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USDOT Integrated Corridor Management (ICM) Initiative

System Requirement Specification for the I-880 Corridor in Oakland, California

March 31, 2008
FHWA-JPO-08-047
EDL Number 14427

U.S. Department of Transportation
Research and Innovative Technology Administration
Federal Transit Administration
Federal Highway Administration

Integrated Corridor Management (Oakland, California)

Final
System Requirements

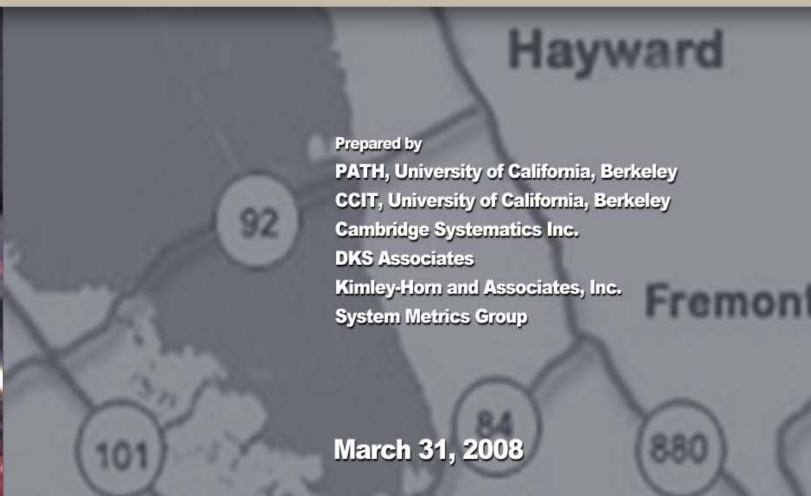
Submitted to

U.S. Department of Transportation

Submitted by

Building on Coalition of Successful Partners

Expanded Stakeholder Coalition



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I-880 Integrated Corridor Management

ICM System Requirements

Final Submittal

Submitted to

U.S. Department of Transportation

Submitted by

Metropolitan Transportation Commission (MTC)
California Department of Transportation (Caltrans) – District 4
Alameda County Congestion Management Agency (ACCMA)
Alameda-Contra Costa Transit District (AC Transit)
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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-08-047 EDL Number 14427		

4. Title and Subtitle System Requirement Specification for the I-880 Corridor in Oakland, California	5. Report Date March 31, 2008
	6. Performing Organization Code
7. Author(s) Oakland Pioneer Site Team	8. Performing Organization Report No.
9. Performing Organization Name and Address Oakland Pioneer Site Team	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes
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FHWA Contact: Dale Thompson
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FTA Contact: Steve Mortensen

16. Abstract

This document summarizes the efforts conducted by the I-880 ICM team for the development of 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. The I-880 corridor is already served by multiple transportation networks; including freeway, arterial and bus and rail transit systems, as well as a major container port and airport. However, despite their significant reliance on ITS technologies to support their own operations, these networks operate with relatively little mutual coordination on a daily basis. The I-880 ICMS is intended to 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.

17. Key Word	18. Distribution Statement
ICM, Integrated Corridor Management, Requirements, Con Ops, I-880, Oakland, Freeway, Arterial, Transit, bus, rail, Intelligent Transportation Systems, ITS, ramp metering, HOV, electronic toll collection, performance monitoring system, PeMS	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	134	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

1. Introduction 1
1.1 Scope and Purpose of the Document.. 1
1.2 System Scope 1
1.3 Development Process 3
1.4 Traceability Method 5
1.5 Normative References.. 5
1.6 Abbreviations, Acronyms, and Definitions 7
2. General System Description.. 9
2.1 Description of the Target Environment and the Existing Conditions........................ 9
2.2 Major System Capabilities 9
2.3 Categorization of the ICM System.. 16
2.4 ICMS Configurations.. 18
2.4.1 Information Sharing (SS-01).. 20
2.4.2 Providing traveler information to travelers (SS-02 to SS-04) 20
2.4.3 Arterial/Ramp Metering Coordination (SS-05).. 22
2.4.4 Facilitating Arterial Signal Control Systems to Handle Special Events (SS-06) 22
2.4.5 Managing Arterial Signal to Provide Transit Signal Priority (SS-07) 23
2.4.6 Managing Transit Operation under Severe Incident Conditions (SS-08)........................ 23
2.4.7 Managing Transit Hub Connection Protection for Special Events (SS-09)........................ 24
2.4.8 Advising Truck Operators and Drivers About Port Delay and Estimated Travel Time (SS-10).... 25
2.4.9 Providing Emergency Vehicles with Signal Pre-emption and Best Routing Recommendations (SS-11) and Facilitating Rapid Incident Response (SS-12)........................ 26
2.5 ICMS Operation.. 29
2.6 Major System Conditions.. 35
2.7 Major System Constraints.. 37
2.7 User Characteristics 39
2. 8 Assumptions and Dependencies.. 40
2.9 Operational Scenarios 40
2.9.1 Normal Operations Scenario 41
2.9.2 Incident Scenario (Highway and Arterial).. 42
2.9.3 Incident Scenario (Transit).. 42
2.9.4 Planned/Scheduled Event Scenario 43
2.9.5 Catastrophic Event Scenario 44
2.10 ICMS Performance Characteristics.. 45
2.10.1 ICMS Performance Measures 45
2.10.2 Estimated I-880 ICMS Performance Characteristics.. 47
3. ICMS General Requirements.. 49
3.1 Non-Functional Needs.. 49
3.2 Non-Functional Requirements 50
4. ICMS Functional Requirements.. 53
4.2 Identify ICMS Needs 53
4.3 Defining Functional Requirements 57
4.4 Categorization of the Functional Requirements.. 57
4.4 Validation of Functional Requirements Through Functional Analysis........................ 82

5. Data Requirements..99
6. Interface Requirements...106
References 111
Appendix A: Performance Characteristics Analysis 113
A.1 ICM Factors Contributing to Achievable Reduction of Traffic Congestion and Travel Time....... 113
A.2 ICM Factors Contributing to Balance of Demand Freeway and Arterial Highways..................... 116
A.3 ICM Factors Contributing to Achievable Improvements in Incident Detection and Efficient Incident Management... 118
A.4 ICM Factors Contributing to Achievable Improvement in Safety.. 122
A.5 ICM Factors Contributing to Mode Shift 124

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1. Introduction

1.1 Scope and Purpose of the Document

This document summarizes the efforts conducted by the I-880 ICM team for the development of 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.

1.2 System Scope

The I-880 corridor is already served by multiple transportation networks; including freeway, arterial and bus and rail transit systems, as well as a major container port and airport. However, despite their significant reliance on ITS technologies to support their own operations, these networks operate with relatively little mutual coordination on a daily basis.

The I-880 ICMS is intended to 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 specific objectives for the ICMS include:

- Improve highway efficiency by facilitating arterial and freeway control systems' sharing of information in order to achieve coordinated control.
- Improve operating efficiency of transit operations by using information about highway conditions.
- Reduce waiting times for transfers between transit services through enhanced coordination.
- Reduce delays for truck traffic to and from the Port of Oakland.
- Reduce recurrent congestion through improved real-time balancing of demand and supply between freeways and arterials.
- Support travelers' trip planning using improved real-time multimodal information.
- Advise travelers about modal shift using real-time operations information (connections, traffic interactions).
- Reduce non-recurrent congestion through improved incident response
- Reduce the impacts of incidents and other service disruptions by providing real-time incident information to travelers.
- Enhance the ability of the transportation network operators to respond to service disruptions.
- Improve the transportation networks' performance around planned events by facilitating information sharing among event organizers and transportation operators.
- Minimize the service disruptions from transportation facility construction and maintenance activities by sharing information about these activities among network operators.

In order to develop an ICMS that specifically addresses the needs of the I-880 corridor, a ‘gaps and needs analysis’ was conducted at an early stage of the ConOps development process. Based on the gaps and needs identified by the stakeholders, a thorough study was conducted by the I-880 ICM team to develop a set of ICM strategies to address these gaps and needs. The left two columns in Table 1.1 summarize the gaps, needs and corresponding strategies developed under the I-880 ICMS ConOps development process.

It is worth noting that the ICMS project is not intended to encompass the entirety of the ITS technologies and systems within the I-880 corridor, but rather is intended to focus on the integration of the information collected by the diverse systems operating in that corridor. As such, there are some important constraints on the scope of the requirements to be defined here:

- not addressing requirements on individual field elements, since the ICMS is not meant to include deployment of new field elements;
- not addressing requirements on individual means of distributing information to end users, since those are already in service prior to the advent of the ICMS;
- not addressing component-level requirements, since this is a high-level requirements definition, prior to the development of a specific system design that would specify the components.

1.3 Development Process

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.

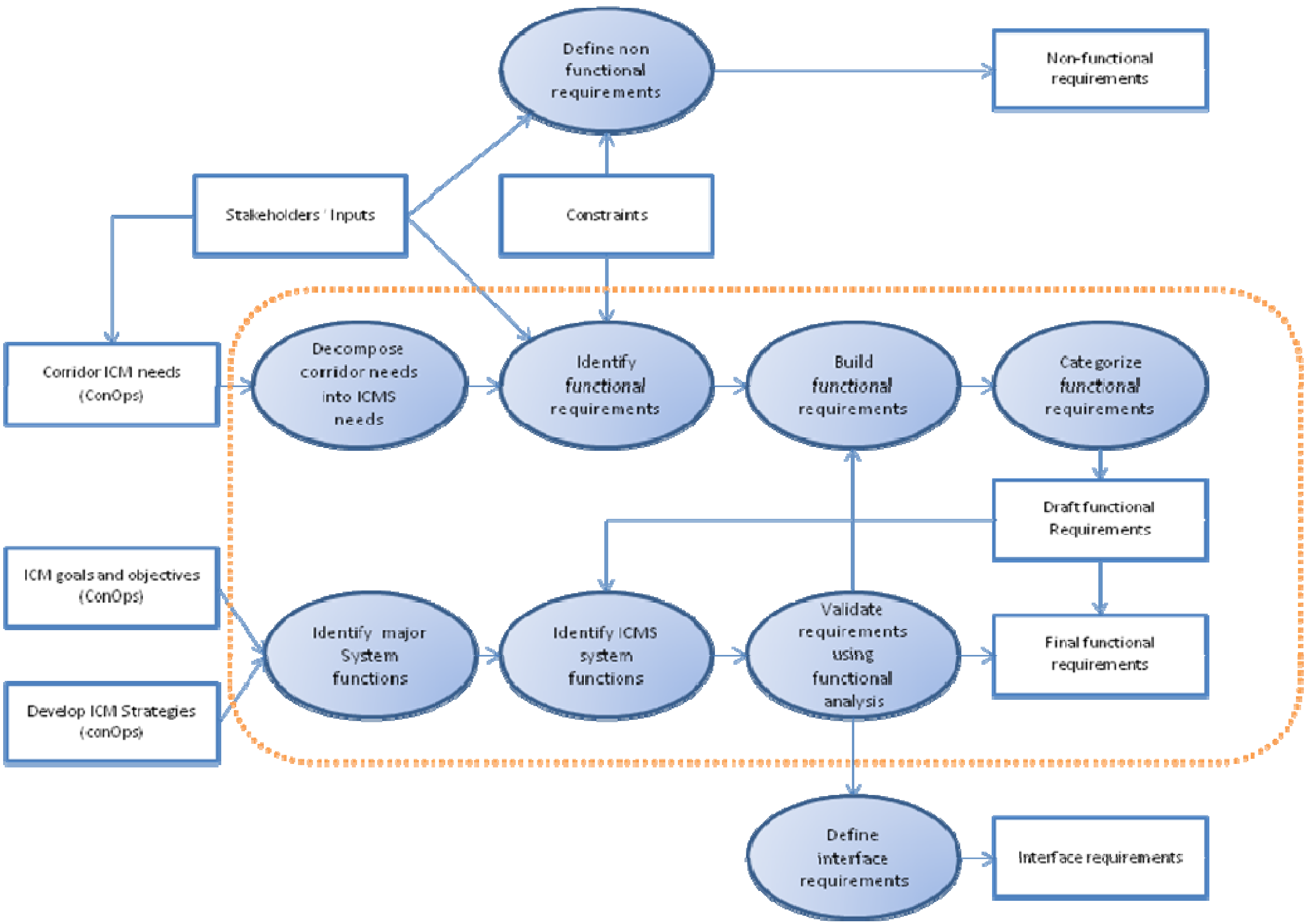
1.4 Traceability Method

The I-880 ICMS functional and data requirements were developed based on a set of functional needs decomposed from the stakeholders' needs defined in the ConOps. The ICMS non-functional requirements were developed based on a set of non-functional needs which pose constraints on the design or implementation. The interface requirements were defined based on the relationships among various functions identified through the functional requirement definition process. Accordingly, a traceability method has been established to trace between the needs and functional and data requirements, between the design/implementation needs and non-functional requirements, and between functional requirements and interface requirements.

1.5 Normative References

- IEEE Guide for Developing System Requirements Specifications, IEEE 1233, 1998 Edition
- National ITS Architecture
- Bay Area ITS Plan, June 2004
- Bay Area ITS Plan Update, April, 2007
- Bay Area Real-time Transit Information Architecture, September 2006
- I-880 ConOps Document, September 28, 2007
- ICMS SE White Paper #1_V1_6, USDOT

Figure 1.1 Development Process of I-880 ICMS Requirements



1.6 Abbreviations, Acronyms, and Definitions

AADT	Annual Average Daily Traffic
ACCMA	Alameda County Congestion Management Agency
ACS	Advanced Communication System
AC Transit	Alameda-Contra Costa Transit District
APC	Automatic Passenger Counter
AVL	Automatic Vehicle Locator
BAIRS	Bay Area Incident Response System
BART	Bay Area Rapid Transit District
BRT	Bus Rapid Transit
CAD	Computer Aided Dispatch
Caltrans	California Department of Transportation
CCPJA	Capitol Corridor Joint Powers Authority
CCTV	Closed Circuit TV
CHP	California Highway Patrol
CMS	Changeable Message Sign
ConOps	Concept of Operations
FHWA	Federal Highway Administration
FSP	Freeway Service Patrol
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
ICD	Interface Control Document
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System

ITS	Intelligent Transportation system
LTDB	Long Term Database
MDT	Mobile Data Terminals
MTC	Metropolitan Transportation Commission
OCC	Operation and Control Center (Transit)
PATH	California Partners for Advanced Transit and Highways
PeMS	Performance Monitoring System
RTMS	Remote Traffic Microwave Sensor
TASAS	Caltrans Traffic Accident Surveillance and Analysis System
TEMS	TOS Equipment Management System
TMC	Traffic Management Center
TTA	Time to Arrival
TOS	Traffic Operations System
TSP	Transit Signal Priority
USDOT	US Department of Transportation
XML	Extensible Markup Language

2. General System Description

2.1 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.

