:

TABLE 1.1

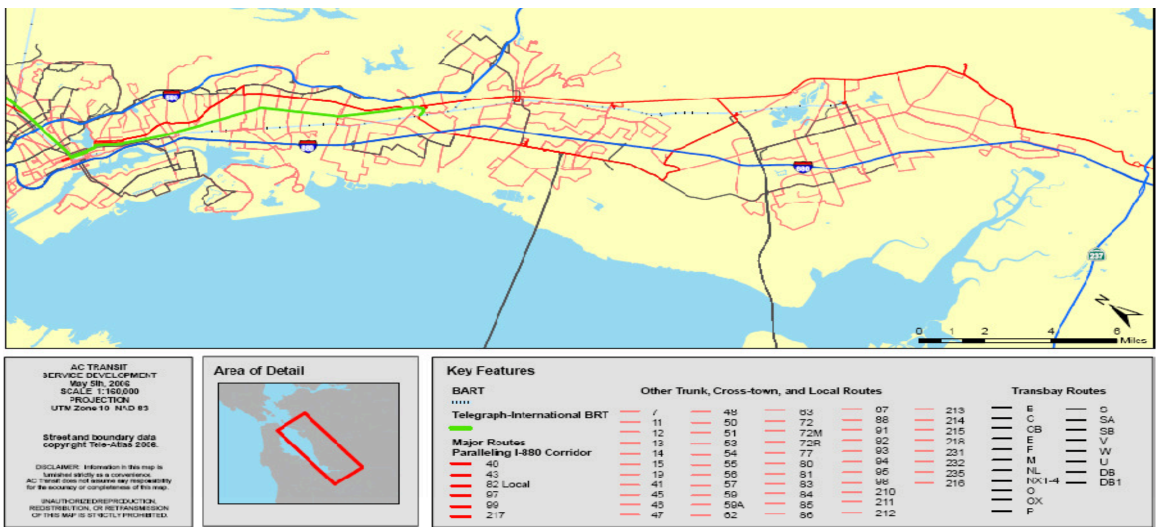
Existing Transit Service on E. 14th Street/International Boulevard

	Weekday Service				Weekend Service		
	Daily Operating	Service Frequency (min)			Daily Operating	Service Frequency (min)	
	Span	Peak	Base	Eve	Span	Base	Eve
al	24 hours	12	15	No service	24 hours	15-60	No service
al (SL AIR	7:30 p.m. to 7:00 a.m.	No service	No service	15-60	7:00 p.m. to 10:00 a.m.	No service	15-60
nal ntown T)	7:00 a.m. to 7:00 p.m.	12	15	No service	10:00 a.m. to 7:00 p.m.	15	No service

AC Transit is in the process of implementing Bus Rapid Transit (BRT) between Berkeley and San Leandro along the E.14th Street/International Blvd. corridor. Completion of the first phase of arterial infrastructure to support BRT operations was completed in January 2007, featuring signal coordination and transit priority. Phase Two is scheduled to begin in 2008 and will feature dedicated transit ways at a large percentage of its run-ways and significant ITS and other technological improvements. Ridership for the BRT is anticipated to reach about 30,000 boardings per day in the next 20 years, which is almost double the current ridership for the corridor. Construction of the full BRT project is scheduled for completion in 2008.

FIGURE 1.2

AC Transit Route Map



1.1.3.2– OTHER BUS TRANSIT SERVICES

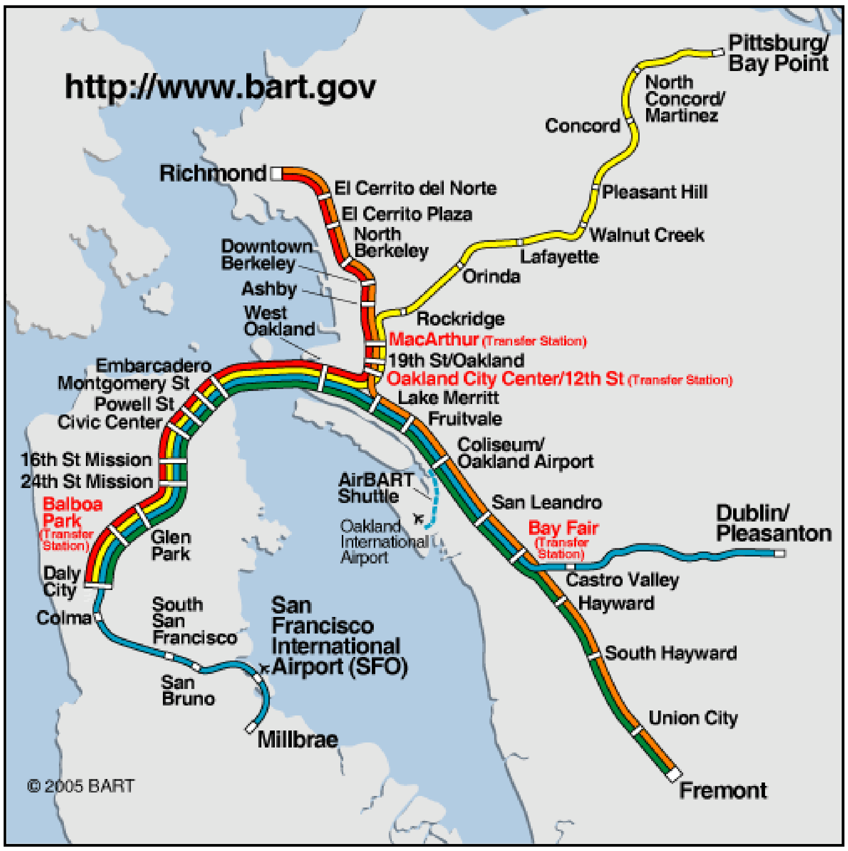
The **Santa Clara Valley Transportation Authority (VTA)** operates primarily in Santa Clara County, but has bus service linking the Fremont BART station to its light rail network as well as ACE and Caltrain stations in Santa Clara and San Jose Diridon Station. **Union City Transit** provides bus transit service exclusively within Union City, including the key arterial Alvarado-Niles Blvd.

1.1.4 Transit Rail (BART)

1.1.4.1 San Francisco Bay Area Rapid Transit District (**BART**) is a public rail rapid-transit system that serves major parts of the San Francisco Bay Area, including the I-880 corridor. The total system comprises 104 miles of track and 43 stations. Figure 1.3 shows the BART system, which along I- 880 corridor includes 20 miles of track and 12 BART stations. BART is connected to regional rail and bus services and to San Francisco International Airport and Oakland International Airport (via AirBART buses).

FIGURE 1.3

BART System Map



1.1.4.2 Intercity Passenger Rail Lines

Two intercity passenger rail lines provide service along the I-880 freeway corridor, providing additional travel options for commuters and interregional travelers.

Amtrak Capitol Corridor is an intercity passenger train system that provides a convenient alternative to traveling along the congested I-80, I-680 and I-880 freeways by operating intercity rail service connecting the Sacramento and San Francisco Bay Areas. This includes 16 stations in 8 Northern California counties (Placer, Sacramento, Yolo, Solano, Contra Costa, Alameda, San Francisco, and Santa Clara) along a 170-mile rail corridor. An extensive, dedicated Amtrak motorcoach network provides connecting bus service beyond the Capitol Corridor route. The Amtrak Capitol Corridor is operated by a Capitol Corridor Joint Powers Authority (CCJPA), which is managed by the Bay Area Rapid Transit District (BART) with support from Amtrak and Caltrans. The CCJPA Board consists of representatives from the eight counties in The Capitol Corridor. Within the I-880 ICM corridor limits, the Amtrak Capitol Corridor runs parallel to the BART tracks with key stations at Jack London Square in Oakland, Coliseum/Oakland Airport, and Fremont Centerville Station. The Coliseum Station is a true “cross-platform” connection point with BART.

Altamont Commuter Express (ACE) rail line provides service from Stockton in San Joaquin County to San Jose in Santa Clara County. The route parallels the highly congested I-580 corridor, part of the I-680 corridor (Sunol Grade), then along I-880 (Fremont Centerville Station, Great America, Santa Clara, San Jose). Near the southern limits of the I-880 ICM corridor, the rail line connects from the Diridon Intermodal Station to Fremont Centerville Station, and has an intermediate stop at the Great America Intermodal Station (just south of SR-237). The possibility of Union City BART Station becoming an intermodal connection for the Altamont Commuter Express (ACE) and the proposed Dumbarton Rail line has also been discussed.