2.2 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.

Table 2.3 provides the map among the needs, the strategies and the major capabilities or functions. It is important to note that these major functions are used later in the requirements development process to decompose lower level functions and subsequently to develop functional requirements.

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.

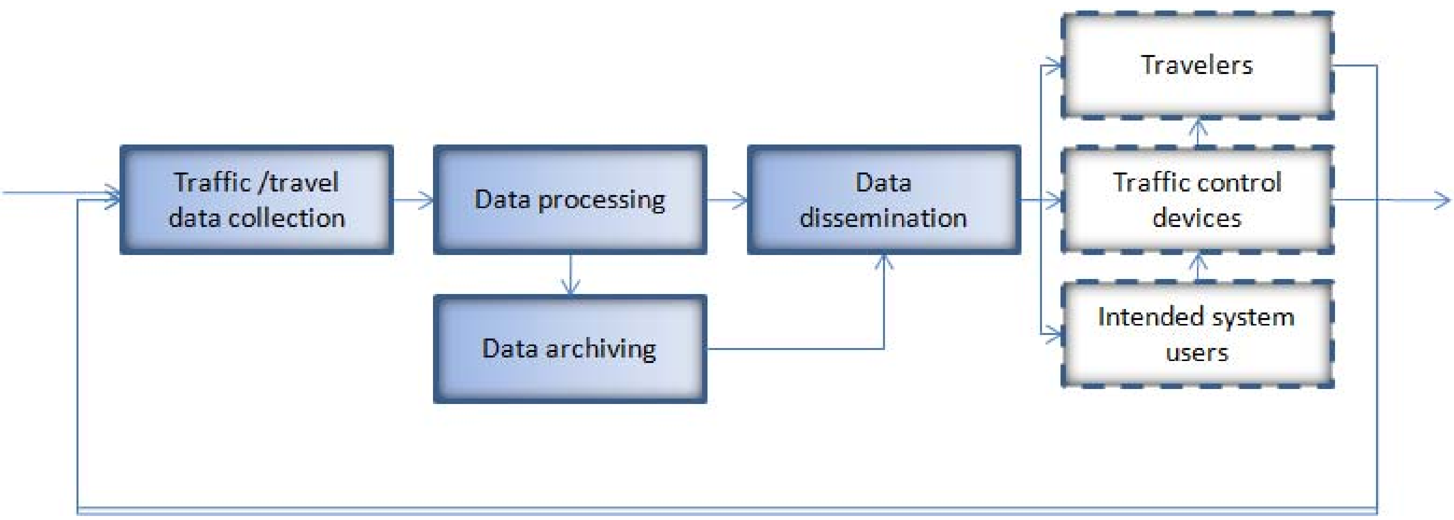


Table 2.1 I-880 Network Conditions and Environment

	Freeway	Arterials	AC Transit	BART
Network	▪ I-880 between I-580/I-80 interchange in the north and SR-237 in the south; length 38 miles	▪ International Blvd, East 14th St, San Leandro Blvd, Hesperian Blvd, and Union City Blvd; length 40 miles	▪ Two major local AC Transit lines along I-880 (82, 82L) plus about 15 express lines	▪ 20 miles of double track
Facility	▪ TMC located in Caltrans District Office in Oakland. 250+ freeway lane miles, all under TMC surveillance and control. 39 miles HOV lanes. ▪ Dense ITS deployment includes traffic detectors, CMS, CCTV, HAR, etc.	▪ Distributed TMC with satellite locations. Arterials are primarily 4-6 lane undivided highways. Over 250 signalized intersections, 40 arterial miles, 48 miles under TMC surveillance and control.	▪ TMC located in Division D-2, Emeryville, CA. ▪ There are approximately 200 bus stops along the corridor, with three major parking facilities. ▪ AC Transit is in the process of implementing BRT between Berkeley and San Leandro along the International/E.14th Street corridor	▪ 12 BART stations along study corridor. 10 stations have parking lots/garages, with 11,432 spaces.
Operations	▪ Overall traffic volumes along I-880 corridor are very heavy, with AADT between 120,000 to 275,000 per weekday. ▪ I-880 is an intermodal freeway which serves major traffic generators, including the Port of Oakland, Oakland International Airport, and Oakland Coliseum. Trucks comprise up to 11% of the AADT in the corridor.	▪ Current ADT along the arterials is between 15,000 and 60,000 vehicles per day.	▪ Passenger boarding for Route 82 and 82L is 16,727 per day on weekdays. ▪ AC Transit has several major transfer points along the corridor. Each of these stations serves between 5 and 8 bus routes and provides intermodal transfers with the BART service. Over 7000 passengers per day access BART or buses at these stations	▪ At stations along I-880, approximate number of passenger boarding and alighting per weekday is 138,000.
Problems & Issues	▪ Recurrent congestion causes more than 10,000 veh-hrs of delay per weekday, and significantly disrupts freight movement through the corridor. ▪ Non-recurrent congestion is also a major problem. I-880 averages over 10 collisions per day and over 100 incidents per day. It is estimated that collisions account for 30 percent of overall corridor delay.	▪ The arterials along the project corridor currently operate at level of service D 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 with the freeway is crucial to optimizing the overall capacity of the system.		

Table 2.2 Existing ITS Systems on I-880 Corridor

	Freeway	Arterials	Bus Service (AC Transit)	Passenger Rail (BART)
Infrastructure and Maintenance	▪ Dense deployment of ITS infrastructure on freeway, including 83 vehicle detection stations, 25 CCTVs, 5 CMSs, 86 operational ramp meters, 5 HARs, and communication to and from the Traffic Management Center (TMC). ▪ CCTVs, CMSs, and HARs are checked by TMC Operators weekly or monthly. Problems are reported to Caltrans electrical maintenance staff. Ramp meters are monitored daily by Caltrans Field Operations. ▪ A TOS Equipment Management System (TEMS) is being developed which will improve management of the TOS inventory, and help ensure the reliability and accuracy of the TOS and TMC information. The database will begin to be populated in July 2006.	▪ CCTV and Non-Intrusive Monitoring Stations are installed on the arterials. There are also transit signal priority units (on E. 14th/International) and emergency preemption units installed. ▪ Weekly manual inspection of all CCTV and Monitoring Stations units for functionality. ▪ A maintenance contractor also provides annual and semi-annual inspection and cleaning for all units. Maintenance contractor will be issued a task order for corrective action.	▪ Two main infrastructure systems: Orbital "Satcom" radio and AVL System; and the Nextbus prediction system. ▪ When malfunctions are detected in the Orbital system, on-site personnel diagnose and correct the issues. ▪ The Nextbus prediction system is provided under contract with an outside vendor; any malfunction is either handled by on-site personnel, or referred to the vendor.	▪ BART operation is entirely automated by using the Automated Train Control System (see Section 3.1.4 for detail). ▪ BART has also developed a communication based train control system that uses MASH communication system to position and operate trains. The system has great potential for significantly increasing passenger throughput and can collected operation data in finer resolution. ▪ BART and CCPJA are seeking assistance from telecommunication industry to provide Wi-Fi service onboard (see Section 3.1.4 for detail).
Data Collection	▪ Volume, speed, occupancy, travel time, ramp metering rate, HOV volume, and incident clearance time data are collected on I-880. ▪ Data are collected using vehicle loop detectors, video, magnetic, microwave, and toll tag readers. ▪ Data are owned mostly by Caltrans and exchanged with other agencies through dedicated network.	▪ Volume and speed data are collected on arterials using RTMS data collection units. ▪ The data are owned by ACCMA and data exchanges with other networks are carried through a leased T1 line.	▪ Boarding and alighting passenger data, running times, schedule adherence, vehicle location, and prediction reports are collected using Automatic Passenger Counter (APC); Automatic Vehicle Locators (AVL), and Nextbus prediction systems. ▪ The data are owned by AC Transit, and currently, historical data are sometimes viewed by other agencies, but there is no real-time communication.	▪ Train movements monitored in real-time through track circuits and twisted wires at stations. Route information (through switch positions), signal status and system health information are collected also. Fare collection information is also collected.

	Freeway	Arterials	Bus Service (AC Transit)	Passenger Rail (BART)
Data Archiving	▪ Real-time detector station data are exported to TravInfo and PATH's Performance Monitoring System (PeMS) using an XML interface.	▪ Radar data, i.e. traffic counts and speeds, are archived by 30-second intervals. Transit signal priority usage data will be archived starting Sept 2006. ▪ The data are stored on the production server for 6 months. Every month the data that are 7th months back are moved onto a separate archive server on which they are held indefinitely.	▪ AC Transit's bus fleet is 100% equipped with CAD/AVL equipment. Archiving methodologies are in place to fully support both real-time and post processing requirements. Schedule Adherence "events" are recorded in the long term database (LTDB). Reports requiring post processing, such as monthly schedule adherence reports, are available for a 3 month period and based on the back-up, data is available for up to a year.	▪ Data related the system operation (route, switch positions and signal status), train operation (movements, schedule adherence) and passenger data are extensively archived for both operation and safety reasons. BART's internal website has real-time information available such as the location of all of the trains and fare collection information within the system.

Table 2.3 Gaps, Functional Needs and Capabilities

Gaps and Functional Needs	Strategies	Major Functions (capabilities)
I. Gaps in traveler information for influencing travelers' decisions and choices		
N1) Needs for information sharing	▪ ICM Enabling strategy: Information sharing	▪ F-01 Information sharing
N2) Needs for distributing traveler information across the corridor/region wide	▪ Strategy #1 A corridor-based multimodal advanced traveler information system that supports travelers' pre-trip planning ▪ Strategy #2 Promote route shifts between roadways via en-route traveler information devices advising motorists of congestion ahead, directing them to adjacent freeways or arterials. ▪ Strategy #3 Promote modal shifts from roadways to transit via en-route traveler information devices advising motorists ▪ Strategy #4 Promote shifts between transit facilities via en-route traveler information devices advising riders of outages and directing them to adjacent rail or bus services.	▪ F-02 Providing traveler information through 511 ▪ F-03 Providing information in real time to travelers for en-route decision making ▪ F-04 Presenting travel advisory information in real time at transit stations and on transit vehicles
II. Gaps in collaboration among agencies for operational collaborations		
N3) Needs for coordination between freeway and arterial operations	▪ Strategy #5 Coordinated operation between freeways and arterial traffic signals ▪ Strategy #6 Enhance arterial signal timing with advance information about special events at Oakland Coliseum.	▪ F-05 Coordinating operations between freeway ramp metering and arterial signals ▪ F-06 Helping arterial signal control systems to handle special events.
N4) Needs for coordination between highway and transit operations	▪ Strategy#8 AC Transit adjusts operations based on real-time information about highway incidents and special events	▪ F-07 Managing arterial signals to provide priority for transit vehicles ▪ F-08 Managing transit operation under severe incident conditions and for special events
N5) Needs for coordination between transit systems	▪ Strategy #9 Transit hub connection protection for special events or major incidents	▪ F-09 Managing transit operation for transit hub connection protection for special events
N6) Needs for coordination between highway and freight operations	▪ Strategy # 10 Port of Oakland advises arriving and departing trucks about port delay and estimated travel times	▪ F-10 Advising truck operators and drivers about port delay and estimated travel time
N7) Needs for coordination between highway control systems and emergency response needs	▪ Strategy #11 Signal preemption or "best route" for emergency vehicles	▪ F-11 Providing emergency vehicle with signal pre-emption and best routing recommendations

Gaps and Functional Needs	Strategies	Major Functions (capabilities)
N8) Needs for coordination for incident responses	▪ Strategy #12 Multi-agency or multi-network incident response teams and service patrols and training exercises.	▪ F-12Facilitate rapid incident response
III. Gaps in Collaboration among Agencies for Event Planning		
(N9) Needs for coordination for infrastructure construction and maintenance	▪ Strategy #13 Coordinate scheduled maintenance and construction activities among corridor networks	▪ F-13 Supporting maintenance and construction coordination
N10) Needs for coordination of construction work during emergencies	▪ Strategy #14 Guidelines for construction work hours during emergencies.	▪ F-14 Supporting coordination of construction work during emergencies

2.3 Categorization of the ICM System

The I-880 ICMS is a distributed system, which will contain a set of subsystems accomplishing four types of goals, including:

- Facilitate information sharing among different systems
- Influence travelers' decisions and choices
- Provide coordinated decision support for operations
- Support planning coordination

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. The ICMS subsystems in this category include:

   - SS-01 Information sharing subsystem

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. The ICMS subsystems in this category include:

- SS-02 Enhanced 511 traveler information subsystem for pre-trip planning
- SS-03 Real-time traveler information subsystem for en-route decision making
- SS-04 Real-time travel advisory information subsystem at transit stations and on transit vehicles

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. The ICMS subsystems in this category include:

- SS-05 Subsystem for coordinating operations between freeway ramp metering and arterial signals
- SS-06 Subsystem for facilitating arterial signal control systems to handle special events.
- SS-07 Subsystem for managing arterial signals to provide priority for transit vehicles
- SS-08 Subsystem for managing transit operation under severe incident conditions and for special events
- SS-09 Subsystem for managing transit operation for transit hub connection protection for special events
- SS-10 Subsystem for advising truck operators and drivers about port delay and estimated travel time
- SS-11 Subsystem for providing emergency vehicles with signal pre-emption and best routing recommendations
- SS-12 Subsystem for facilitating rapid incident response

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. , The ICMS subsystems in this category include:

- SS-13 Subsystem for supporting maintenance and construction coordination
- SS-14 Subsystem for supporting coordination of construction work during emergencies

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

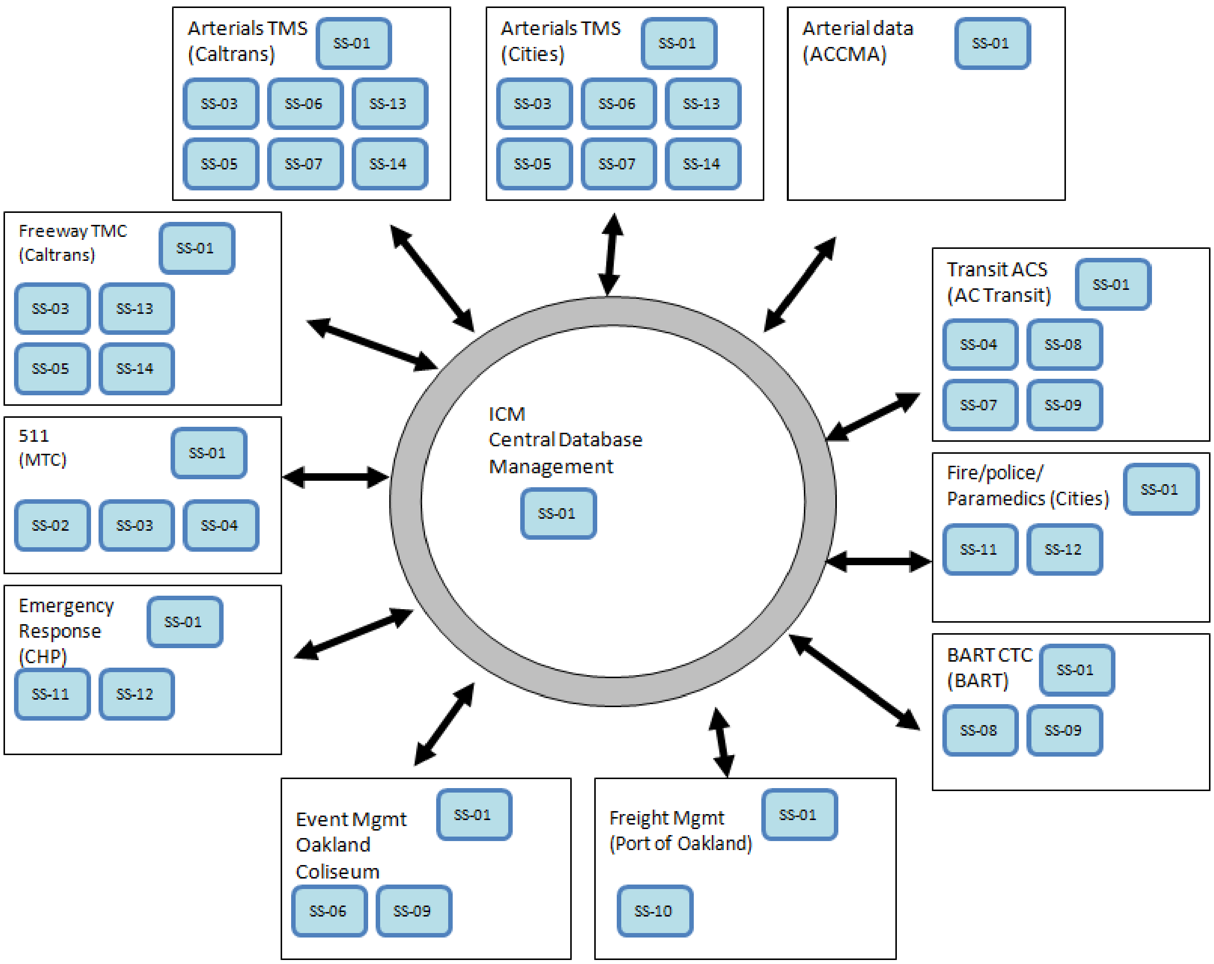
Table 1.1 illustrates a traceable mapping among corridor needs, ICM goals, strategies and ICMS subsystems. This mapping expands upon the 'needs driven' traceability method by ensuring that the definition of the subsystem also traces back to the needs.

2.4 ICMS Configurations

Based on the existing condition and operation of the transportation systems, the I-880 corridor stakeholders decided that a physically centralized ICMS control center would be very costly and not practical within the scope of the current ICM program. Instead, the proposed I-880 ICMS will be a distributed system. An ICMS subsystem can be composed of a number of components. New ICMS functions, to be implemented based on the needs of the selected strategies, will be integrated into existing transportation systems. In many cases, the ICMS subsystems will be distributed into a number of existing transportation systems. For example, the subsystem for arterial and ramp metering coordination (SS-05) includes components separately located within the existing freeway TMS and arterial TMS.

Figure 2.2 provides an illustration of the distributed nature of the I-880 ICMS, showing where the functions of the ICMS subsystems will reside within the existing transportation systems.

Figure 2.2 ICMS Configuration



Communication links among operating agencies, system interfaces, and bridging functions will be critical for ICMS, 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. The grey circle and the arrows between the individual ITS systems and the grey circle in the center show the communication links through which all ITS systems are connected with the central database manager, allowing information sharing to support the proposed ICM strategies. The interactions between the ICMS subsystems and the existing ITS systems are depicted in Sections 2.4.1 through 2.4.10. The communication or data links are denoted using letters. Various ICMS subsystems may share the same communication links, which are represented using the same letters in the separate figures. Existing communication or data links are denoted by ‘x’.

2.4.1 Information Sharing (SS-01)

Information sharing is the central element of the ICMS, which enables improved coordination of operations among the transportation networks and therefore facilitates management of the total capacity and demand in the corridor. Realizing that a number of databases have already been developed for different networks or applications, a central database manager will be developed to interact with and manage these databases to form a physically distributed but centrally managed ICMS data repository allowing real-time data exchange among agencies. Communication links, noted as ‘a’ through ‘l’ enable the data sharing among the ITS systems, enabling ICMS functions. Communications systems and system networks will be integrated to support the centrally managed data base. Voice, data, video, information, and control will be provided to all agencies based on the adopted protocols and standards for the sharing of information and the distribution of responsibilities. Note that in the figures below, dashed boxes represent users or existing devices.

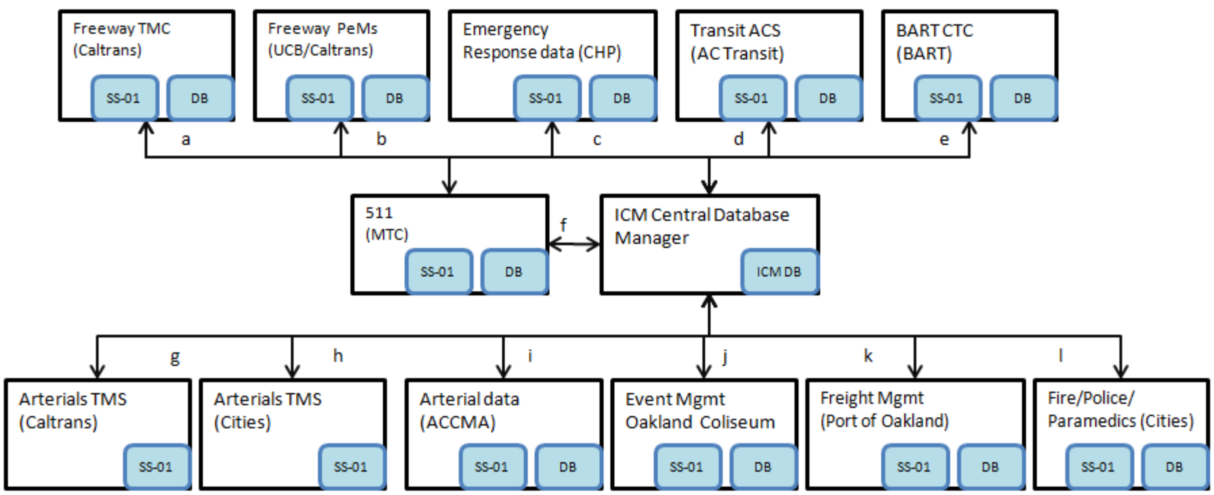


Figure 2.3 Interface diagram for SS-01

2.4.2 Providing traveler information to travelers (SS-02 to SS-04)

The ICMS subsystems SS-02 through SS-04, shown in Figure 2.4, are intended to provide real-time traveler information for making decisions about route choice and mode choice prior to a trip or during the trip. Again, the communication links (a, e, d, f, g, h) are the same as the ones with the same notation in Figure 2.3.

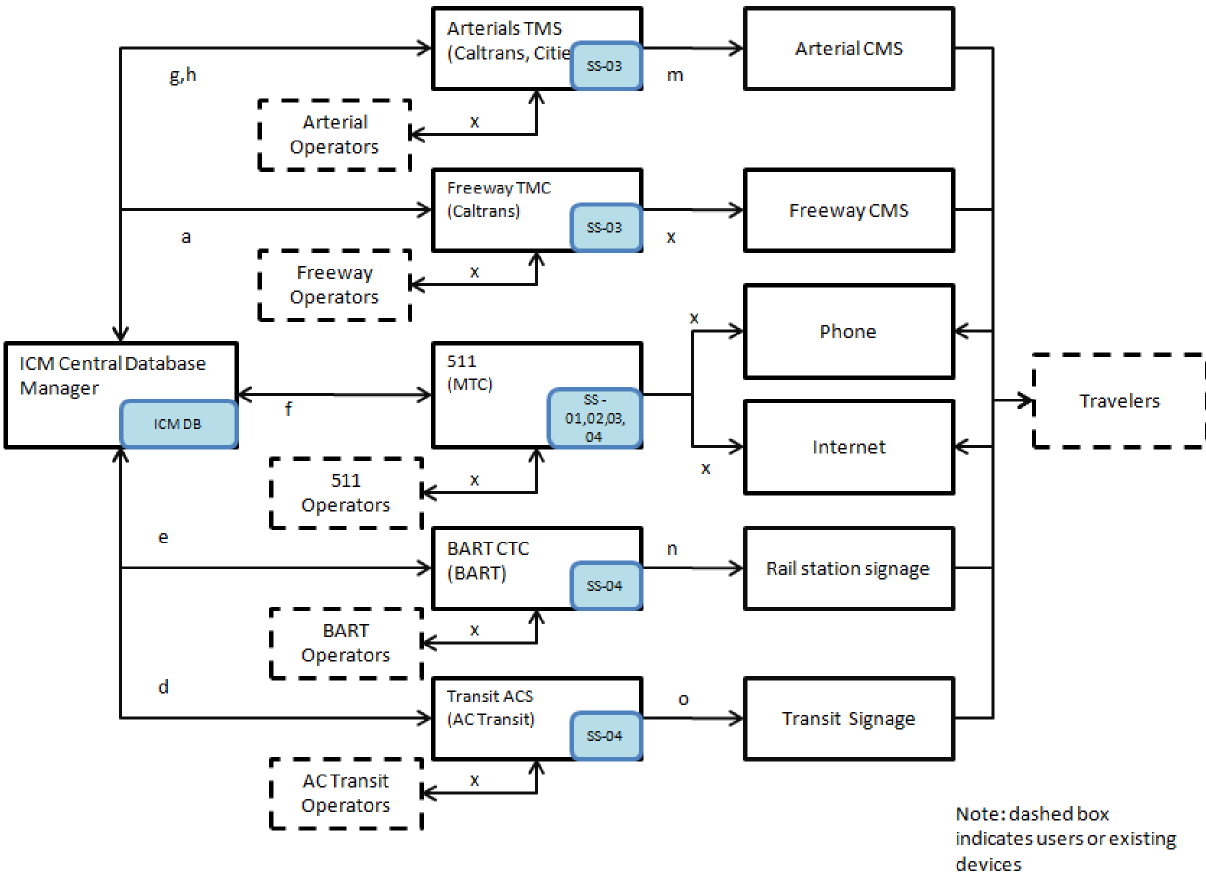


Figure 2.4 Interface diagram for SS-02 to SS-04

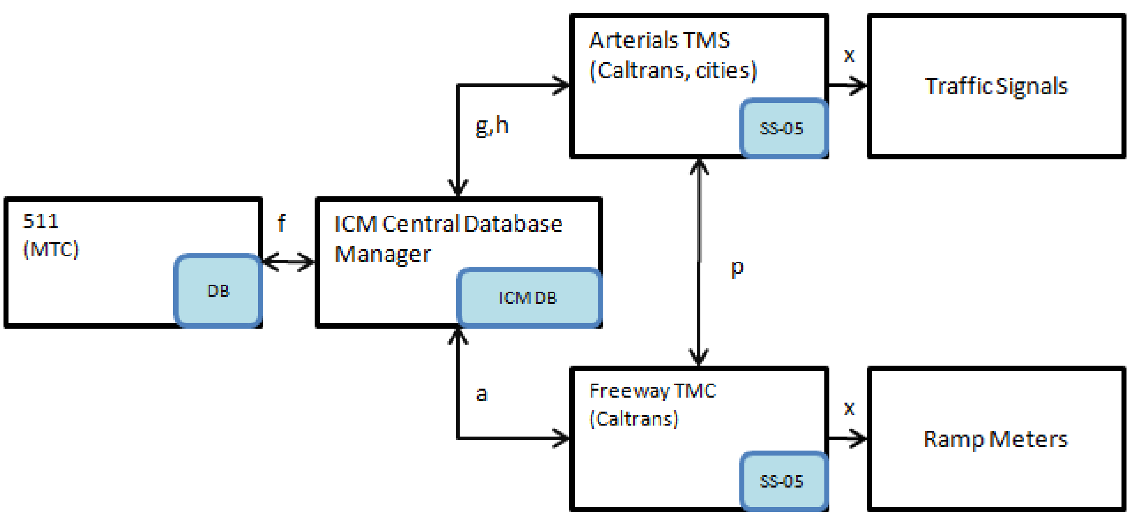


Figure 2.5 Interface diagram for SS-05

2.4.3 Arterial/Ramp Metering Coordination (SS-05)

The ICMS subsystem SS-05, shown in Figure 2.5, establishes coordination between ramp metering and arterials to help reduce vehicle queuing and delays at freeway on-ramps, and therefore reduce delays for arterials as well at intersections connected to ramps, based on real-time traffic conditions on these two networks. Because of the real-time nature of the two systems, the communication link ‘p’ enables direct communication between the freeway and arterial traffic systems.

2.4.4 Facilitating Arterial Signal Control Systems to Handle Special Events (SS-06)

The ICMS subsystem SS-06, as shown in Figure 2.6, enables special signal plans for arterial traffic signals during special events at the Oakland Coliseum and will provide traveler information through 511.