1.1.5 Water Transit Authority

The Water Transit Authority (WTA) operates a comprehensive San Francisco Bay Area public water transit system. Alameda-Oakland-San Francisco is the most popular route.

1.2 Individual Network and Corridor Problems, Issues and Needs

1.2.1 Freeway System

In the Bay Area, Alameda County has the greatest amount of freeway congestion, with 50,000 vehicle-hours of daily delay. I-880 alone has average daily delays of more than 10,000 vehicle-hours. The corridor has multiple bottleneck locations and a high incident/accident rate.

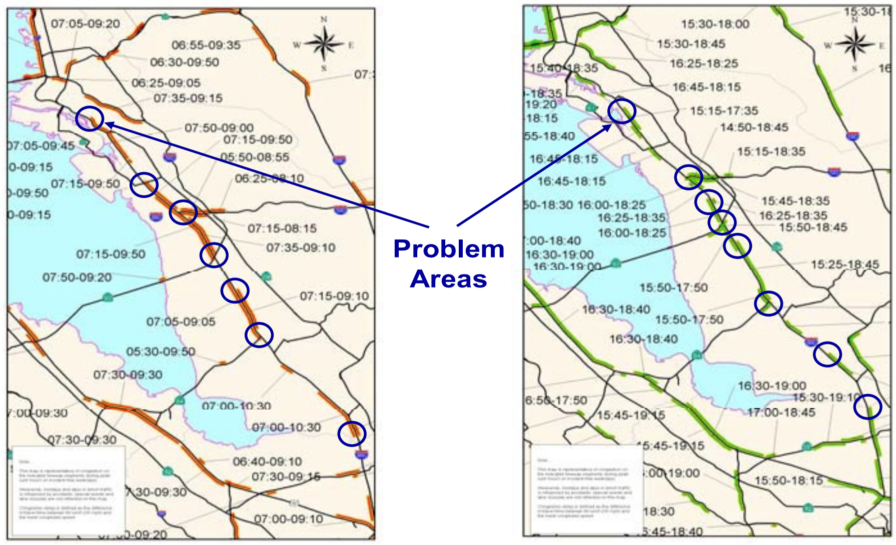
In order to address the increasing congestion problem, Caltrans is currently conducting a corridor management study for the I-880 corridor. The study builds on Caltrans District 4's corridor analysis efforts to blend long-range planning with near-term operational strategies on 24 corridors in the San Francisco Bay Area. This prior work included a review of possible improvements on the I-880 corridor to prioritize future projects and to incorporate traffic operation strategies into the corridor. The current corridor management study for the I-880 corridor is funded by Caltrans and is being conducted by the California Center for Innovative Transportation (CCIT) of the University of California at Berkeley and a team of consultants. As an important part of this study, micro-simulation models using Paramics for the I-880 corridor have been developed, building on the Alameda County travel demand model. The study is to be completed in the summer of 2006. Extensive research was done with available detection, ramp metering, accident, incident data, and field observations to identify problem areas in the corridor. Intermediate results of the performance evaluation task under this study have already revealed some important findings on recurrent congestion and its potential causes.

Figure 1.4 shows the problem areas along the I-880 freeway (circled in blue), further described in Table 2 which shows potential causes. Recurrent congestion is the result of demand exceeding capacity at several bottlenecks, related to interchange in-flow traffic from other highways (e.g., 238) and on-ramps (e.g., Tennyson). There are locations at the northern end of the corridor with older interchanges not updated to current standards, and closely spaced ramps with weaving problems. This corridor includes freeway-to-freeway junctions at three locations that lead to transbay toll crossings at the Bay Bridge, San Mateo-Hayward Bridge, and Dumbarton Bridge. Operational strategies for the I-880 corridor need to be coordinated with operational strategies for the Bay Area toll bridges, and demand management needs to be integrated with traffic management strategies at the arterials and also with intermodal opportunities. Furthermore, trucks comprise between 4% and 11% of the average annual daily traffic in the corridor. Truck traffic is highest at the junctions in Oakland near the Port of Oakland (26,000 trucks and 11% of total traffic), and trucks comprise about 8 to 9% of total traffic at the junctions of Hegenberger Road (to Oakland Airport), SR-112 in San Leandro and I-238 in Hayward.

Non-recurrent congestion is also a major problem on this corridor. I-880 averages over 10 collisions per day and over 100 incidents per day. The most severe incidents often involve heavy trucks, and consequently the incident response and recovery takes longer than average incident response and recovery time across the state. It is estimated that collisions account for 30 percent of overall corridor delay.

FIGURE 1.4

I-880 bottleneck locations identified through simulation model



1.2.2 Arterial System

A parallel study on SMART Corridor conducted by ACCMA has focused on the arterial highways. The study results show that the arterials along the project corridor currently operate at level of service C to E or worse during the peak hours. Due to incidents on the freeway, there are routine diversions to the local arterials that will increase the delay and reduce the levels of service along these arterials. Therefore, coordination of the operation of the network of arterials, ramp metering and the freeway is crucial to optimizing the overall capacity of the system.

1.2.3 AC Transit

AC Transit system operates on several arterial roadway systems along 880 ICM Corridor with the other traffic. The increasing congestion in the region is the major challenge for AC Transit to operate their buses on time. Improving running time is a high priority for AC Transit to meet their goal of an effective and efficient transit system. As indicated in Section 3.4.3.3, AC Transit collects bus operation data, including vehicle movements, running time, schedule adherence reports for its entire fleet every 2 minutes using AVL associated with the Orbital system. Bus predictions on a number of routes are also provided by NextBus systems. Additionally, Automatic Passenger Counters are used to collect ridership and schedule adherence data.

To improve day to day operations, AC Transit is actively engaged in finding efficient ways to use their resources using the cutting edge of transportation technology.

AC Transit has introduced Rapid Bus service along San Pablo Corridor in collaboration with ACCMA. The 72R Rapid Bus line, a first in Alameda and Contra Costa Counties, was launched in the summer of 2003 has been a tremendous success, both in terms of ridership and travel time to destination. NextBus signs are installed at nearly every stop along the line providing bus arrival information. The Transit Signal Priority (TSP) at the intersections helps reduce the intersection delays for AC Transit buses. As a part of East Bay SMART Corridors program, emergency vehicle preemption and transit signal priority equipment is being installed along the East 14th Street/International Boulevard Corridor. Operational strategies of the AC Transit could be coordinated with traffic signal operations on other arterials to have integrated traffic management strategies.

The AC Transit's system is based on pre-determined routes and schedules and the system is not flexible to accommodate dynamic schedules and route decisions based on real-time traffic information. Another operational constraint that AC Transit has to face during incidents is that, the service cannot bypass any bus stops unless it is absolutely necessary due to intending riders that may be waiting for the bus. When it is necessary to bypass any bus stops, other means needs to be adopted to convey the message to the riders. AC Transit utilizes information from ACCMA East Bay SMART Corridors website to obtain real-time traffic information on the arterials to make decisions about the re-routing of buses during an incident. AC Transit has the control over the SMART Corridors' CCTV cameras when needed to have more coverage of the traffic conditions. This information is very useful for the AC Transit supervisors to make decisions about the transit operations during an incident. To improve their route making decisions, real-time traffic information on freeways and control over Caltrans Dist 4 cameras on as needed basis will be useful for AC Transit.

The current Orbital software version that AC Transit is using is many versions behind the current version offered by Orbital TMS. Upgrading the current software and the hardware it uses will be essential for AC Transit to improve the efficiency of fleet operation, and prepare for the integration of other operational systems in the future including real time systems.

1.2.4 BART

BART plays a major role in the mobility along the 880 corridor accommodating huge ridership levels as indicated in Section 3.3.2.4. Any kind of disruption in BART service has a huge impact on the corridor not just the commuters. BART operates on a grade-separated system unlike AC Transit and the traffic congestion does not have direct impact on normal operations. However, real-time traffic information in the corridor will help BART to anticipate the needs during an incident and to plan immediate actions. There is no direct information exchange between MTC's 511 and BART in the current operational scenario. For automated and complex operations like BART system, more information is always helpful to make instantaneous decisions.

Along the 880 corridor, the headway between the BART lines is 5 to 6 minutes. Any simple incident will cause huge backup and takes time to restore back to normal conditions. With the ICM concept, the coordination between different agencies involved and emergency response teams could to be improved to cut down response time.