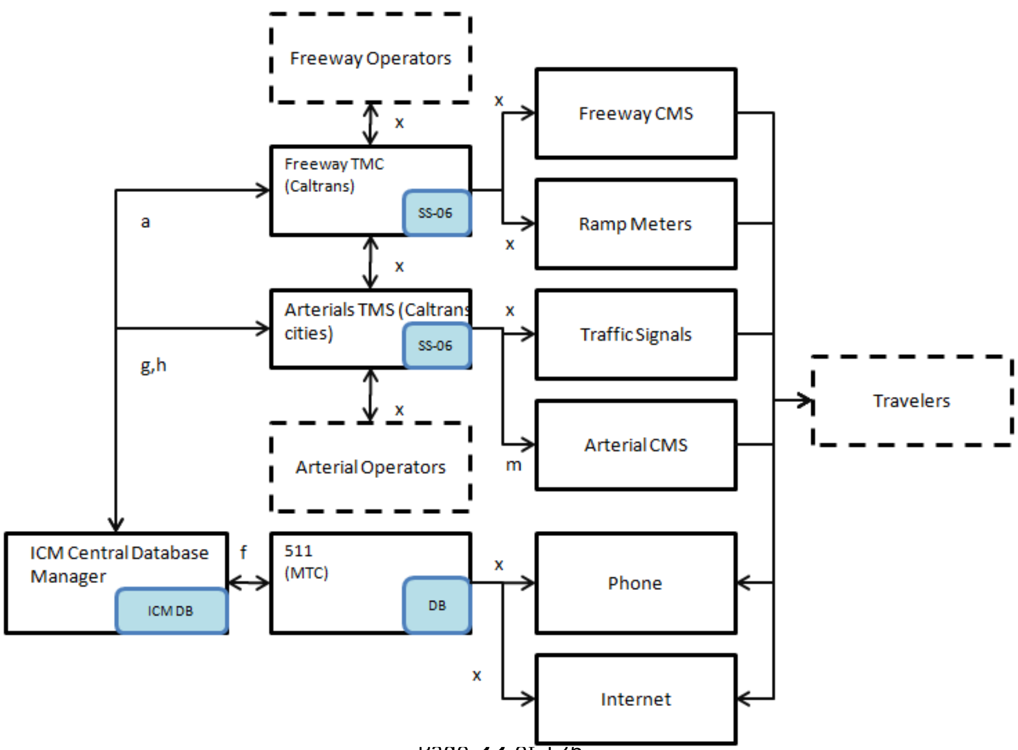


Figure 2.6 Interface diagram for SS-06

2.4.5 Managing Arterial Signal to Provide Transit Signal Priority (SS-07)

The bus signal priority system enables buses to interface with traffic signals to gain priority. TSP has already been implemented along International Blvd and East 14th Street. Additional bus signal priority-enabled intersections are planned for other arterial corridors. A possible TSP approach is to utilize the existing CAD/AVL to implement signal priority, as shown in Figure 2.7.

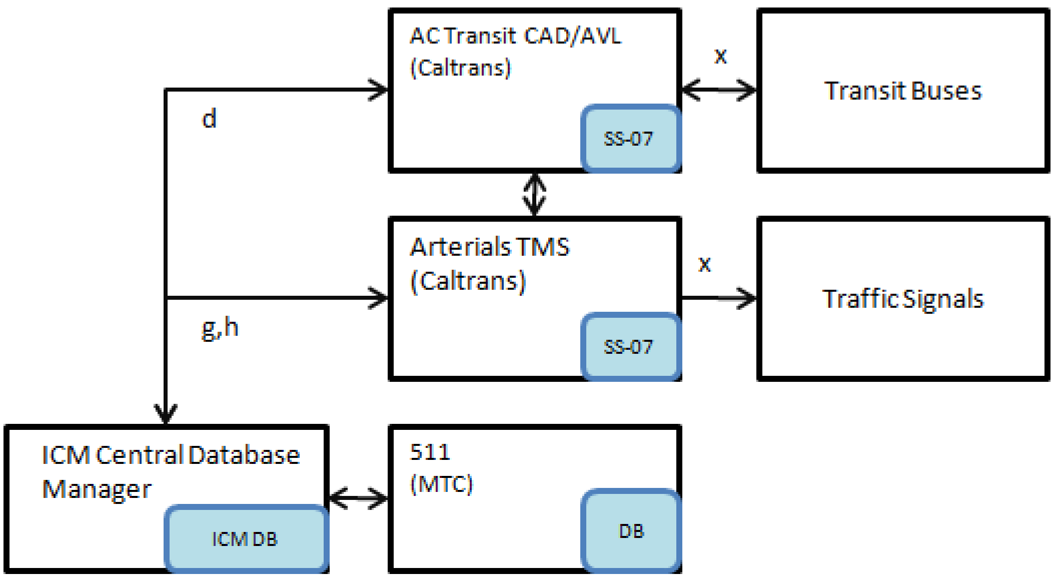


Figure 2.7 Interface diagram for SS-07

2.4.6 Managing Transit Operation under Severe Incident Conditions (SS-08)

The SS-08, as shown in Figure 2.8, 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 having its buses stuck in the traffic.

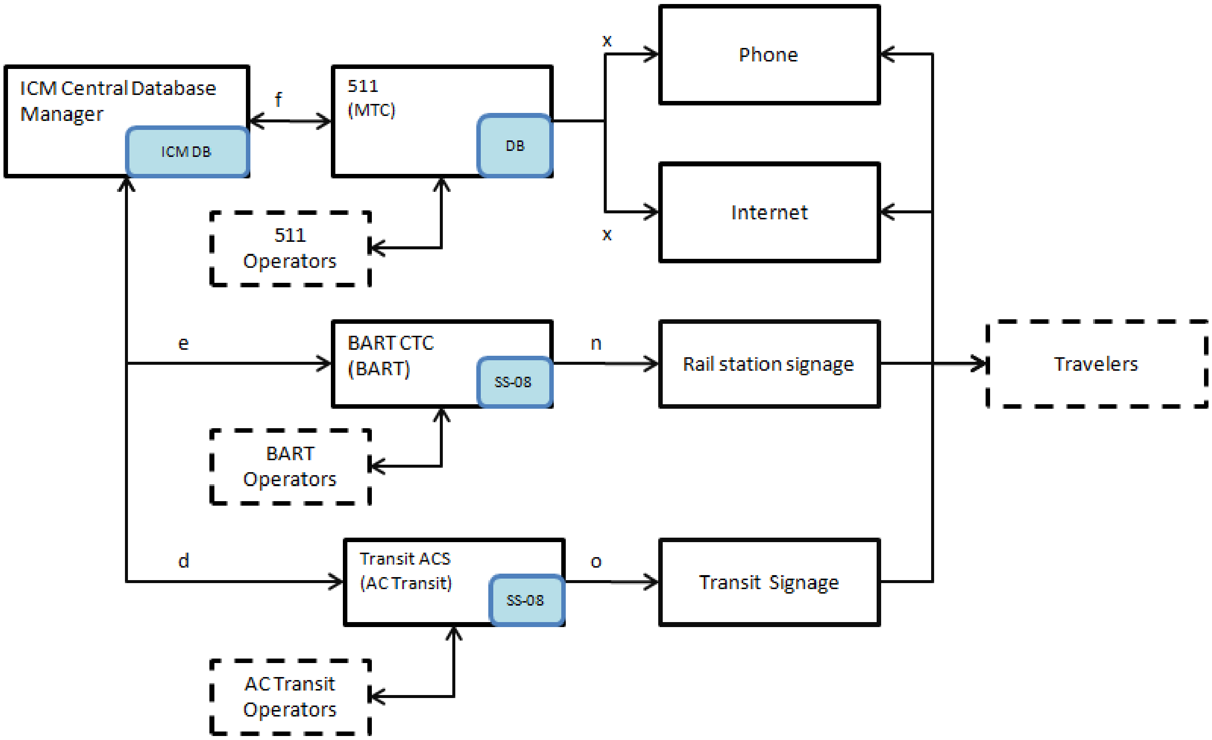


Figure 2.8 Interface diagram for SS-08

2.4.7 Managing Transit Hub Connection Protection for Special Events (SS-09)

The ICMS subsystem SS_09, shown in Figure 2.9, will allow AC Transit to provide connection protection for pre-planned special events and emergencies due to major events.

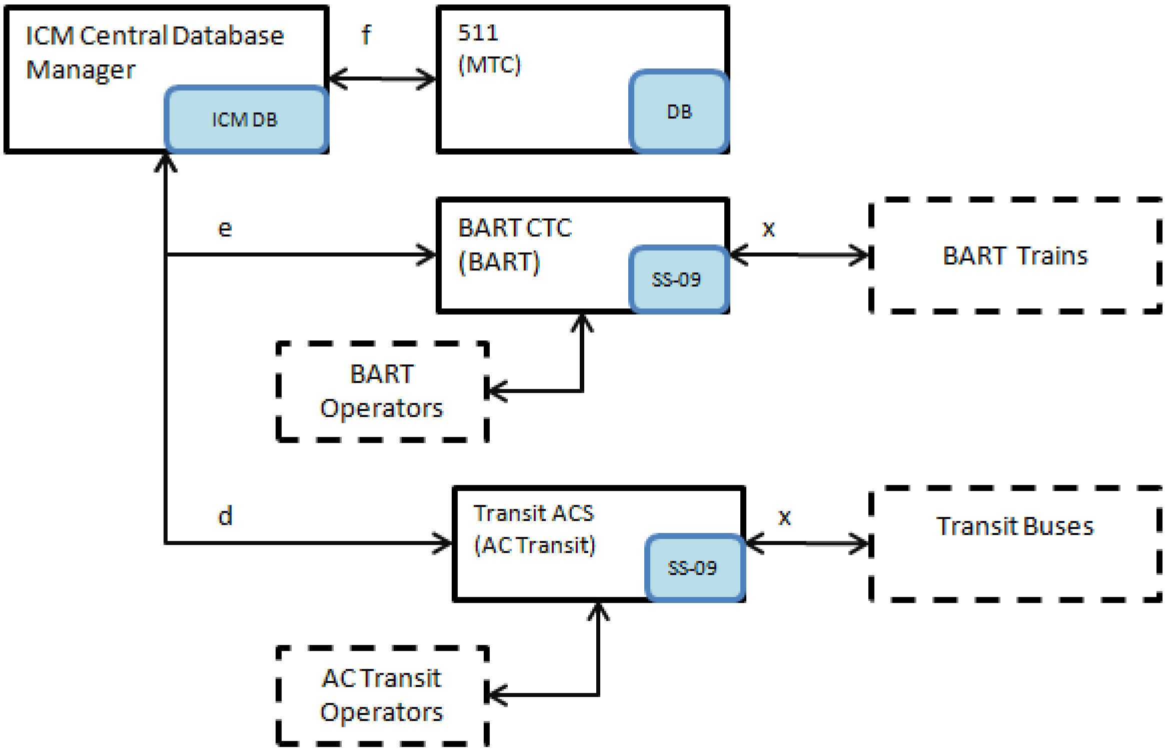


Figure 2.9 Interface diagram for SS-09

2.4.8 Advising Truck Operators and Drivers About Port Delay and Estimated Travel Time (SS-10)

The ICMS subsystem (SS-10), shown in Figure 2.10, 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.

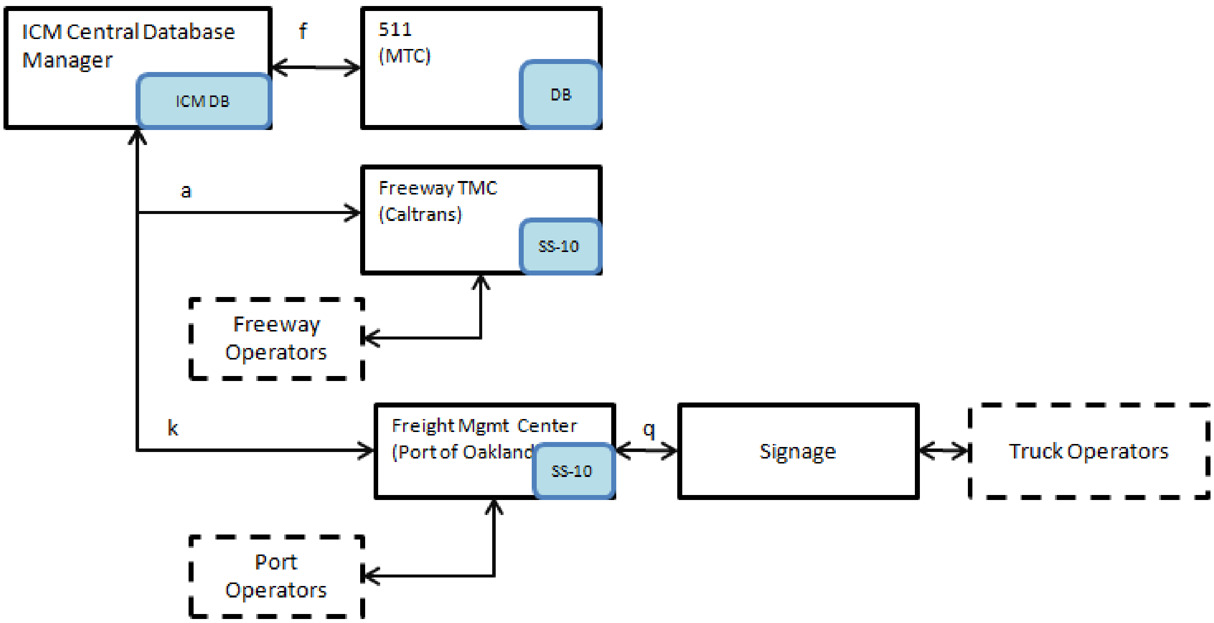


Figure 2.10 Interface diagram for SS-10

2.4.9 Providing Emergency Vehicles with Signal Pre-emption and Best Routing Recommendations (SS-11) and Facilitating Rapid Incident Response (SS-12)

The ICMS Subsystem SS-11intends to facilitate all emergency response vehicles (i.e., fire trucks, police, paramedics) with signal preemption capabilities and to provide 'best route' information in order to reduce emergency response time. The ICMS subsystem SS-12 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. These two subsystems are illustrated in Figure 2.11.

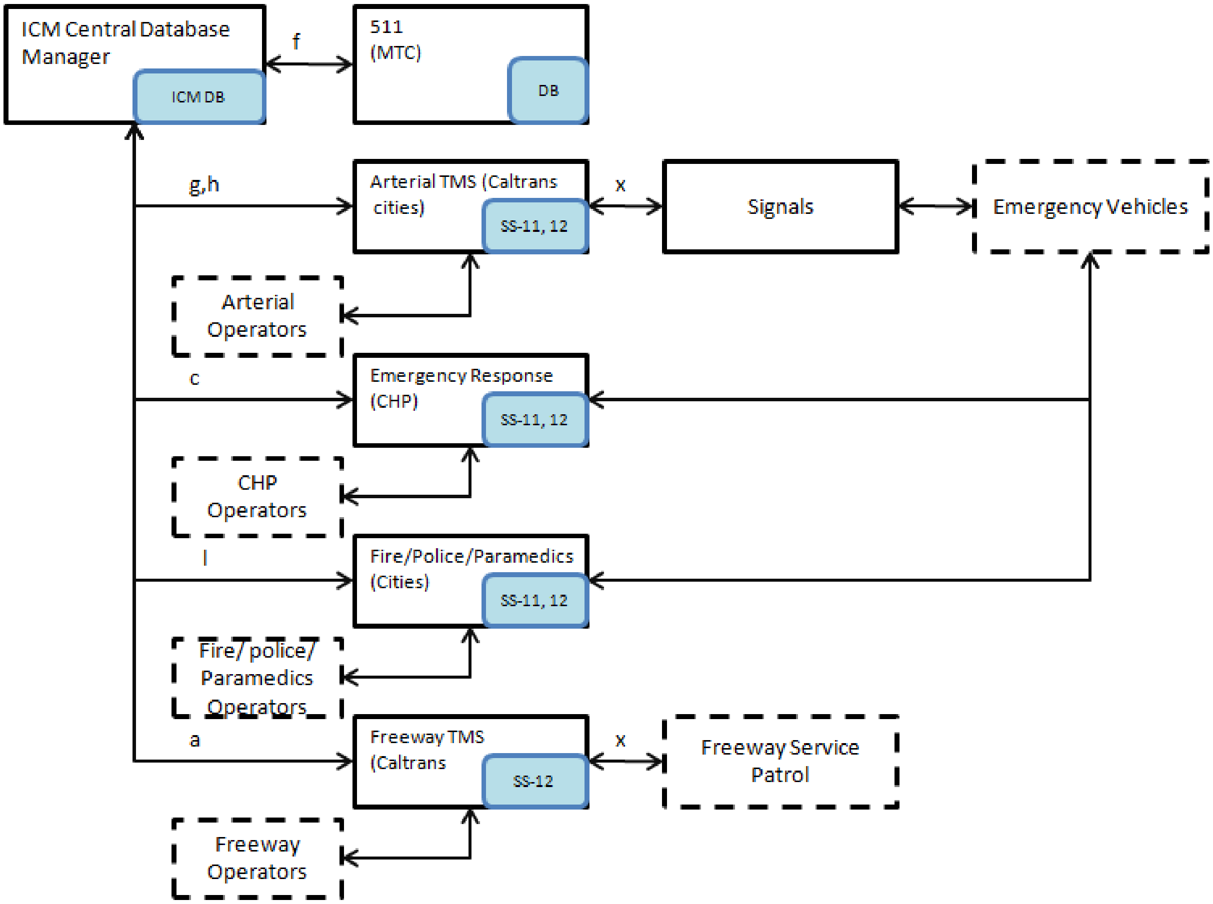


Figure 2.11 Interface diagram for SS-11 and SS-12

2.4.10 Supporting Maintenance and Construction Coordination (SS-13) and Supporting Coordination of Construction Work During Emergencies (SS-14)

The ICMS subsystem SS-13 will allow a standardized repository for reporting on routine maintenance closures of freeways and local arterials, accessible to other agencies. The subsystem SS-14 will support the development of guidelines for coordination of different transportation agencies for procedures and coordination protocols. The two ICMS subsystems are illustrated in Figure 2.12.

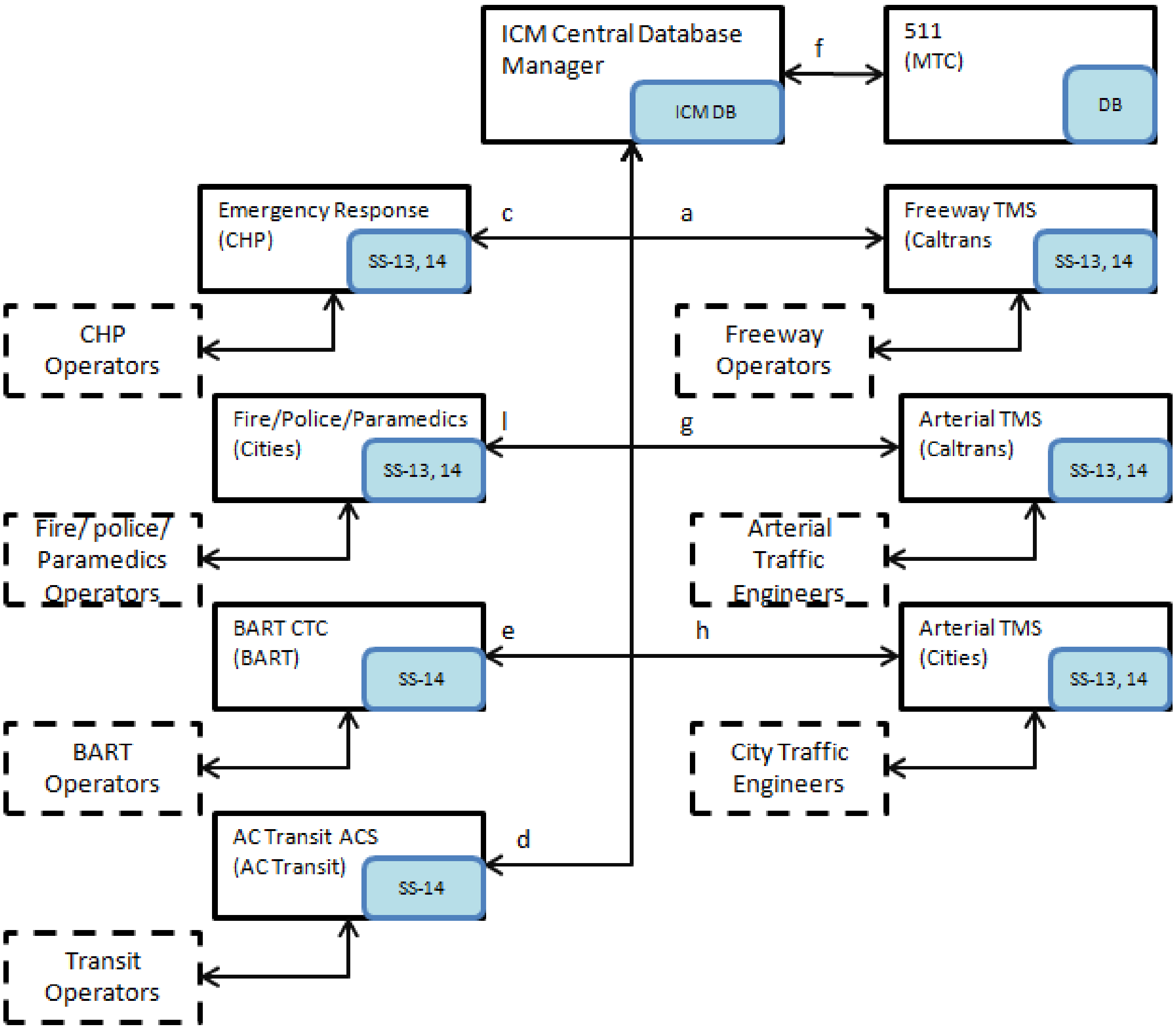


Figure 2.12 Interface diagram for SS-13 and SS-14

The interface diagrams of the ICMS subsystems and the existing ITS systems described in Section 2.4.1 through 2.4.10 define the distributed nature and the interfaces of the I-880 ICMS subsystems. The functional composition of the ICMS subsystems, which reside within the existing ITS systems, are provided in Section 4.4.

2.5 ICMS Operation

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 ICMS, 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 final approval of operation plans and protocols. The ICMOC will be the consensus body to make decisions on coordination among stakeholders and to help resolve issues encountered across agencies.

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

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

Table 2.4 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

STAKEHOLDER/ AGENCY	RESPONSIBILITIES
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 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
MTC	Provide Traveler information through 511 system Provide overall coordination for the I-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

STAKEHOLDER/ AGENCY	RESPONSIBILITIES
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 planned route,-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

STAKEHOLDER/ AGENCY	RESPONSIBILITIES
Private vehicle drivers	Use pre-trip information to decide whether to make a trip and whether to change departure time, mode, route or destination Use en-route information to decide whether to change route or mode
Transit passengers	Use information to decide whether to make a trip and whether to change departure time, bus or rail route, or connection.
Truck drivers, fleet managers and dispatchers	Use pre-trip information to decide whether to change departure time or route to destination Use en-route information to decide whether to change route
Bus drivers	Follow guidance provided by dispatchers

The I-880 ICMS will be a distributed system. All stakeholders along the I-880 corridor will be collaborating on the implementation of the proposed strategies, based on their roles and responsibilities in the existing operation of transportation networks along the I-880 corridor. The operation of the ICMS subsystems will be led by the operating agencies that have primary responsibility in today's operations. The control and related functions for specific strategies will be shared among the corridor agencies, coordinated by the lead agency. 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 that 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. Table 2.5 provides further details on how each of the ICMS subsystems will be operated.

Table 2.5 – Roles and Responsibilities Per Subsystem

Strategies	Responsibilities
SS-01 Information sharing subsystem	Lead agency: MTC Supporting agencies: Caltrans, Alameda CMA, AC Transit, BART, Port of Oakland, Water Transit Authority
SS-02 Enhanced 511 traveler information subsystem for pre-trip planning	Lead agency: MTC Supporting agencies: Caltrans, Alameda CMA, AC Transit, BART, Port of Oakland, Water Transit Authority
SS-03 Real-time traveler information subsystem for en-route decision making	Lead agency: Caltrans Supporting agencies: AC Transit for buses; BART for rail
SS-04 Real-time travel advisory information subsystem at transit stations and on transit vehicles	Lead agency: AC Transit and BART Supporting agencies: 511
SS-05 Subsystem for coordinating operations between freeway ramp metering and arterial signals	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: Cities
SS-06 Subsystem for facilitating arterial signal control systems to handle special events.	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: Cities and Oakland Coliseum
SS-07 Subsystem for managing arterial signals to provide priority for transit vehicles	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: AC Transit and Cities

Strategies	Responsibilities
SS-08 Subsystem for managing transit operation under severe incident conditions and for special events	Lead agency: AC Transit Supporting agencies: MTC
SS-09 Subsystem for managing transit operation for transit hub connection protection for special events	Lead agency: AC Transit Supporting agencies: BART, MTC
SS-10 Subsystem for advising truck operators and drivers about port delay and estimated travel time	Lead agency: Port of Oakland Supporting agencies: Caltrans, MTC
SS-11 Subsystem for providing emergency vehicles with signal pre-emption and best routing recommendations	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: CHP, cities, paramedics
SS-12 Subsystem for facilitating rapid incident response	Lead agency: CHP for freeways Local Policy Agencies Supporting agencies: Caltrans, MTC, AC Transit, BART and Cities
SS-13 Subsystem for supporting maintenance and construction coordination	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: All stakeholders
SS-14 Subsystem for supporting coordination of construction work during emergencies	Lead agency: Caltrans (for state routes) Alameda CMA (for local streets) Supporting agencies: All stakeholders

The administration of the ICMS will require many elements to be addressed in order to ensure smooth and ongoing operations. Ongoing measurement of data quality is of high priority, as are staff training and documentation in order to disseminate and ensure consistency in procedures.

As the system elements are installed, the following should be developed:

- Documentation of user procedures and standard operating procedures
- Training materials
- Documentation of equipment inventory
- Documentation of maintenance procedures – routine and non-routine maintenance

Staff training is a major element of any new system operation. Detailed training should be developed and rolled out so that staff is aware not only of the user responsibilities and procedures, but also so that the protocols and change control processes developed by the ICMOC and others are followed.

2.6 Major System Conditions

The I-880 corridor in Alameda County, CA 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.

Alameda County has the greatest amount of freeway congestion of the nine Bay Area counties, with 50,000 vehicle-hours of daily delay. I-880 alone has average daily delays of more than 10,000 vehicle-hours. The corridor also has a high incident/accident rate, with an average of over 10 collisions and over 100 incidents per day. It is estimated that collisions account for 30 percent of overall corridor delay. These statistics suggest a significant opportunity to demonstrate improvements gained from ICM,

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.

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 the I-880 ICMS Field Operational Tests, the primary operating agencies along I-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.

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.

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.

2.7 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.

2.7 User Characteristics

The direct users of the I-880 ICMS are the operators and users of the transportation networks along the corridor. Specifically, the operators include:

- Caltrans freeway operations management personnel
- Caltrans engineers who operate arterial highways
- City traffic engineers
- AC Transit OCC operations personnel
- BART control center operations personnel
- Port of Oakland transportation coordinator
- MTC 511 system administrator
- CHP dispatchers
- Dispatchers of fire fighting agency
- Dispatchers of city police department
- Paramedics dispatchers
- Ferry operator
- Alameda CMA Smart Corridor system administrator
- Oakland Coliseum event schedulers
- Maintenance personnel at each transportation agency
- Construction managers at each transportation agency
- ICMS operations personnel
- Maintenance personnel of ICM system

The users at transportation agencies are all professionally trained. As the ICMS will add additional functions and likely new components (such as communication links), training will be necessary in order for them to fully understand the capabilities and operation procedures for the ICMS.

Travelers are the ultimate users of many of the ICMS functions, either through traveler information or through interacting with traffic control devices. These are expected to include both members of the general public and professionals:

General public:

- Passenger car drivers
- Transit passengers

Professionals:

- Transit bus drivers
- Truck drivers serving Port of Oakland
- Truck fleet managers and dispatchers
- Public safety vehicle drivers (police, fire, EMS)

The traveler information and traffic control devices need to be designed to be usable by the general public without any specialized training, although they may benefit from public awareness campaigns to introduce the new ICMS capabilities. More specialized functions for use by the professionals could require some training, which needs to be developed and distributed through various channels, including but not limited to media, web, fliers, and public workshops.

2. 8 Assumptions and Dependencies

The preliminary requirements developed in this document are to address all needs identified by the I-880 ICM stakeholders. It is likely that only selected strategies will be implemented during the Phase Three ICM program. The implementation scenario will affect the level of improvements. The requirements definition also relies on the assumption that the I-880 ICM program will focus on integration. New field elements are not required unless they are absolutely needed for enabling integration, such as the communication link between two systems. The functional and performance requirements are dealing with abstractions of the system rather than with any specific design. Detailed requirement specifications need to be developed before the design stage.

2.9 Operational Scenarios

The I-880 ICMS will support a number of application scenarios, as defined in the ConOps, including: Normal operations, Incident (highway and arterial), Incident (transit), planned/scheduled event, and catastrophic event.

2.9.1 Normal Operations Scenario

The normal operations scenario addresses corridor management activities in response to typical day-to-day traffic flows and recurrent congestion. The I-880 freeway experiences high levels of traffic congestion for much of the day under normal conditions, not only during the typical AM and PM peak periods but also in the middle of the day. The corridor experiences recurrent delays at known bottlenecks that could benefit greatly from the implementation of ICM strategies to provide comprehensive multi-modal information to travelers, enhanced transit service quality, more efficient sharing of roadway capacity among freeways and arterials and facilitated emergency vehicle access.

The AC Transit bus services in the corridor are operating at seating capacity during peak periods. Although the agency has no plans to increase the number of bus operators or fleet size due to financial constraints, AC Transit buses can still accommodate a significant number of standees on their existing buses. The peak period capacity of the BART rail transit services in the corridor is determined by the availability of rolling stock. Typically, during the peak hours, the passenger density become higher as the train approaches San Francisco in the morning peak or leaves San Francisco in the afternoon. Ridership is also constrained by the limitations in the capacity of BART's park-and-ride garages. The unreserved parking lots are already operating completely full during weekdays. The reserved parking spaces for most of stations however are typically not fully utilized until 10 am, when the extra spaces become available to all riders. A more effective utilization of the reserved parking could help to attract more riders during the peak hours. During the off-peak times both transit agencies have significant excess capacity, although their practical ability to expand operations at those times is still constrained by their operating budgets.