Most of parking lots at the BART stations along the 880 corridor are full during the weekdays. In the case of emergency where there is a need for a modal shift, BART does not have means to accommodate vehicles at the BART parking lots. In such cases, agreements with agencies who own parking lots in the vicinity of BART station could be considered to accommodate the excess flow.

1.3 Corridor Management Strategies Already Implemented for the I-880 Corridor

The Bay Area Transportation Agencies have already adopted a number of corridor management strategies, namely pre-ICM operation strategies, to improve network efficiency and to mitigate incidents. The highway meltdown incident that recently occurred in the Bay Area tested these strategies at work.

In the early morning hours of April 29, 2007, a tanker fire destroyed two vital freeway connectors in the I-80/580/880 interchange at the north end of the I-880 ICM corridor in Oakland, California. This unfortunate emergency provided the opportunity for the Oakland Pioneer Site Team to apply a variety of strategies:

- 511 Traveler Information System provided pre-trip information to the public for alternate routes and multi-modal transit options. Immediately following the incident, 511 call & web volumes surged and highway traffic volumes decreased.
- In-route dynamic messages signs were activated and 511 phone system “floodgate” announcements were created to promote route shifts between roadways.
- Automated data collection systems provided instantaneous traffic performance information to system operators and to the media.
- Arterial signal timing was manually adjusted to accommodate diverted highway traffic --a function that could be enhanced in the future through remote signal operations.
- Transit agencies modified operations. AC Transit adjusted routes and increased its operational fleet size. BART lengthened trains and deployed parking alternatives for select stations to accommodate increased transit ridership.

Although most of these strategies required manual communication and interventions and are in many ways not yet comprehensive, they have demonstrated potential benefits of ICM strategies. Coordinated network efforts resulted in the successful multi-modal and multi-agency response to the loss of a critical segment of the Bay Area's regional transportation system.

1.4 The Needs for ICM

The I-880 corridor stakeholders have identified a set of corridor-level needs specific to the I-880 corridor that would be served by a fully-functioning ICMS.

I. Need for robust information sharing among different transportation systems	**(N1)** Need for cross-systems information Sharing: Information and data sharing among transportation systems is essential for achieving close coordination and integration among agencies, thereby to achieve balanced transportation service and reduced congestion levels for the I-880 corridor. Developing a consistent and reliable means of sharing information will ensure that the corridor can truly be managed in an interactive and dynamic way. By interactive and dynamic, any transportation agency along the corridor can monitor the condition of all networks along the corridor in real time and can interact with the others to achieve coordinated management of the transportation systems as a whole.
II. Need for more comprehensive traveler information to influence travelers' decisions and choices	**(N2)** Need for or a corridor/regional based multimodal traveler information system: To encourage mode shift and route shift, a corridor/regional based multimodal traveler information system that supports pre-trip planning and in-trip route shifts is needed. Travelers on the corridor would benefit greatly from having accurate real-time information on whether other routes or modes along this corridor would be better choices for them. The information will facilitate smart travel decisions and encourage the use of transit systems.

III. Need for enhanced operational collaboration among agencies	Operational decisions for the corridor are largely done by each mode and network independently. Although there is some coordination, these processes are largely manual and not well integrated. As a result, overall corridor efficiency would be significantly enhanced by instituting true collaboration among all modes and networks. **(N3)** Needs for coordination between freeway and arterial operations: Coordination between freeway and arterial highways is needed in order to guide vehicles from one system to the other when either unbalanced demands or major incidents occur on one system, causing significant delay. The coordination between the two systems can help to effectively use existing transportation infrastructure and to mitigate congestion.
	(N4) Need for coordination between highway and transit operations: Coordination between transit vehicles and arterial traffic control is needed to allow the buses to have minimum intersection delay. Dispatchers at the AC Transit Operation Control Center can also be benefited by traffic condition data from highways and freeways within the operation area in order to provide best guidance to drivers to avoid large incidents and to achieve on-time performance.
	(N5) Need for coordination between transit systems: Close coordination between AC Transit, BART and the Oakland Ferry is needed to provide better connection protection for major events and for incident mitigation. Real-time information sharing by ICM will facilitate better collaboration when incidents or service disruptions occur.

(N6) Need for coordination between highway and freight operations: Coordination between highway operations and the Port of Oakland can help truck drivers make decisions about their departure time and route between Central Valley truck 'hubs' and the Oakland Port depending on traffic conditions along I-880 and the status of the port operation. Therefore, there is a need for ICM to collect the traffic information and port operation status. This information can then be provided to truck drivers and the Port of Oakland. This coordination will not only help truck drivers to arrive at the port on time, but also reduce unnecessary trips during peak hours when their scheduled loadings have been delayed, which consequently will help to reduce congestion.

(N7) Need for Coordination between highway control systems and emergency response: Signal pre-emption infrastructure has been available for major intersections along arterial highways parallel to the I-880 corridor. There is a need for emergency vehicles, including not only fire fighting vehicles but also police and paramedics vehicles to have signal preemption capability for the intersections that are preemption capable. Additionally, it is desirable that 'Best route' information be available for emergency service agencies in order to reduce emergency response time.

(N8) Need for coordination for incident response: Major incidents can involve hours-long road closures, hazardous materials spills, extreme weather conditions, and multi-vehicle pile-ups. There is a need for coordination among agencies for incident response in order to timely resolve the incidents and re-open the road. The coordination involves better real-time data for incident detection and information exchange among agencies for collaborative responses.

IV. Need for enhanced Event Planning and collaboration among agencies	**(N9)** Need for coordination for infrastructure construction and maintenance: Because of the large venues along the corridor, a coordinated special event response strategy would greatly enhance travel reliability. There is a need for coordination of event planning among agencies for effectively managing traffic around infrastructure construction and maintenance areas and for publishing accurate information ahead of time to the public regarding the scheduled construction and maintenance in order to facilitate route and mode shifts.
	(N10) Need for coordination of construction work during emergencies: The San Francisco Bay Area is particularly exposed to earthquake and fire hazards. There is a great need to develop and implement comprehensive cross-agency guidelines and protocols for transportation agencies to effectively coordinate the post emergency repair and construction. The guidelines and protocols will help to identify the information needs for ICM and coordination of actions to be taken by each transportation agency during and after the emergency event.

2. ICM System Concept Of Operations

This chapter begins with a description of the approach taken in developing the Concept of Operations for the I-880 ICM project, then works through the approach step by step. The Vision, Goals and Objectives are defined, and the basic concept behind the project is described. The operational strategies are described, then discussed in the context of the five basic application scenarios and how they can help improve transportation in the corridor.

2.1 I-880 ICM ConOps Development Approach

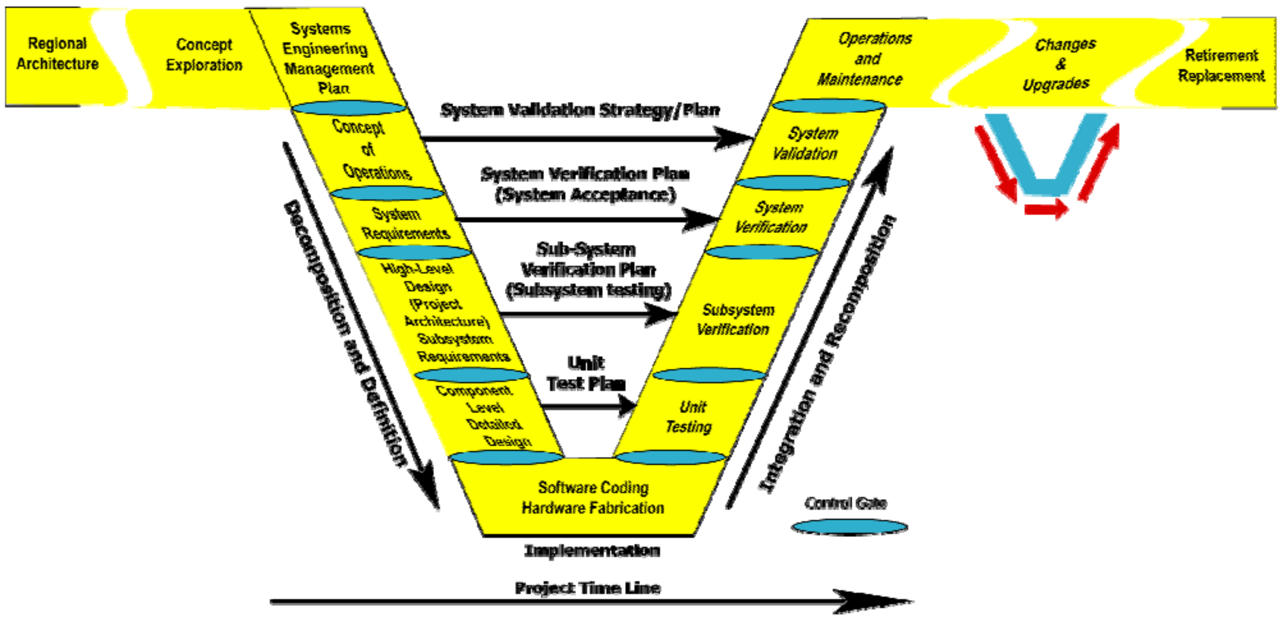
The development of the integrated corridor management (ICM) system has to be founded on a sound system engineering approach because of the inherent complexity of ICM and the need to connect diverse legacy systems in order for it to work, in addition to the applicable federal regulations. Corridor integration cannot be approached haphazardly, but requires careful consideration of both technical and institutional issues, because both of these will determine the needs that must be satisfied and the impediments to satisfying them.