The overall roadway capacity of the corridor is not fully utilized at present because of the lack of coordination between freeway and arterial operations and the lack of information for travelers about real-time arterial operating conditions. Most automobile-oriented travelers also lack information about the public transit alternatives that could potentially be viable for serving their travel needs.

Finally, there is limited direct coordination between the transportation network operators and the public sector operators of the major traffic generators within the corridor, such as the Port of Oakland, which operates both the container port and Oakland Airport.

2.9.2 Incident Scenario (Highway and Arterial)

The incident scenario addresses corridor management activities and strategies in response to incident-related non-recurrent congestion.

A significant amount of congestion delay on the I-880 freeway is caused by incidents (crashes, breakdowns, spilled loads and other random events). The I-880 corridor experiences over 100 incidents every day. Many of these incidents occur in the afternoon, when traffic volumes and congestion are greater than at other times of the day.

It is important that effective and efficient management procedures be in place to quickly detect, verify, respond and clear incidents to minimize their adverse impacts on traffic. In 2003 the Bay Area Incident Response System (BAIRS), a computerized incident management tool, was implemented by Caltrans District 4 in the San Francisco Bay Area to improve freeway incident management capabilities. BAIRS reduced incident durations by about 15%, but there is still room for further improvements in the dispatching process and corresponding personnel response times to clear incidents.

Other concerns under the existing condition in the management of roadway incidents in the corridor include:

- real-time information about impacts of incidents on travel times is not generally available to system operators or travelers
- system operators lack the tools to adjust their operations accordingly in response to incidents
- there is currently no effective way to provide guidance to drivers to minimize their delay if the incident occurs after they have started their trip
- prompt incident detection on arterials is not generally available
- even after an arterial incident is detected, there is no effective way to notify drivers about it.

2.9.3 Incident Scenario (Transit)

The I-880 corridor depends heavily on its two primary transit services, the BART rail transit line and the AC Transit buses. The transit operators have to contend with a wide range of potential incidents, which have different implications when they occur during peak and off-peak operations. In addition, the AC Transit express bus services operating on the freeway may encounter major freeway incidents that require re-routing of the buses and/or serious schedule delays.

The transit agencies have general procedures in place for handling incidents, but they are limited by resource constraints as well as shortfalls in real-time information. Issues of particular concern with regard to transit incidents include:

- need for enhanced coordination between the two major transit system operators
- limited availability to travelers of information about alternative modes
- the transit trip planner in the 511 system is based on nominal transit schedules and does not include a dynamic capability to respond to real-time schedule deviations
- real-time information about service interruptions and connection problems is only partially available to travelers
- transit-dependent travelers have limited options, even if better information is available to them.

2.9.4 Planned/Scheduled Event Scenario

Planned and scheduled events, such as major sporting or entertainment events at the Oakland Coliseum, major weeknight sporting events in San Francisco, major travel surges at Oakland Airport associated with holiday travel peaks, etc. can place severe demands on the transportation system, but because they are planned and scheduled it should be possible to mitigate their impacts on transportation services by developing and implementing effective strategies. These strategies are likely to depend at least as much on pre-event coordination as on real-time information sharing. The coordination should be planned among all involved organizations far enough in advance to provide time to settle on the most acceptable response strategy and contingency plans.

Some of the scheduled events (especially the infrequent ones) occur in locations that do not normally handle the volume or patterns of traffic that are generated by the special events. This requires particular care in planning, particularly for providing assets that are not normally in place there (officers to direct traffic, portable CMS to provide information, etc.) and to disseminate information to the public.

One particularly significant aspect of special events traffic is that a large proportion of the people traveling for these events are not familiar with the area. They may not know the most appropriate routes to take, where parking is available, what turn restrictions apply at intersections, which transit services can take them there, etc. This places a particular premium on providing comprehensive and easily understandable information to the traveling public. The information needs include real-time traffic information, real-time transit information, real-time parking information, and guidance for alternate routes.

2.9.5 Catastrophic Event Scenario

Major events, such as a large fire, widespread flooding, major earthquake, terrorist attack, etc. are generally unpredictable and have widespread impacts on the transportation system as well as on other aspects of the regional economy, so the transportation system responses need to account for the likelihood of other services being disrupted. Key challenges in managing this scenario include:

- The priorities and constraints faced by the public authorities will change multiple times as the corridor management activities progress through the different stages of emergency response and recovery, requiring timely information and decision making agility.
- The patterns of damage could occur in infinite combinations, making it impossible to anticipate them all in detail.
- With some sources of information likely to be disabled by the event, there will be large uncertainties about the true condition of the transportation infrastructure, vehicles, and personnel.
- The transportation needs of the corridor will change significantly throughout the event and recovery, depending on the extent and geographical distribution of the disruptions to commerce and work patterns.

MTC is already working towards integrated coordination of responses to catastrophic events by transportation agencies throughout the San Francisco Bay Area, and has developed agreements for resource sharing, timely communication, and unified public information. ICMS should be able to support multiple sources of information about the true condition and operations of the transportation networks within the corridor, helping to improve operational effectiveness and flexibility for responding to a major event and facilitating the cooperation among the operators of the different networks.

2.10 ICMS Performance Characteristics

The benefits of the ICMS are challenging to evaluate because the ICMS is in effect a "system of systems", each of which provides benefits to its own network operator. The benefits gained from use of these independent systems are not in fact the benefits of the ICMS, but rather the ICMS benefits are the *additional* benefits gained from the integration of the other systems. So, in order to identify ICMS benefits, we need to estimate the combined benefits from integrated use of all the ITS in the corridor, and then subtract the benefits from use of the independent systems in isolation. The performance measures therefore need to be able to capture both the individual benefits from use of the independent systems and the benefits of the integrated systems throughout the corridor.

2.10.1 ICMS Performance Measures

The performance measures at the corridor level will include:

- mean value of travel delays throughout the corridor, including all networks and modes
- predictability of travel delays throughout the corridor, including all networks and modes
- duration of unplanned incidents (from incident occurrence to complete dissipation of disruption to normal operations)
- emergency response time distribution (from incident occurrence to arrival of incident responders)
- frequency of occurrence of incidents of several levels of severity and total delays associated with these incidents
- changes in mode split of bus transit, rail transit, shared ride automobile and solo automobile

- traveling and waiting times for trucks serving the Port of Oakland from key origins
- fuel consumption savings associated with changes in mode split and reductions in traffic flow disturbances
- pollutant emission savings associated with changes in mode split and reductions in traffic flow disturbances.

At the level of the individual networks in the corridor, the performance measures will include:

- transit bus trip times – total time and reliability of travel time (schedule adherence)
- transit bus travel time saved by route diversions
- transit bus and rail transit ridership
- freeway speed and travel times, by location and time of day (mean and distribution)
- arterial speed and travel times, by location and time of day (mean and distribution)
- queue lengths at ramp meters and intersection traffic signals (mean and distribution)
- efficiency of utilization of transit park-and-ride facilities.

2.10.2 Estimated I-880 ICMS Performance Characteristics

Performance characteristics can be discussed at various levels. It is most important to first establish the performance characteristics at the system level, with which performance at functional or subsystem levels can be established. The I-880 ICM team performed analysis on the performance characteristics for a number of proposed ICM strategies. The performance characteristics analysis is provided in Appendix A. This analysis lays out the performance improvements the region would expect to achieve with the proper implementation of these strategies. These improvements have been estimated based on national, state, and regional experiences and research. During the next phase of the ICM, these estimates will be further refined using micro-simulation modeling and additional analysis. It is noted that, if only selective ICM strategies are implemented, the performance estimation provided below will need to be updated. Table 2.1 summarizes the performance characteristics and how to quantify the performance characteristics.

Table 2.1 ICM Performance Characteristics by Strategy

EXPECTED IMPROVEMENT BY PERFORMANCE MEASURE			
ICM STRATEGY	**TRAVEL TIME**	**TRAVEL TIME RELIABILITY**	**SAFETY**
	▪ Computed as total hours of delay, broken down by facility, mode, and bottleneck area. Data from FasTrak travel times, PeMS, BART and AC Transit.	▪ Computed using the Travel Time Buffer Index (the 95th percentile of travel time over 50th percentile travel time.) Data from FasTrak travel times, PeMS, BART and AC Transit.	▪ Computed using accident reduction including fatality, injury and property damage only accidents. Data from CHP database and from PeMS.
▪ Improved Freeway Management ▪ Ramp metering	▪ Travel delay reduced during peak hours by 7 percent.	▪ Trip reliability improved by 10 percent.	▪ Overall number of crashes reduced by 10 percent.
▪ More efficient Incident Management ▪ Improve response time ▪ Improve accuracy of incident logging at CHP CAD system ▪ Improve integration between freeway, and arterial and transit operations	▪ System travel time reduced by 7 percent during incident ▪ Overall incident delay reduced by 10 percent. ▪ Decreased incident response times by 5 percent ▪ Reduced incident duration by 10 percent	▪ Travel time reliability improved by 10 percent under incident conditions.	▪ Secondary crash rates reduced by 20 percent
▪ Improved Highway Traveler Information ▪ Improved pre-trip and en-route traveler information and CMS	▪ System travel time reduction by 1 percent ▪ Additional mode shift of 2 percent in response to traveler information about recurrent and non-recurrent congestion	▪ Trip reliability improved by 5 percent.	▪ Small expected benefits
▪ Improved Transit Traveler Information ▪ Improved pre-trip and en-route traveler information	▪ System travel time reduction by 1 percent ▪ Additional mode shift of 2 percent in response to traveler information about recurrent and non-recurrent congestion	▪ Trip reliability improved by 2 percent.	▪ Small expected benefits
▪ Improved Arterial Traffic Management ▪ Adaptive signal control	▪ 10 percent improvement in arterial delay	▪ Small expected benefits	▪ Small expected benefits
▪ Mode shift	▪ Mode shift 2-4% of total corridor trips in response to traveler information	▪ Small to moderate expected benefits	▪ Small expected benefits

3. ICMS General Requirements

3.1 Non-Functional Needs

Following the functional needs identified in the ConOp development process, the I-880 stakeholders also developed a set of non-functional needs for the ICMS.

Table 3.1 Functional Requirements

- NN-01 Need for interagency cooperation, communication and coordination
  - NN-01-01 Needs for interagency cooperation agreement
  - NN-01-02 Needs for interagency coordination and communication protocols
- NN-02 Need for a durable and modifiable system
  - NN-02-01 Needs for a durable system
  - NN-02-02 Needs for a modifiable system
- NN-03 Need for intuitive and easy to use designs
  - NN-03-01 Needs for an intuitive user interface for operators
  - NN-03-02 Needs for an intuitive user interface for travelers
- NN-04 Need for a reliable system
- NN-05 Need for a maintainable system
- NN-06 Need for policy and regulations for data sharing
- NN-07 Need for interface standards and protocols
- NN-08 Need for a quality information processing infrastructure
  - NN-08-01 Performance
  - NN-08-02 Function 7/24
  - NN-08-03 Function 99.99% of the time
  - NN-08-04 Process 50 concurrent operator commands
  - NN-08-05 Process user authentication within 2 seconds
  - NN-08-06 Provide user information storage for up to 500 users
  - NN-08-07 Provide organization information storage up to 500 organizations
  - NN-08-08 Provide data acquisition configuration capability for up to 500 data sources
  - NN-08-09 Provide data publishing configuration capability for up to 500 data subscribers
- NN-09 Security
  - NN-09-01 Operations center firewall
  - NN-09-02 Only allow authorized access to data and system
  - NN-09-03 Each ICM subsystem manages its own security as per security requirement of the host ITS system
- NN-10 Documentation
  - NN-10-01 Maintenance documentation
  - NN-10-02 Operator manuals
  - NN-10-03 Administration Manuals
- NN-11 Training
  - NN-11-01 Maintenance training
  - NN-11-02 Operator training

These non-functional needs form the basis for a set of non-functional requirements which impose constraints on the design or implementation.

3.2 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.

Table 3.2 Non-Functional Requirements

ID	*Requirement*	*Traceability*	*Comment*	*Criticality*
RN-01	The ICMS shall be available 24 hours a day, 7 days a week.	NN-04		H
RN-02	The ICMS subsystems shall be designed to last 10 years.	NN-02-01		H
RN-03	The ICMS subsystems and components shall be operational between -40C and 70C outdoors and between 0C and 50C indoors	NN-04		H
RN-04	The ICMS shall have a MTBF. RN-04-01 The ICMS shall have a MTBF greater than 180 days for major system failures. RN-04-02 The ICMS shall have a MTBF greater than 60 days for minor system failures.	NN-04		H
RN-05	The major hardware ICMS shall be replaceable through plug and play process.	NN-05 NN02-02		H
RN-06	The software components of ICMS shall be maintainable with minimum down time. Typical maintenance down time shall not exceed 30 minutes.	NN-02-02 NN-05		H

ID	Requirement	Traceability	Comment	Criticality
RN-07	The Human-Machine Interface of ICMS shall be designed in such a way that training for new institutional user will not exceed 48 hours.	NN-03-01		H
RN-07	The Human-Machine Interface of ICMS shall be designed in such a way that no training is needed for travelers in order to understand and use the system.	NN-03-02		H
RN-08	The ICMS shall function 99.99% of the time (i.e., at most 60 seconds of down time per week).	NN08-02		H
RN-09	The ICMS shall process 50 concurrent operator commands.	NN-08-04		H
RN-10	The ICMS shall process user authentication within 2 seconds after user log in information is received.	NN-08-05		H
RN-11	The ICMS shall provide user information storage up to 2Mb for 5000 users.	NN-08-06		H
RN-12	The ICMS shall provide organization information storage up to 20Mb for 500 organizations.	NN-08-07		H
RN-13	The ICMS shall provide data acquisition configuration capability for up to 500 data sources.	NN-08-08		H
RN-14	The ICMS shall provide data publishing configuration capability for up to 500 data subscribers.	NN-08-09		H
RN-15	The ICMS operations center shall have firewall for security purposes.	NN-09-01		H
RN-16	The ICMS operations center shall require authentication of users	NN-09-03		H
RN-17	The ICMS subsystems shall follow security requirements of the host ITS system	NN-09-03		H

ID	Requirement	Traceability	Comment	Criticality
RN-18	The ICMS shall have documentation for maintenance.	NN-10-01	.,	H
RN-19	The ICMS shall have operator manuals.	NN-10-02		H
RN-20	The ICMS shall have administration manuals.	NN-10-03		H
RN-21	The ICMS shall have features allowing on-line training for maintenance personnel	NN-11-01		H
RN-22	The ICMS shall have features allowing on-line training for system operators.	NN-11-02		H
RN-23	The administration of the ICMS shall be performed by a lead agency with the support from other agencies.	NN-01-01 NN-01-02		H
RN-24	Communication protocols shall be developed for ICMS allowing effective communication among operators from various agencies.	NN-01-01 NN-01-02		H
RN-25	The institutional framework for operating ICMS shall be defined by a partnership agreement among all transportation agencies along the I-880 corridor.	NN-01-01		H

4. 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.