The San Francisco Bay Area is already well served by ITS deployments on the various networks of its transportation system, which have been making important contributions to the performance of the system under normal operating conditions and for managing incidents. The region has even benefited from a first level of integration through its regional 5-1-1 system, which provides real-time information about highway and transit network operating conditions (speeds, travel times and incidents) and its TransLink integrated transit fare payment system. Mention east bay smart corridor? Given this relatively advanced current state of affairs, it is important to consider carefully the most important advances still to be gained through work on the ICM program.

A carefully structured process, based on a systems engineering approach, has been followed to determine how best to proceed in defining the Concept of Operations for the I-880 ICM. This represents the initial stages of the systems engineering model recommended by USDOT for ITS projects, which is shown schematically in the “V diagram” of Figure 2.1.

FIGURE 2.1

USDOT's "V diagram" Schematic of System Engineering Process for ICM Projects



2.2 I-880 Corridor Vision, Goals and Objectives

The San Francisco Bay Area has been a national champion for implementing advanced ITS technologies for improving efficiency and effectiveness of the transportation systems. It has become a program objective for the stakeholders along the 880 corridor to use ICM as a tool to further integrate the ITS systems already deployed in the San Francisco Bay Area and to enhance collaborative operations among the operation agencies. Under this program objective, through various workshops and meetings, the stakeholders have formulated ICM visions intending to address the current corridor conditions, deficiencies, and needs, and to help achieve the long-term. The 880 corridor stakeholders also developed the ICM goal and objectives of the ICM program for the 880 corridor is to provide the information sharing tools to enable the individual network operators within the corridor to manage their respective systems collaboratively and cooperatively.

Vision: The I-880 ICM program will help the existing highway, arterial, rail and bus transit networks along the corridor, operated by separate agencies, to function as an integrated transportation system, enhancing efficiency, mobility and transportation choices for all travelers (people and goods) under all conditions.

880 ICM GOALS AND OBJECTIVES TABLE 2.1

Goals	Objectives
Improve the efficiency of their individual networks through shared information from, and collaborative operations with, the other networks.	• Improve highway efficiency by sharing information between arterial and freeways • Improve operation efficiency of transit operation by using information about highway conditions and by improving the interface between highway and transit • Reduce waiting times for transfers between transit services through enhanced coordination • Reduce delays for truck traffic to and from Port of Oakland
Balance demand across the networks to most efficiently utilize the available capacity.	• Reduce recurrent congestion through improved real-time balancing of demand and supply between freeways and arterials.
Enable travelers to make informed choices among transportation options, based on reliable information about travel conditions.	• Support travelers' trip planning using improved multimodal real-time information. • Advise travelers about modal shift using real-time operations information (connections, traffic interactions).
Respond quickly and effectively to service disruptions that may be planned or unplanned, whether based on human or natural causes.	• Reduce non-recurrent congestion through improved incident response and incident information to travelers. • Improve the ability of the transportation network operators to respond to service disruptions through information sharing and better information to travelers.

2.3 Development of Candidate ICM Strategies

The proposed 880 ICM system will be built upon on the existing ITS systems already deployed for the networks that operate along the I-880 corridor. The focus of the ICM ConOps is therefore placed on the integration of the existing ITS systems, which will facilitate data sharing capabilities, enhanced real-time cross-network coordination and operations involving various agencies and jurisdictions using a set of transportation management strategies.

2.3.1 Information Sharing

Addresses the gaps need N1.

Information sharing is an enabler for ICM, which enable improved coordination and operations among the transportation networks and therefore facilitate management of the total capacity and demand of the corridor. Communication links among operating agencies, system interfaces, and bridging functions will be critical for ICM, by which information and system operations and control functions can be effectively shared and distributed among networks and their respective transportation management systems and by which the impacts of operational decisions can be immediately viewed and evaluated by the affected agencies and across networks.

2.3.2 Candidate ICM Strategies

In developing the ICM candidate strategies, the I-880 ICM Team conducted a series of workshops with the stakeholders to determine those strategies that can be realized based on the current infrastructure and ITS system condition, strategies that can address the gaps and needs identified under Section 3.9.

In order to quickly ramp up the ConOps development process and at the recommendation of USDOT representatives, the I-880 ICM team referenced the list of candidate strategies provided by FHWA in the Generic ICM Concept of Operations document, eliminating those that are not applicable to the I-880 corridor and adding additional ICM strategies that will provide benefits for the corridor. Appendix B is a working table used by the 880 ICM Team to conduct exercises on candidate selected scenarios.

The I-880 ICM Team initially selected 29 candidate strategies for consideration. In addition to soliciting stakeholders inputs, in an effort to determine which ones should be further analyzed, the initial set of candidate strategies were evaluated by the project consultant team based on five criteria – significant traffic impact, high benefit/cost ratio, minimal institutional or political challenge, little technical complexity, and improved national competitiveness (see Appendix C for the rating results). When the non-numerical scale of the rating sheets was converted to a simple linear scale with a range of possible combined scores from -60 to +60, all of the 14 strategies under active consideration scored within the relatively narrow range of -2 to +20. At the January 18 meeting, the stakeholders suggested keeping this full set for functional analysis, since they believed all the 14 strategies could bring significant benefit to the corridor and shouldn’t be eliminated prematurely.

Based on stakeholders’ inputs and preliminary analyses, 14 candidate strategies were selected for the I-880 ICM. These strategies are categorized into three groups, including:

I. Influencing travelers’ decisions and choices/traveler information strategies (Addresses the need N2)

Decisions about route choice and mode choice can be made prior to the trip or during the trip. The I-880 ICM stakeholders recommended four strategies for filling the gaps in pre-trip and en-route trip planning.

Strategy 1

A corridor-based multimodal advanced traveler information system (ATIS) that supports travelers pre-trip.

Encourage travelers to shift mode and use public transportation has been a goal for Bay Area transportation agencies for many years. The I-880 stakeholders believe that an accurate and easily accessible multimodal trip planner that can help to plan trips with more than one mode of transportation will help travelers to determine route, mode and travel time. It could potentially encourage mode shift the most, and therefore is a high priority strategy for the I-880 ICM. Strategy 1 will involve real-time information about integrating the I-880 freeway, adjacent arterials, AC Transit, BART, ferries and park and ride into the Bay Area 511 system to provide the traveler information through various easily accessible media.

Strategy 2

Promote route shifts between roadways via en-route traveler information devices (e.g. DMS, HAR, "511") advising motorists of congestion ahead, directing them to adjacent freeways or arterials.

When incidents occur either on the I-880 freeway or major arterials, diverting some traffic to the other roadway will help to reduce the total delay. Strategy 2 will detect traffic conditions on freeways as well as arterials and dynamically advise motorists the duration of the delay, to move to an adjacent roadway and which entrance or exit to use.

Strategy 3

Promote modal shifts from roadways to transit via en-route traveler information devices (e.g. DMS, HAR, "511") advising motorists of congestion ahead, directing them to high capacity transit networks and providing real-time information on the number of parking spaces available in the park and ride facility.

Strategy 3 will advise motorists about the condition of the congestion and about the availability of park and ride facilities near BART or AC Transit stations. This strategy is particularly useful when major congestion events occur. The stakeholders realized that this strategy may be more helpful for travelers on their trips to the office, but probably will not be very effective for their trips back home.

Strategy 4

Promote shifts between transit facilities via en-route traveler information devices (e.g. station message signs and public announcements) advising riders of outages and directing them to adjacent rail or bus services.

Strategy 4 is intended to facilitate passenger transfers between BART, AC Transit and WTA ferry when a service abnormality occurs in one of these systems.

II. Facilitating collaboration among agencies for operational improvement (Addresses the needs N1-N7)

In order to address the gaps identified in 3.9, multiple aspects of coordination are needed among the transportation agencies operating in the I-880 corridor. A total of 10 strategies are identified for facilitating coordination among operating agencies for operational improvements.

Strategy 5

Coordinated operation between freeways and arterial traffic signals

This strategy will establish coordination between ramp metering and arterials, which will help to reduce vehicle queuing and delays at freeway on-ramps and therefore reduce delays for arterials as well at intersections connected to ramps. In collaboration with Strategy #4, this strategy will also facilitate coordinated operation between highways and arterials to mitigate congestion under incident situations.

Strategy 6

Enhance arterial signal timing with advance information about special events at Oakland Coliseum.

This strategy will enable special signal plan for arterial traffic signals during special events at the Oakland Coliseum.

Strategy7

Signal priority for AC Transit buses

This strategy has already been implemented along International Blvd and East 14th Street. Additional bus signal priority-enabled intersections are planned for other arterial corridors.

Strategy 8

AC Transit adjusts bus operations based on real-time information about highway incidents and special events

This strategy will allow AC Transit to receive real-time information about highway incidents and, based on the severity of the incidents, to make decisions to adjust its routes, schedules and operations to maintain operations instead of being stuck in the traffic. As AC Transit has the obligation to serve all the bus stops unless a certain street is closed, this strategy is primarily designed for express buses that run on the freeways and for buses running on arterials only when a major highway incident occurs.

Strategy 9

Transit hub connection protection for special events or major incidents

This strategy allows AC Transit to provide connection protection for pre-planned special events and emergencies due to major events. Specific transit hubs/connection points such as the Coliseum will be selected for a demonstration of transit connection protection on routes that have long headways. Connection protection for BART stations under normal operating situation is not appropriate, as delays at one station can affect the arrival time at the downstream stations.Strategy10

Port of Oakland advises arriving and departing trucks about port delays and estimated travel times

The main freight distribution centers are located in the Central Valley of California, and most of the trucks take I-880 and I-238 between there and the Port of Oakland. Container traffic along these corridors is expected to triple by the year 2020. The Oakland Port is currently implementing an electronic identification system to reduce truck waiting times. This strategy will allow truck drivers to be informed about port delay and estimated travel times prior to their departure from the freight distribution centers so that they can better plan their trips and minimize their congestion losses.

Strategy 11

Signal preemption or “best Route” for emergency vehicles

This strategy intends to facilitate all emergency response vehicles (i.e., fire trucks, police, paramedics) with signal preemption capabilities. It also intends to provide ‘best route’ information in order to reduce emergency response time. The ICM team will work with these stakeholders to determine if this is doable within the ICM scope.

Strategy 12

Multi-agency or multi-network incident response teams and service patrols and training exercises.

Currently, MTC, Caltrans, and CHP are working together for a workshop and training program toward a closer collaborative working relationship and to develop collaborative incident response plans. The first phase of this program involves first responders (CHP, and Caltrans). The second phase will involve local agencies.

This ICM strategy intends to facilitate communication and coordination among agencies to help the first responders to identify types of incidents and the equipment needed to respond to the incidents.

III. Facilitate Collaboration among Agencies for Event Planning (Addresses the needs N9-N10)

Though the 880 ICM will focus on technological and operational integration around real-time information sharing, the ICM Team believes that guidelines and protocols, particularly those that deal with infrastructure construction and maintenance, will be needed to support the strategies dealing with real-time operations.

Strategy 13

Coordinate scheduled maintenance and construction activities among corridor networks.

Strategy #13 will allow a standardized repository for reporting on routine maintenance closures of freeways and local arterials, accessible to other agencies. This will be very helpful for network operators as well as travelers.

Strategy 14

Guidelines for construction work hours during emergencies.

During emergency recovery as a result of a major event (e.g. earthquake), infrastructure repair and construction work is expected. This strategy will support the development of guidelines for coordination of different transportation agencies for procedures and coordination protocols.

2.4 Implementation Institutional Framework

The primary purpose of the I-880 ICM Concept Implementation Institutional Framework is to implement, operate, and manage the corridor. The operating agencies along I-880 include multiple jurisdictions and agencies. The management and operations of the corridor and the ICMS will be a joint effort involving all the stakeholders. For the effective operation and management of the I-880 ICM system, an ICM Operations Committee (ICMOC), consisting of representatives from each of the stakeholder agencies, is proposed. The I-880 ICM Operations Committee (ICMOC) will be in charge of the development of policies and to final approval of operation plans and protocols. The ICMOC will be the consensus body to make decisions on coordination among different stakeholders and to help resolve issues encountered across agencies.

Under the guidance of ICMOC, MTC will be the administrative agency for the I-880 ICM, serving as the decision-making body for budget development, project initiation and selection, and overall administrative and operational policy.

The I-880 ICM will be a distributed system. While all stakeholders along the I-880 corridor will be collaborating on the implementation of all of the proposed strategies, based on the roles and responsibilities of the stakeholders in the existing operation for transportation systems along the I-880 corridor, a lead agency will be assigned for the implementation of a particular strategy. The lead agency will be responsible for the daily operation of the strategy it is in charge of and will coordinate with other agencies that are involved in the operation of such strategy. A clear communication protocol will be identified between agencies in order to facilitate the timely implementation of the protocols. When issues occur, the lead agency will be responsible for reporting the issues to the ICMOC and will assist the ICMOC to resolve the issues.

The table below illustrates the responsibilities of the ICMOC and each stakeholder for successful operation and management of the I-880 ICM corridor.

TABLE 2.2

Roles and Responsibilities

STAKEHOLDER/ AGENCY	RESPONSIBILITIES
ICMOC	▪ Monitor all conditions within the I-880 ICM corridor including performance measures ▪ Ensure coordination between different stakeholders to provide accurate traveler information ▪ Suggest adjustments to network operating parameters in the event of significant variations in network demands ▪ Demonstrate I-880 ICM concept
Caltrans District 4	▪ Daily maintenance and operations of freeway and local arterials which are part of state highway system ▪ Coordinate truck and freight activities on freeway and local arterials which are part of state highway system ▪ Monitor traffic operations of freeway and local arterials which are part of state highway system ▪ Coordinate construction and maintenance activities on freeway and local arterials which are part of state highway system ▪ Provide ramp metering information to local jurisdictions

STAKEHOLDER/ AGENCY	RESPONSIBILITIES
MTC	▪ Provide traffic and incident information to traveler information systems ▪ Freeway Surveillance ▪ Monitor/Operate Dynamic Message Signs ▪ Provide Support for the I-880 ICM operational test ▪ Provide Traveler information through 511 system ▪ Provide overall coordination for the 880 ICM
ACCMA	▪ Monitor arterial traffic operations ▪ Arterial Surveillance on East Bay SMART corridors ▪ Provide East Bay SMART corridors information to local jurisdictions ▪ Provide East Bay SMART corridors information to Caltrans District 4 ▪ Provide East Bay SMART corridors information to MTC's 511 traveler information ▪ Provide East Bay SMART corridors information to Transit agencies AC Transit and BART ▪ Provide support for the I-880 ICM operational test
Local Jurisdictions	▪ Monitor signal operations ▪ Adjust transit signal priority
AC Transit	▪ Daily operation of bus transit service along the I-880 ICM corridor ▪ Monitor bus transit on-time performance ▪ Provide pre-schedule and real time information to traveler information systems ▪ Enact response plans during special events and incidents
BART	▪ Daily operation of rail transit service along the I-880 ICM corridor ▪ Monitor rail transit on-time performance ▪ Provide pre-schedule and real time information to traveler information systems ▪ Enact response plans during special events and incidents
Port of Oakland	▪ Coordinate truck and freight activities with Caltrans District 4
Emergency Responding Agencies (CHP, Police, Fire, and Paramedics)	▪ Daily law enforcement activities along the I-880 ICM corridor ▪ Coordination of law enforcement and incident response activities ▪ Coordination of emergency services and incident response activities ▪ Integration of all the emergency responding agencies' interfaces

3. I-880 Data for Analysis, Modeling and Simulation

Analysis, Modeling, and Simulation (AMS) leads to a comprehensive understanding of the performance of a given corridor or set of corridors, the identification of problems (e.g., bottlenecks, high incident locations) and the causes of these problems, and the development of investment strategies that eliminate or ameliorate the congestion caused by these problems.