4.2 Identify ICMS Needs

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.

Table 4.1 I-880 ICMS Needs Summary

- N1 Need for cross-systems information sharing
    - N1-01 Acquire information
        - N1-01-01 Acquire traffic information
        - N1-01-02 Acquire transit information
        - N1-01-03 Acquire parking information
        - N1-01-04 Acquire event information
    - N1-02 Process information
        - N1-02-01 Check information quality
        - N1-02-02 Calculate travel times
        - N1-02-03 Determine new incident
        - N1-02-04 Determine transit service schedule/route adherence
        - N1-02-05 Determine remaining network capacity
        - N1-02-06 Forecast network demand
        - N1-02-07 Forecast congestion
        - N1-02-08 Determine actions in response to current and forecast conditions
    - N1-03 Publish information
        - N1-03-01 Publish information to colleague systems
        - N1-03-02 Publish response actions to colleague systems
    - N1-04 Archive information
        - N1-04-01 Archive traffic information
            - N1-04-01-01 Archive freeway traffic information
            - N1-04-01-02 Archive arterial traffic information
        - N1-04-02 Archive transit information
            - N1-04-02-01 Archive bus transit information
            - N1-04-02-02 Archive rail transit information
        - N1-04-03 Archive incident information from difference sources

N2 Need for a corridor/region-based multimodal traveler information system
    N2-01 Acquire information
        N2-01-01 Acquire traffic information
        N2-01-02 Acquire transit information
        N2-01-03 Acquire parking information
        N2-01-04 Acquire event information
    N2-02 Process information
        N2-02-01 Check information quality
        N2-02-02 Store information
        N2-02-03 Calculate travel times
        N2-02-04 Determine new incident
        N2-02-05 Process video
        N2-02-06 Determine transit service schedule/route adherence
        N2-02-07 Determine remaining network capacity
        N2-02-08 Forecast congestion
    N2-03 Publish information
        N2-03-01 Publish information via DMS
        N2-03-02 Publish information via 511
        N2-03-03 Publish information via HAR

N3 Need for coordination between freeway and arterial operations
    N3-01 Configure system response plans
    N3-02 Acquire information
        N3-02-01 Acquire traffic information
        N3-02-02 Acquire event information
    N3-03 Process information
        N3-03-01 Check information quality
        N3-03-02 Calculate travel times
        N3-03-03 Determine new incident
        N3-03-04 Determine remaining network capacity
        N3-03-05 Forecast network demand
        N3-03-06 Forecast congestion
        N3-03-07 Determine actions in response to current and forecast conditions
    N3-04 Publish information
        N3-04-01 Publish information via DMS
        N3-04-02 Publish information via 511
        N3-04-03 Publish information via HAR
        N3-04-04 Publish information to colleague systems

N4 Need for coordination between highway and transit operations
    N4-01 Prepare operational procedures
    N4-02 Train operations staff
    N4-03 Acquire information
        N4-03-01 Acquire traffic information
        N4-03-02 Acquire transit information
        N4-03-03 Acquire parking information
        N4-03-04 Acquire event information
    N4-04 Process information
        N4-04-01 Check information quality
        N4-04-02 Calculate travel times
        N4-04-03 Determine new incident
        N4-04-04 Determine transit service schedule/route adherence
        N4-04-05 Determine remaining network capacity
        N4-04-06 Forecast network demand
        N4-04-07 Forecast congestion
        N4-04-08 Determine actions in response to current and forecast conditions

    - N4-04-09 Determine bus arrival time at downstream intersections
    - N4-04-10 Request bus priority at downstream intersections
- N4-05 Publish information
    - N4-05-01 Publish information via DMS
    - N4-05-02 Publish information via 511
    - N4-05-03 Publish information via HAR
    - N4-05-04 Publish information to colleague systems
    - N4-05-05 Publish traffic information to transit users

N5 Need for coordination between transit systems

- N5-01 Prepare operational procedures
- N5-02 Train operations staff
- N5-03 Acquire information
    - N5-03-01 Acquire transit information
    - N5-03-02 Acquire parking information
    - N5-03-03 Acquire event information
- N5-04 Process information
    - N5-04-01 Check information quality
    - N5-04-02 Determine transit service schedule/route adherence
    - N5-04-03 Forecast network demand
    - N5-04-04 Determine actions in response to current and forecast conditions
    - N5-04-05 Log information regarding requests for connection protection
- N5-05 Publish information
    - N5-05-01 Publish information via DMS
    - N5-05-02 Publish information via 511
    - N5-05-03 Publish information via HAR
    - N5-05-04 Publish information to colleague systems
    - N5-05-05 Publish information at transit stops

N6 Need for coordination between highway and freight operations

- N6-01 Acquire information
    - N6-01-01 Acquire traffic information
    - N6-01-02 Acquire port operation information
- N6-02 Process information
    - N6-02-01 Check information quality
    - N6-02-02 Calculate travel times
    - N6-02-03 Calculate port delay times
- N6-03 Publish information
    - N6-03-01 Publish information to trucking companies
    - N6-03-02 Publish information to truck drivers
    - N6-03-03 Publish information to information kiosk at rest stops
    - N6-03-04 Publish information to DMS
    - N6-03-05 Publish information at the port

N7 Need for coordination between highway control systems and emergency response

- N7-01 Prepare operational plans
- N7-02 Train operations staff
- N7-03 Acquire information
    - N7-03-01 Acquire traffic information
    - N7-03-02 Acquire event information
- N7-04 Process information
    - N7-04-01 Check information quality
    - N7-04-02 Calculate travel times
    - N7-04-03 Forecast network demand
    - N7-04-04 Forecast congestion
    - N7-04-05 Determine actions in response to current and forecast conditions

- N7-04-06 Determine best route for emergency vehicles
- N7-05 Publish information
  - N7-05-01 Publish information to related cities
  - N7-05-02 Publish information to emergency vehicles

N8 Need for coordination for incident response

- N8-01 Prepare operational procedures
- N8-02 Train operations staff
- N8-03 Configure system response plans
- N8-04 Acquire information
  - N8-04-01 Acquire traffic information
  - N8-04-02 Acquire transit information
  - N8-04-03 Acquire event information
- N8-05 Process information
  - N8-05-01 Check information quality
  - N8-05-02 Calculate travel times
  - N8-05-03 Determine new incident
  - N8-05-04 Determine transit service schedule/route adherence
  - N8-05-05 Determine actions in response to current and forecast conditions
- N8-06 Publish information
  - N8-06-01 Publish information to colleague systems
  - N8-06-02 Publish response actions to colleague systems
  - N8-06-03 Publish information to transportation network users
  - N8-06-04 Publish response actions to transportation network users
- N8-07 Archive incident data from different sources

N9 Need for coordination for infrastructure construction and maintenance

- N9-01 Prepare guidelines and protocols for coordination
- N9-02 Train operations staff
- N9-03 Acquire information
  - N9-03-01 Acquire traffic information
  - N9-03-02 Acquire transit information
  - N9-03-03 Acquire event information
- N9-04 Process information
  - N9-04-01 Check information quality
  - N9-04-02 Estimate impact of the special event
  - N9-04-03 Determine response actions based on the prepared guidelines and protocols
- N9-05 Publish information
  - N9-05-01 Publish information to colleague systems
  - N9-05-02 Publish response actions to colleague systems
  - N9-05-03 Publish information to 511 system

N10 Need for coordination of construction work during emergencies

- N10-01 Prepare guidelines and protocols for coordination
- N10-02 Train operations staff
- N10-03 Acquire information
  - N10-03-01 Acquire traffic information
  - N10-03-02 Acquire transit information
  - N10-03-03 Acquire event information
- N10-04 Process information
  - N10-04-01 Check information quality
  - N10-04-02 Calculate travel times
  - N10-04-03 Determine transit service schedule/route adherence
  - N10-04-04 Determine remaining network capacity
  - N10-04-05 Determine action in response to current and forecast conditions

N10-05 Publish information
- N10-05-01 Publish information to colleague systems
- N10-05-02 Publish response actions to colleague systems

4.3 Defining Functional Requirements

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.

4.4 Categorization of the Functional Requirements

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 (A series of requirements – RA)
- Data archiving functional requirements (B series of requirements – RB)
- Data processing functional requirements (C series of requirements – RC)
- Data dissemination functional requirements (D series of requirements – RD)

Tables 4.4.1 through Table 4.4.4 document the four sets of the ICMS functional requirements. 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.

Table 4.4.1 Data Collection Functional Requirements

ID	Requirement	Traceability	Data Requirements	Allocation		Criticality
RA	ICMS shall acquire corridor-wide transportation information. .	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10		FWY TMC Arterial control center Alameda CMA Cities AC Transit ACS BART control center		H
RA-01	ICMS shall acquire traffic information at a sampling rate of 30 seconds with no more than 30 seconds latency.	N1-01-01 N2-01-01 N3-02-01 N4-03-01 N6-01-01 N7-03-01 N8-04-01 N9-03-01 N10-03-01		FWY TMC Arterial control center Alameda CMA Cities		H
RA-01-01	ICMS shall acquire freeway traffic data from existing detection systems.	N1-01-01 N2-01-01 N3-02-01 N4-03-01 N6-01-01 N7-03-02 N8-04-01 N9-03-01 N10-03-01		FWY TMC		H

RA-01-01-01	ICMS shall acquire freeway traffic flow volume, occupancy, sensor status and speed data along the mainline.	N1-01-01 N2-01-01 N3-02-01 N4-03-01 N6-01-01 N7-03-02 N8-04-01 N9-03-01 N10-03-01	DF-02 DF-03	FWY TMC	Existing	H
RA-01-01-02	ICMS shall acquire freeway ramp volume and sensor status data at all on-ramps with errors of 20% or less.	N1-01-01 N2-01-01 N3-02-01 N4-03-01 N6-01-01 N7-03-02 N8-04-01 N9-03-01 N10-03-01	DF-06	FWY TMC	Existing	H
RA-01-01-03	ICMS shall acquire freeway travel time estimates between predetermined location pairs based on the existing 511 system.	N1-02-02 N2-02-03 N3-03-02 N4-04-02 N6-02-02 N7-04-02 N8-05-02 N10-04-02	DF-01	FWY TMC	Existing	H
RA-01-01-04	ICMS shall acquire status information about the freeway traffic operations system, including the current operational condition of all ramp meters and current messages displayed on variable message signs.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N10-04-03	DF-04 DF-05 DF-07	FWY TMC	Existing data at TMC	H

RA-01-02	ICMS shall acquire arterial traffic data at intervals of 30 s, with latency of no more than 5s.	N1-01-01 N2-01-01 N3-02-02 N4-03-02 N8-04-01 N9-03-01 N10-03-01		Arterial control center Alameda CMA Cities		H
RA-01-02-01	ICMS shall acquire traffic volume data at signalized intersections on the major arterials parallel to I-880, with errors of 20% or less.	N1-01-01 N2-01-01 N3-02-02 N4-03-02 N8-04-01 N9-03-01 N10-03-01	DA-01	Arterial control center Alameda CMA Cities	Existing for smart corridor	H
RA-01-02-02	ICMS shall acquire traffic speed information at signalized intersections on the major arterials parallel to I-880.	N1-01-01 N2-01-01 N3-02-02 N4-03-02 N8-04-01 N9-03-01 N10-03-01	DA-02	Arterial control center Alameda CMA Cities	Existing for smart corridor	H
RA-01-02-03	ICMS shall acquire traffic flow and speed along major arterials parallel to I-880.	N1-01-01 N2-01-01 N3-02-02 N4-03-02 N8-04-01 N9-03-01 N10-03-01	DA-02	Arterial control center Alameda CMA Cities	Existing for smart corridor	H
RA-02	ICMS shall acquire transit operation data.	N1-01-02 N2-01-02 N4-03-02 N5-03-01 N8-04-02 N9-03-02 N10-03-02		Transit ACS BART control center	Existing but at lower sampling rate	H

RA-02-01	ICMS shall acquire transit bus operation data at a sampling interval of 15 seconds with a latency no greater than 30 seconds.	N1-01-02 N2-01-02 N4-03-03 N5-03-01 N8-04-02 N9-03-02 N10-03-02	DT-01 DT-02 DT-03	Transit ACS BART control center	Existing but at lower sampling rate	H
RA-02-02	ICMS shall acquire rail transit (BART) travel operation data at a sampling interval of 30 seconds, with a latency no greater than 5 seconds.	N1-01-02 N2-01-02 N4-03-03 N5-03-01 N8-04-02 N9-03-02 N10-03-02	DT-04 DT-05 DT-06	Transit ACS BART control center	Existing	H
RA-03	ICMS shall acquire information about the availability of parking spaces at major parking facilities in the corridor (BART lots, Oakland Coliseum, Oakland Airport), with a latency not to exceed 5 minutes and errors not to exceed 5 %.	N1-01-03 N2-01-03 N4-03-03 N5-03-02	DT-07	BART control center Caltrans TMS		H
RA-04	ICMS shall acquire information about major events and major incidents with a latency not to exceed 60 s.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N9-03-03		Caltrans TMS Oakland Coliseum		H
RA-04-01	ICMS shall acquire freeway, arterial and transit incident reports from the CHP CAD system or the regional 511 system.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03	DI-01 DI-02 DI-03	FWY TMC CHP		H

RA-04-02	ICMS shall acquire local incident reports from the city police departments in the corridor, including traffic incidents, major fires and law enforcement actions that disrupt traffic.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03		Arterial control center Alameda CMA Cities		H
RA-04-02-01	ICMS shall acquire positions of fire, ambulance vehicles.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03	DI-04	Cities		H
RA-04-03	ICMS shall acquire incident reports from participating incident response agencies in the corridor.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03	DI-04	FWY TMC Arterial control center Transit ACS BART control center Alameda CMA CHP Cities		H
RA-04-04	ICMS shall acquire reports of strong earthquakes or floods.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03	DI-05			H