Moreover, AMS helps prioritize these investments by quantifying the benefits (e.g., delay reduction, air quality improvements) of given investments and comparing them to the associated costs. To do that, transportation professionals must rely on solid modeling. Traditional 4-step models are adequate for expansion project evaluation. Micro- or meso-scopic models are needed to analyze and evaluate operational strategies.

Finally, AMS also provides for improved “learning” and “accountability”. We can learn from projects that do not deliver the expected benefits and make sure we understand why and how to avoid such projects in the future. We can also learn from projects that meet or exceed the expected benefits. We can also communicate to the public and decision makers what they should expect from proposed investment packages.

3.1 Summary of I-880 Data for AMS

Table 1.1 summarizes the available data for I-880 AMS. Entries highlighted in light green represent data that are available and already in the possession of the I-880 ICM team; those in yellow are partially available and can be supplemented by new data collection efforts; those in light blue are available but not currently in the possession of the I-880 ICM team and requests have been sent to corresponding agencies; and finally those not highlighted represent data that are neither currently available nor relevant, because they are not considered as critical to I-880 ICM.

Table 1.1 Input Data for I-880 AMS

Network	Travel Demand	Traffic Control	Transit	ITS Elements
Link distances	Freeway link volumes	Freeways	AC Transit	Surveillance system
Free-flow speeds	Traffic composition	Ramp metering	Transit routes	*Detector type*
Geometrics-freeways	On & off-ramp volumes	*type (local responsive)*	Transit stops	*Detector spacing*
Number of travel lanes	Arterial link counts and turning movement volumes	*Detectors*	*location*	*CCTV*
Presence of shoulders	Vehicle trip tables	*Metering rates*	*geometrics*	*Ramp Meters*

Network	Travel Demand	Traffic Control	Transit	ITS Elements
Number of HOV lanes	Person trip tables	*Algorithms (adaptive metering)*	*dwell times*	Information Dissemination
Operation of HOV lanes	Transit Ridership	Arterials	Transit schedules	*CMS*
Accel/ecel lanes		Signal system description	Schedule adherence data	*HAR*
Grade		*Controller type*	Transfer locations	*511*
Curvature		*Phasing*	Transit speeds	*In vehicle systems*
On- and off-ramps		*Detector type & placement*	Transit Fares	Incident management
Geometrics – arterials		*Signal settings*	*Payment mechanisms*	*Incident detection*
Number of lanes		Signal timing plans	BART	*CAD system*
Lane usage		Transit signal priority system	BART routes	*Response & clearance*
Length of turn pockets		*Control logic*	BART stations	Tolling system
Grade		*Detection*	*location*	*Type*
Turning restrictions		*settings*		*Pricing mechanisms*
Arterial parking facilities		Emergency preemption system	*dwell times*	TMC
Location		*control logic*	BART schedules	*Control software/ functions*
Capacity		*detection*	BART adherence data	*Communications*
BART Parking facilities			Transfer locations	*Data archival/ dissemination*
Location			Train speeds	Transit/Fleet management system for AC Transit
Capacity			BART fares	*AVL*
Caltrans Park & Ride lots			*payment mechanisms*	*Communications*
Location			Paratransit	*Traveler information at bus stops*

Network	Travel Demand	Traffic Control	Transit	ITS Elements
Capacity			*demand-responsive*	Transit/Fleet management system for BART
			ride-share programs	*AVL*
				Communications
				Traveler information at bus stops

As discussed in Section 7 (Table 7.1), most of the data that are needed for the I-880 ICM strategies and approaches are also shown in Table 1.1. The extra data needs for ICM strategies are motorists' travel changes due to traveler information systems and market penetration of these systems. As discussed in Section 3.3, the impacts of the 511 system and CMS travel times on motorists' choices can be obtained from travel surveys that were completed or are being conducted. The market penetration can be estimated from 511 survey or obtained from the literature (for other traveler information systems).

3.2 Available Models for I-880 Corridor

Several models are available for the I-880 corridor, including regional travel demand models, microscopic simulation models, and mesoscopic simulation models for the corridor area. Table 2.1 summarizes information related to each model, including model type, characteristics of the network modeled, who performed the model development, date of the development, and documentation for each available model.

3.2.1 Travel Demand Models

There are two sets of travel demand models related to the I-880 corridor, developed by the Metropolitan Transportation Commission (MTC) and Alameda County Congestion Management Agency (ACCMA), respectively. The MTC travel demand model was originally developed in 1990 and further validated in 2004 using 2000 travel survey data. The model covers the nine San Francisco Bay Area counties (including Alameda County where the I-880 corridor resides). The model was developed using TP+/Viper, with both base years (2000, 2006) and forecast years (2015 and 2025). The ACCMA travel demand model was developed specifically for Alameda County which covers 14 cities in the county. The model was developed in Cube and was validated for Year 2000. It has both base year (2005) and forecast years (2015 and 2030). The ACCMA model is consistent with the MTC regional travel demand model. Either the MTC or ACCMA model may be used for the I-880 ICM study.

3.2.2 Microscopic Simulation Model

The Paramics micro-simulation model, developed in the Corridor Management Plan Demonstration (CMDP) study (see Section 2.2.1), covers all of the freeway and some parallel arterial networks of the I-880 ICM study area. The model simulates the I-880 freeway from downtown Oakland to SR-237 for about 34 miles, which coincides with the proposed freeway coverage of the I-880 ICM. It includes major arterials of the ICM study, such as International Blvd, East 14 St., San Leandro St., Hesperian Blvd., Mission Blvd., etc. It also includes all on/off ramps and interchanges along the freeway, together with 157 actuated and 25 fixed-timed signalized intersections. It also includes the API (Application Programming Interface) for simulating the ramp metering control logic for the freeway. More importantly, extensive data collection has been conducted during the course of the Paramics simulation model development, which will significantly reduce the data collection efforts for ICM AMS. This model is expected to play an important role in the simulation development of the I-880 ICM AMS. The model development was led by the California Department of Transportation (Caltrans), starting in 2004. Currently, the base-year (2005) simulation model is near completion and the future-year model will be completed by September 2007.

3.2.3 Mesoscopic Simulation Model

A mesoscopic simulation model was developed using DYNASMART-P[1], as part of the efforts of the CMPD study. The coverage of the model is larger than, but encloses, the Paramics model. The mesoscopic model functions as an intermediate layer between the travel demand model and the micro-simulation model. It estimates dynamic Origin-Destination travel demands via sub-area analysis and a bi-level optimization model. For details, please refer to the CMPD report at http://calccit.org/resources/publications.html.

3.3 Performance Data for Model Calibration and Validation

It is essential that the models used in the corridor analysis are properly calibrated prior to the evaluation of alternative scenarios. This is particularly critical for microscopic traffic simulation models. Calibration involves the adjustment of model parameters so that predicted performance reasonably matches observed operating conditions in the corridor. For the I-880 corridor, the baseline simulation model in Paramics has been completed and can serve as a valuable platform to develop more comprehensive simulation models for ICM AMS purposes. Correspondingly, most of the performance data needed for model calibration and validation have been made available via this current simulation effort for I-880.

The performance data can be obtained from PeMS and recently conducted field data collection efforts (in 2005 and 2006). Spatial and temporal extents of queuing can be obtained via analyzing the speed contour maps based on PeMS data. Data (travel times, delays, and speeds) collected over several days and time periods will be analyzed to provide reliable estimates of the average and the variability in traffic performance.

[1] http://www.dynasmart.umd.edu/dynasmartp/index.htm

4. Development of Requirements for ICMS

4.1 Description of the Target Environment and the Existing Conditions

The San Francisco Bay Area is the fifth most populous metropolitan area in the United States, and the I-880 corridor is centrally located within the region. It is a strategic route providing connectivity between densely populated residential areas and major commercial and industrial centers. The I-880 corridor is a multi-modal, multi-use urban freeway corridor. The corridor also plays a key role in freight and goods movement, directly serving the Port of Oakland, the fourth busiest port in the United States. Thus, the efficient operation of I-880 is of critical economic importance to the region, the state, and the entire nation. During the past 15 years, the congestion level has been worsening significantly. The I-880 ConOps document provides a detailed description of the corridor environment and the existing conditions, which is summarized in Table 2.1. In order to improve mobility along the I-880 corridor, stakeholders have invested heavily in infrastructure and ITS technologies. Table 2.2 summarizes the ITS systems and subsystems that have been implemented along the I-880 corridor. However, because of the traditional institutional arrangements, there has been less than ideal coordination and cooperation among the operating agencies. The I-880 ICM is intended to help integrate the transportation systems from the institutional, technical and operations perspectives.

4.2 Major System Capabilities

The integrated information processing system of the ICMS will enable travelers to obtain more complete and accurate information about travel conditions, while also enabling the operating agencies to collaborate on real-time operating decisions under both normal and incident conditions and on planning for special events, including construction and maintenance activities that interfere with normal operations. The sharing of information in the ICMS is expected to enable four new strategies involving enhanced information provided directly to travelers, two new strategies for agency collaboration on planned events and eight new strategies for agency collaboration on enhancing real-time operational coordination.
Similar to all transportation information systems, the ICMS will have four major system capabilities, including:

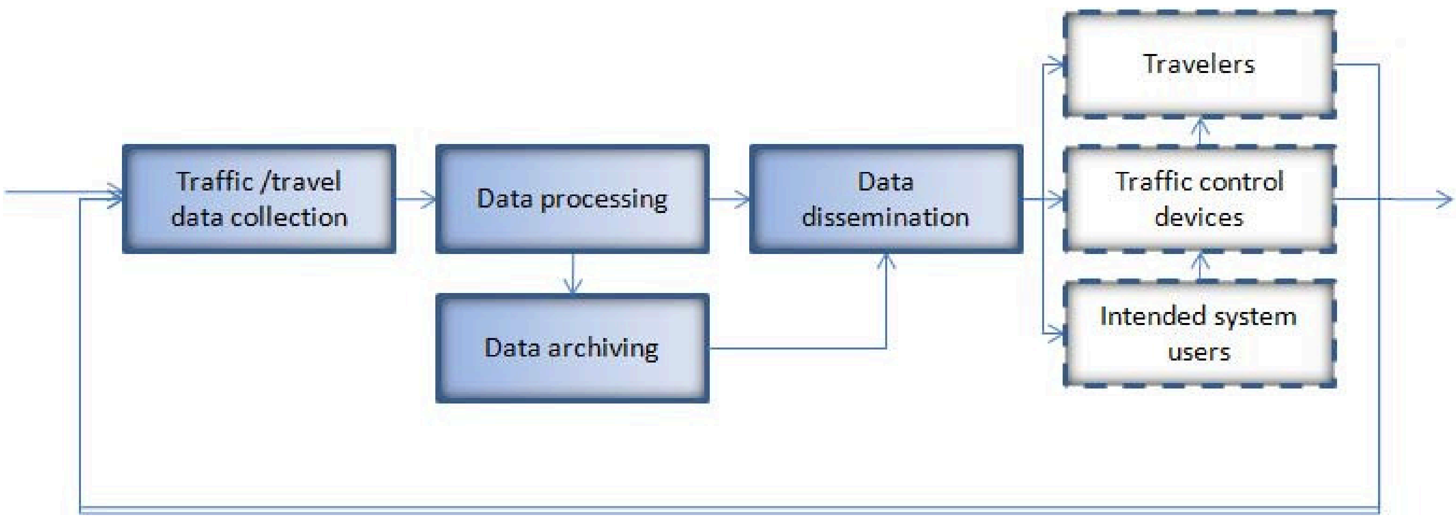
Data acquisition: Collect additional data to supplement data collected by the existing traffic control systems to support ICMS functions;

Data archiving: Supplement the existing data archiving capabilities to archive the new data and the existing data that has not been archived and share data among ICMS subsystems;

Data processing: Process data to obtain information needed for ICM functions or to accomplish ICM strategies.

Data dissemination: Provide information or outputs to travelers, traffic control devices or intended system users.

Figure 2.1 illustrates these major ICM capabilities and their relationship to each other.



4.3 Categorization of the ICM System

In order to better define the categorization and configuration of the ICMS, its subsystems must be defined. During the ConOps process, the ICMS stakeholders, based on the I-880 ICMS goals and objectives and through several iteration of discussions, have defined a set of ICM strategies to address corridor gaps and needs and to achieve the overall goals identified under US DOT's ICM program. It is envisioned by the I-880 ICMS stakeholders that the I-880 ICMS will be composed of a total of 14 subsystems, each implementing one operational strategy specifically developed by the I-880 ICM Team.

A. Subsystem that facilitates information sharing: The I-880 ICMS is intended to strengthen the coordination among all transportation agencies by providing an easy and efficient means for sharing data among the networks, through technical interfaces and an institutional coordination mechanism. The heart of the ICMS is an information processing and storage system with real-time connections to the existing information systems of all the local network operators, providing each with access to the relevant information from the others.

B. Subsystems that influence travelers' decisions and choices: These subsystems will be built upon on the Bay Area 511. The 511 system provides traveler information based on traffic data from the Caltrans freeway TMC, CHP incident reporting and transit schedule information. 511 will include real-time transit information soon. The ICMS will facilitate the inclusion of additional arterial data from the Caltrans arterial traffic control center and the Alameda CMA Smart Corridor.

C. Subsystems that provide operational decision support: This category of subsystems will primarily be built upon the existing freeway, arterial and transit management systems, with the addition of communication among the networks (when needed) and coordination strategies. The ICMS will provide the system operation personnel with cross-network information in order to allow operational decisions to be made not only based on the conditions of an individual network but also the knowledge of the conditions at the corridor level. In some cases, such as coordinated arterial and ramp metering, the ICMS will enable the operation of individual networks to be coordinated based on the conditions of more than one network.

D. Subsystems that support planning coordination for maintenance and construction of infrastructure: Aided by better information about the condition of the network, this category of subsystems will be implemented based on the existing and newly developed regional emergency response plans and coordination protocols and will provide decision support for maintenance and construction coordination.

It is noted that, other than the information sharing subsystem, these ICMS subsystems can be selectively implemented based on budgets and stakeholders' decisions.

4.4 Major System Constraints

The most basic constraints on ICMS operations include the need for electrical power to all ICMS components and the working conditions of the associated ITS systems that provide the raw data to the ICMS. Loss of power will disable all ICMS functions. Failure of any ITS system associated with ICMS will disable the functions that depend on data flowing to or from that ITS system.

Technical constraints on the operation of the ICMS are expected to include:

- Compliance with national ITS standards: 511, Caltrans eTMS, and ACCMA's arterial traffic data systems are in compliance with the regional ITS architecture and have used national ITS standards for communication protocols. The AC Transit CAD/AVL and BART's train traffic control system were developed using proprietary architectures.

- Interfaces to existing ITS systems in the corridor: ICMS needs to interface with existing ITS systems through existing interfaces. Standard interfaces such as Ethernet and series ports will be applied. Data contents will be defined to be compatible with existing systems. The data formats include commonly used XML data format and MS Media video format.

- Software compatibility: Software components can reside within the existing hardware and software environment. Therefore ICMS will need to be developed using compatible computer languages.

- Performance and availability of communication links to and from the existing ITS systems in the corridor: The existing ITS systems at all partner agencies are not designed to provide direct links to the ICMS. Rather, they have or will have direct connections with 511.

- Gaps in available data based on limitations of existing data collection systems (sensor performance, geographic coverage, etc.): Data gaps have been defined in the functional requirements section.

Institutional constraints on the operation of the ICMS are expected to be based on:

- Operating agreements among the agencies: Operating agreements are needed among stakeholder agencies. Some agreements already exist within the Bay Area, as described in the ConOp document. Others will have to be developed as soon as a decision on ICMS implementation is made.

- Jurisdictional boundaries on the agencies' authority (geographical and functional): Geographically, all agencies cover the I-880 corridor. Function-wise, Caltrans is responsible for freeways and major arterials along state highways. Cities are responsible for other arterial highways. AC Transit operates buses within the corridor and BART runs the passenger trains. ICMS should help motivate the stakeholders to break the original boundaries to achieve collaborative operations.

- Liability concerns about other agencies' use of data: 511, Caltrans and ACCMA data have already been published to the general public, so their liability concerns have already been resolved. MTC/511 is working with AC Transit and BART on ways of publishing transit real-time data. There are certain concerns regarding where and how data are to be published. For example, BART has concerns that if AC Transit bus connection information is published within the station, it might cause passengers to run for the next bus, which could result in passenger falls. As part of the ICM program, the I-880 ICM team will have to address transit data liability issue to determine the most appropriate locations and methods to publish these real-time data.

- Data ownership and confidentiality concerns about data: Each agency owns the data and the ability to disseminate the data. In AC Transit's case, although AC Transit owns the data, Orbital Science Co. owns the database. AC Transit has worked with Orbital to allow output of CAD/AVL data to a separate system in real-time. Currently, CAD has already provided the bus location information to the NextBus location system. It is expected that CAD/AVL will communicate with ICM in the same manner.

- Ownership of source code: Caltrans D4's eTMS was developed by contractor Siemens. Although Caltrans owns the source code, all changes to the source code have been handled by Siemens. ACCMA owns its source code and can made changes by itself. The AC Transit and BART systems are proprietary, so any changes will have to be made by the suppliers.

The ICMS will also pose operational constraints, as integrated operations will be new to all operating agencies. Collaborative attitudes and additional training will be needed in order to make it successful.

4.5 ICMS Requirements

The I-880 ICM team developed the ICMS requirements based on the corridor level needs identified by the stakeholders and documented in the I-880 ConOps document. Using the systems engineering approach as per IEEE 1233, the team developed a logical, systematic and traceable methodology for documenting the three sets of ICMS systems requirements, including (a) functional analysis, (b) non-functional analysis, and (c) interface requirements. A significant part of this process was the stakeholder participation and their contributions toward the requirements development. Figure 1.1 shows the process used to develop the I-880 ICMS requirements.

<u>Development of Non-functional requirements:</u> Non-functional requirements were developed based on needs solicited from stakeholders within the context (or constraints) of the existing systems with which ICMS will have to interface.

<u>Development of ICMS functional requirements:</u> A two-step development process, as shown in the dotted line in Figure 1.1, was utilized for the development of ICMS functional

requirements, including a ‘needs-driven’ requirement development process and a requirement verification process using functional analysis. The following steps were taken in developing the needs-driven requirements:

1) Decompose corridor needs: ICMS needs were decomposed from the corridor ICMS needs identified in the ConOps to the level that requirements can be identified.

2) Identify functional requirements: Each functional requirement was derived from the ICMS needs.

3) Build requirements: Through analysis, detailed requirements were then extracted and refined from the high-level requirements to obtain well-formed requirements.

4) Categorize functional requirements: Similar requirements were combined and the functional requirements were categorized into an ordered set of requirements according to the data flow in the traffic control system.

A functional analysis was conducted to verify the completeness of the functional requirements, ensure that each functional requirement was stated once, and ensure that none were missed. The functional analysis process included the following steps:

1) Identify major ICMS functions (capabilities): A set of major ICMS functions was identified based on the ICMS goals/objectives and strategies developed by the I-880 ICM team during the ConOps process.

2) Identify ICMS functions: From the major ICMS functions, functional decomposition was conducted to derive lower level functions using Functional Block Diagrams (FBD).

3) Validate requirements using functional analysis: Each requirement item developed under the ‘needs’ driven requirement process was mapped into the FBD to verify if such function was indeed needed and if any functions were missing. ICMS functional requirements were further verified in the context of the requirements of the existing system functions.

<u>Development of Interface Requirements</u>: Interface requirements were also developed based on functional analysis. The Functional Block Diagrams of each major system functions depict the interface between existing system functions and ICMS functions, allowing functional interface requirements to be defined based on the characteristics of the existing system functions.

As the ICMS will be built upon the existing ITS systems, the functional analysis are useful for the development of both the functional requirements and the interface requirements. *4.5.1 Non-Functional Requirements*

According to the needs above and based on the technical requirements of the existing ITS systems, the I-880 ICM team developed a set of non functional requirements, documented in Table 3.2, to accompany the functional, interface and data requirements to be discussed in the next few sections. In this table, RN refers to non-functional requirements.

4.5.2 ICMS Functional Requirements

The I-880 ICM team used a systems engineering process is to gather, review, analyze, and transform user needs identified in the ConOps into functional requirements that define "what" the system will do. The ICM functional requirements are specified as capabilities or functions of the ICM system, and qualifying conditions and bounding constraints that are identified distinctly from capabilities.

Functional requirements of ICMS are rooted from the corridor needs, which were identified by the stakeholders in the ConOps stage. In order to extract functional requirements from the corridor needs, detailed ICM system (ICMS) needs must be defined. In the process of identifying detailed ICMS needs, the project consultants conducted an analysis to determine 'what' will be needed in order to meet the corridor needs from the perspectives of information acquisition, archiving, processing and dissemination. The ICMS needs are decomposed to a level where functional requirements can be defined. Table 4.1 is the summary of the I-880 ICMS needs.

A well-formed requirement is a statement of system functionality (a capability) that can be validated, that must be met or possessed by a system to solve a customer problem or to achieve a customer objective, and that is qualified by measurable conditions and bounded by constraints.

The I-880 ICM team followed IEEE1233 and guidance from the U.S. DOT to derive raw functional requirements from the needs. In many cases, after a higher level functional requirement was defined based on the ICMS needs, it was necessary to further decompose such requirements into lower level requirements. After the functional requirements were identified, it was necessary to combine the repetitive requirements as some functions (such as freeway traffic data collection) may be required by more than one need.

Based on the raw functional requirements, well formed requirements were then developed. Requirements were traced back to the needs. In many cases, each requirement may trace to more than one need, as several ICM needs may require one similar ICMS function. Requirements for information content were directly traceable to ITS standards design and data contents (messages and data elements). This was necessary in order to achieve interoperability within the corridor.

The functional requirements must be categorized in order to check the completeness and for indexing. In this process, the I-880 ICM team added structure to the functional requirements by relating them to one another according to the data flow of the traffic control systems. Based on this method, the ICMS functional requirements were categorized into four groups:

- Data collection functional requirements
- Data archiving functional requirements
- Data processing functional requirements
- Data dissemination functional requirements

Detailed ICMS functional requirements are provided in [XX]. When applicable, quantitative requirements, including primarily time delays and sampling rate, are provided. The requirements are traced back to ICMS needs, denoted under the traceability. The comments section is intended to provide current availability of the function and validation methods.

4.5.3 Data Requirements

ICM data requirements are provided in Table 5.1, which defines the information needed to perform the desired ICMS functions. The data requirements specify the source of the data, the frequency of the data, and the characteristics of the data.

4.5.4 Interface Requirements

I-880 ICM will be a distributed system and will be built upon the existing ITS systems responsible for managing the transportation systems and providing traveler information along the I-880 corridor. These systems include:

- Bay Area 511 (operated by MTC)
- Freeway management system (operated by Caltrans)
- Arterial traffic control system (operated by Caltrans)
- Arterial traffic control systems (operated by Oakland, San Leandro, Hayward, and Fremont)
- Alameda Smart Corridor (operated by Alameda CMA)
- Transit Advanced Communication System – ACS (operated by AC Transit)
- BART train control system (operated by BART)
- Transit NextBus information system (operated by NextBus under AC Transit contract)

While these systems will become the foundation for the I-880 ICM, new ICM elements that include limited hardware add-ons, additional communication links and software that support the integration of the existing systems into an ICM will be established. The interfaces of the ICM subsystems in the context of the existing ITS systems are defined. These interfaces between the new ICM elements and the existing ITS systems will apply the interface standards and protocols adopted for these existing systems.

5. Summary

The I-880 corridor is a truly multimodal corridor, including a robust freeway network, major arterials which carry high volumes of local traffic as well as absorb diversion from the freeway networks, a transit network which includes the Bay Area Rapid Transit (BART) rail system and multiple AC Transit bus transit lines, and heavy freight movements in the corridor. The I-880 ICM will help the existing highway, arterial, rail and bus transit networks along the corridor, operated by separate agencies, to function as an integrated transportation system, enhancing efficiency, mobility and transportation choices for all travelers (people and goods) under all conditions. The I-880 ICMS stakeholders have conducted detailed analysis of this corridor and have developed the ICM concept of operation, data available for supporting ICM analysis, modeling and simulation, documented in three documents, including: (1) I-880 ICM Concept of Operation, (2) I-880 ICM Sample Data for Analysis (submitted earlier), Modeling and Evaluation, and (3) I-880 ICMS System Requirements.

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