RA-04-05	ICMS shall acquire information about damaged infrastructure, planned road closures and construction from the agencies responsible for operating the affected facilities.	N1-01-04 N2-01-04 N3-02-02 N4-03-04 N5-03-03 N7-03-02 N8-04-03 N9-03-03 N10-03-03	DI06	FWY TMC		H
RA-04-06	ICMS shall acquire maintenance and construction schedules from all agencies (location and time of lane and road closures).	N9-03-03	DI-07	FWY TMC Arterial control center Cities		H
RA-04-07	ICMS shall acquire information about the type and condition of the emergency response.	N10-03-03	DI-08	FWY TMC CHP Cities		H
RA-04-08	The ICMS shall acquire information about special events at the Coliseum.	N9-03-03		Oakland Coliseum		H
RA-04-09	The ICMS shall receive information about incidents at Port of Oakland.	N9-03-03		Port of Oakland		H

Table 4.4.2 Data Archiving Functional Requirements

ID ***RB= Functional requirement for Data Archiving Functions***	***Requirement***	***Traceability***	***Allocation (Where the function will be allocated, i.e.,*** - ***FWY TMC*** - ***Arterial control center*** - ***Transit ACS*** - ***BART control center*** - ***Alameda CMA*** - ***CHP CAD)***	***Comment*** ***(Measurements methods are to be included here, which will be developed once the requirements are confirmed)***	***Criticality***
RB	ICMS shall archive corridor-wide traffic, transit, and incident data.	N1-04-01 N1-04-02 N1-04-03 N1-04-05 N5-05-04 N8-07	511 FWY TMC		H
RB-01	ICMS shall archive traffic data within 1 second after data are received.	N1-04-01	511 FWY TMC		H
RB-01-01	ICMS shall archive freeway traffic data within 1 second after data are received.	N1-04-01-01	511 FWY PeMs		H
RB-01-02	ICMS shall archive arterial highway traffic data within 1 second after data are received.	N1-04-01-02	Arterial PeMs Alameda CMA Cities		H

RB-02	ICMS shall archive transit data within 1 second after data are received.	N1-04-02		Existing but at lower sampling rate	H
RB-02-01	ICMS shall archive bus transit data within 1 second after data are received.	N1-04-02-01	Transit ACS	Existing but at lower sampling rate	H
RB-02-02	ICMS shall archive rail transit data within 1 second after data are received.	N1-04-02-02	BART control center	Existing	H
RB-02-03	ICMS shall archive transit schedules.	N5-05-04	Transit ACS BART control center		H
RB-02-04	ICMS shall log the confirmation of a schedule modification within 60 seconds after it is received from the AC Transit and/or BART.	N5-05-04	Transit ACS BART control center		H
RB-02-05	ICMS shall log a request from a transit agency for connection protection with a delay of no more than 60 seconds.	N5-04-05	Transit ACS BART control center		H

RB-03	ICMS shall archive incident information collected from all the networks in the corridor in a common database.	N1-04-03 N8-07		Existing for highways using speed measurements	H
RB-03-01	ICMS shall archive incident information collected from local police.	N1-04-03 N8-07	511 Cities		H
RB-03-02	ICMS shall archive incident information collected from CHP.	N1-04-03 N8-07	511 CHP		H
RB-03-03	ICMS shall archive incident information collected from local fire departments.	N1-04-03 N8-07	511 Cities		H

Table 4.4.3 Data Processing Functional Requirements

ID RC= Functional requirement for Data Processing Functions	Requirement	Traceability	Allocation (Where the function will be allocated, i.e., • FWY TMC • Arterial control center • Transit ACS • BART control center • Alameda CMA • CHP CAD)	Comment (Measurements methods are to be included here, which will be developed once the requirements are confirmed)	Criticality
RC-01	ICMS shall check and verify data from different sources.	N1-02-01 N2-02-01 N3-03-01 N4-04-01 N5-04-01 N6-02-01 N7-04-01 N8-05-01 N9-04-01 N10-04-01	ICMS		H
RC-01-01	ICMS shall check the quality of information collected.	N1-02-01 N2-02-01 N3-03-01 N4-04-01 N5-04-01 N6-02-01 N7-04-01 N8-05-01 N9-04-01 N10-04-01	ICMS		H

RC-01-02	ICMS shall process data from different data sources.	N1-02-01 N2-02-01 N3-03-01 N4-04-01 N5-04-01 N6-02-01 N7-04-01 N8-05-01 N9-04-01 N10-04-01	ICMS		H
RC-02	ICMS shall estimate corridor-wide travel time for each link of each network within 10 seconds (freeway, arterial, bus and rail transit).	N1-02-02 N2-02-03 N3-03-02 N4-04-02 N6-02-02 N7-04-02 N8-05-02 N10-04-02	511 FWY TMC Arterial control center Transit ACS BART control center Alameda CMA Cities	Existing for freeways through 511, but needs implementation elsewhere	H
RC-02-01	ICMS shall process freeway data to derive freeway condition estimates in terms of average traffic volume and travel time.	N1-02-02 N1-02-09 N2-02-03 N3-03-02 N4-04-02 N6-02-02 N7-04-02 N8-05-02 N10-04-02	511 FWY TMC	Existing through TOS, 511 and PeMs	H
RC-02-02	ICMS shall estimate arterial travel time between predetermined intersection pairs to derive traffic condition estimates in terms of average traffic volume and travel time.	N1-02-02 N2-02-03 N3-03-02 N4-04-02 N6-02-02 N7-04-02 N8-05-02 N10-04-02	511 Arterial control center Alameda CMA		H

RC-02-03	ICMS shall process transit travel data to derive transit operation condition estimates in terms of passenger volume, travel time and schedule delay.	N1-02-04 N2-02-06 N4-04-04 N5-04-02 N8-05-04 N10-04-03	511 Transit ACS BART control center	Existing in limited portions of the corridor, but needs improvements	H
RC-02-03-01	The ICMS shall estimate time of transit vehicle arrival at the next stop.	N1-02-04 N2-02-06 N4-04-04 N5-04-02 N8-05-04 N10-04-03	511 Transit ACS BART control center		H
RC-02-03-02	The ICMS shall estimate time of arrival of other transit vehicles in order to provide connection information at each stop or station.	N1-02-04 N2-02-06 N4-04-04 N5-04-02 N8-05-04 N10-04-03	511 Transit ACS BART control center		H
RC-03	The ICMS shall process information to determine network condition.	N1-02 N2-02 N3-03 N4-04 N5-04 N6-02 N7-04 N8-05 N9-04 N10-04			H
RC-03-01	The ICMS shall process information to determine new incident.	N1-02-03 N2-02-04 N3-03-03 N4-04-03 N8-05-03	ICMS		H

RC-03-02	The ICMS shall process information to forecast major congestion conditions.	N1-02-07 N2-02-08 N3-03-06 N4-04-07 N7-04-04	ICMS		H
RC-03-03	The ICMS shall process information to determine remaining network capacity.	N1-02-05 N2-02-07 N3-03-04 N4-04-05 N10-04-04	ICMS		H
RC-03-04	The ICMS shall process information to forecast network demand.	N1-02-06 N3-03-06 N4-04-06 N5-04-03 N7-04-03 N10-04-04	ICMS		H
RC-04	The ICMS shall generate corridor-wide route/trip guidance information for travelers.	N1-02 N2-02	ICMS 511		H
RC-04-01	The ICMS shall provide dynamic guidance information for requested highway routes.	N1-02 N2-02	ICMS 511		H
RC-04-02	The ICMS shall provide dynamic guidance information for requested transit routes.	N1-02 N2-02	ICMS 511		H

RC-04-03	The ICMS shall provide dynamic guidance information for mixed mode trip requests.	N1-02 N2-02	ICMS 511		H
RC-05	The ICMS shall initiate coordinated operations between freeways and arterials when determining that the available capacity can be better used to balance the network traffic load.	N3	ICMS FWY TMC Arterial control center Cities		H
RC-05-01	The ICMS shall generate signal control strategies for both freeway ramps and arterials when determining that the available capacity can be better used to balance the network traffic load.	N3	ICMS FWY TMC Arterial control center Cities		H
RC-05-02	The ICMS shall generate routing advisory information for travelers based on the updated signal control strategies.	N3	ICMS FWY TMC Arterial control center Cities		H
RC-06	The ICMS shall compute suggested operations for connection protections for incident and special event situations.	N5-04			H
RC-06-01	The ICMS shall compute suggested operations for connection protections for incident.	N5-04			H

RC-06-02	The ICMS shall compute suggested operations for connection protections for special event.	N5-04			H
RC-07	The ICMS shall process information for special event.	N9-04	Oakland coliseum ICMS 511		H
RC-07-01	The ICMS shall estimate traffic volumes on nearby arterial streets and freeway based on the event attendance and event type, combined with normal traffic for that time of day.	N9-04	FWY TMC Arterial control center Alameda CMA Cities		H
RC-07-02	The ICMS shall produce recommendations of a set of signal timing plans to accommodate the estimated traffic volume between 2 hours prior to and 2 hours after the special event.	N9-04-03	FWY TMC Arterial control center Alameda CMA Cities		H
RC-08	ICMS shall process data to enhance OCC's ability to manage transit operation under severe incident conditions and for special events.	N4-05-04	Transit ACS BART control center		H
RC-08-01	ICMS shall process data to support transit OCC's decisions to adjust routes and/or operating schedules based on severity of the incident conditions or to follow pre-arranged operations plans.	N4-05-04	Transit ACS BART control center		H

RC-08-02	ICMS shall process data to support OCC's decisions to adjust routes and/or operating schedules based on special events at least one day in advance.	N9-05-04	Transit ACS BART control center		H
RC-09	ICMS shall enable signal pre-emption for emergency vehicles and recommend best route.	N4-04-09	511 Arterial control center CHP Cities		H
RC-09-01	ICMS shall estimate bus time of arrival (TOA) at intersection with error less than 30 sec at the time when TOA is generated.	N4-04-09	511 Arterial control center CHP Cities		H
RC-09-02	ICMS shall estimate travel time for up to 3 available routes based on real-time traffic data and availability of signal pre-emption.	N4-04-04	511 Arterial control center CHP Cities		H
RC-09-03	ICMS shall generate best routing for emergency vehicles recommendations within 60 seconds of inquiry.	N7-04-06	511 Arterial control center CHP Cities		H
RC-10	ICMS shall process the information about port delays and estimated travel time.	N6	511 Port of Oakland		H

RC-11	*ICMS shall process maintenance and construction schedules.*	*N10*	*511* *FWY TMC* *Cities*		*H*
RC-12	*ICMS shall process traffic condition information to generate recommendations for planning of construction and repair work during emergencies.*	*N10-04-05*	*511* *FWY TMC* *Cities*		*H*
RC-13	*ICMS shall process information for transit signal priority (through centralized transit CAD/AVL).*	*N5*	*Transit ACS*		*H*

Table 4.4.4 Data Dissemination Functional Requirements

ID RD= Functional requirement for Data Dissemination Functions	Requirement	Traceability	Data Requirements	Allocation	Comment	Criticality
RD-01	The ICMS shall enable data exchange between centrally managed database and all transportation systems not to exceed 30 seconds after the information is being requested.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11		ICMS 511 FWY TMC Arterial control center Transit ACS BART control center Alameda CMA CHP Cities		H
RD-01-01	The ICMS shall provide data to freeway operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS FWY TMC		H

RD-01-02	The ICMS shall provide data to arterial traffic operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS Arterial control center Alameda CMA Cities		H
RD-01-03	The ICMS shall provide data to AC Transit operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS 511 Transit ACS		H
RD-01-04	The ICMS shall provide data to BART operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS BART control center		H

RD-01-05	The ICMS shall provide data to CHP operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS CHP		H
RD-01-06	The ICMS shall provide data to police operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS Cities		H
RD-01-07	The ICMS shall provide data to paramedics operation center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS Cities		H

RD-01-08	The ICMS shall provide data to fire department operation management center.	N1 N2 N3 N4 N5 N6 N7 N8 N9 N10 N11	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS Cities		H
RD-02	The ICMS shall provide information to travelers with a latency not to exceed 60 seconds.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 Caltrans TMS		H
RD-02-01	The ICMS shall provide information to travelers through CMS.	N2-03-01 N3-04-01 N4-05-01 N5-05-01 N6-03-04	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 FWY TMC Arterial control center	511 provides real-time highway info and transit schedules	H
RD-02-02	The ICMS shall provide information to travelers through the 511 system.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511	511 provides real-time highway info and transit schedules	H

RD-02-02-01	The ICMS shall provide information to travelers through web.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511		H
RD-02-02-02	The ICMS shall provide information to travelers through phone.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511		H
RD-02-03	The ICMS shall provide information to travelers at transit stations no later than 60 seconds after the information is being generated.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 Transit ACS BART control center		H
RD-02-03-01	The ICMS shall provide information to travelers at AC transit stations.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 Transit ACS		H

RD-02-03-02	The ICMS shall provide information to travelers in AC transit buses.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 Transit ACS		H
RD-02-03-03	The ICMS shall provide information to travelers at BART stations.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 BART control center		H
RD-02-03-04	The ICMS shall provide information to travelers in BART trains.	N2 N3-04 N4-05 N5-05 N6-03 N8-06 N9-05	DPF-01 to 02 DPA-01 to 08 DPT-01 to 07 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03	ICMS 511 BART control center		H
RD-02-04	The ICMS shall provide information to truck drivers at Port of Oakland or truck deport no later than 60 seconds after the information is being generated.	N6	DPF-01 to 02 DPA-01 to 08 DPR-01 to04 DPI-01 to 07 DPCM-01 DPSE-01 to 04 DPER-01 to 03 DPPO-01	ICMS 511 Port of Oakland		H

4.4 Validation of Functional Requirements Through Functional Analysis

In order to make sure the functional requirements are complete, it is necessary to validate the completeness of the set of requirements and identify inconsistencies among requirements. Because ICMS will be integrated with the existing ITS systems, it is critical to validate the functional requirements in the context of these existing ITS systems. The I-880 ICM team chose to establish the relationships among ICMS functional requirements in the context of the existing ITS system functions. This approach helps to ensure that each requirement is a necessary and definitive statement of need. The steps of this approach include:

- Established the Functional Block Diagram for the existing ITS systems.
- Defined the high level functions that accomplish the specific strategy (defined based on needs)
- Identified a set of ICMS functions from corresponding functional requirements. The functional groups are:
  - Data collection functions (A series of functions)
  - Data archiving functions (B series of functions)
  - Data processing functions (C series of functions)
  - Data dissemination functions (D series of functions)
- Established dependency of the ICMS functions in the context of the existing ITS and configured the relevant functions to accomplish high level ICMS functions
- Defined Functional Block Diagram that achieves each of the ICM strategies
- Verified if the function flow is technically sound

Functional analysis provides a systematic view of what functional elements are needed to support an ICMS system. The functional elements can be graphically connected to form a system functional block diagram, which would become the basis for the initial system design.

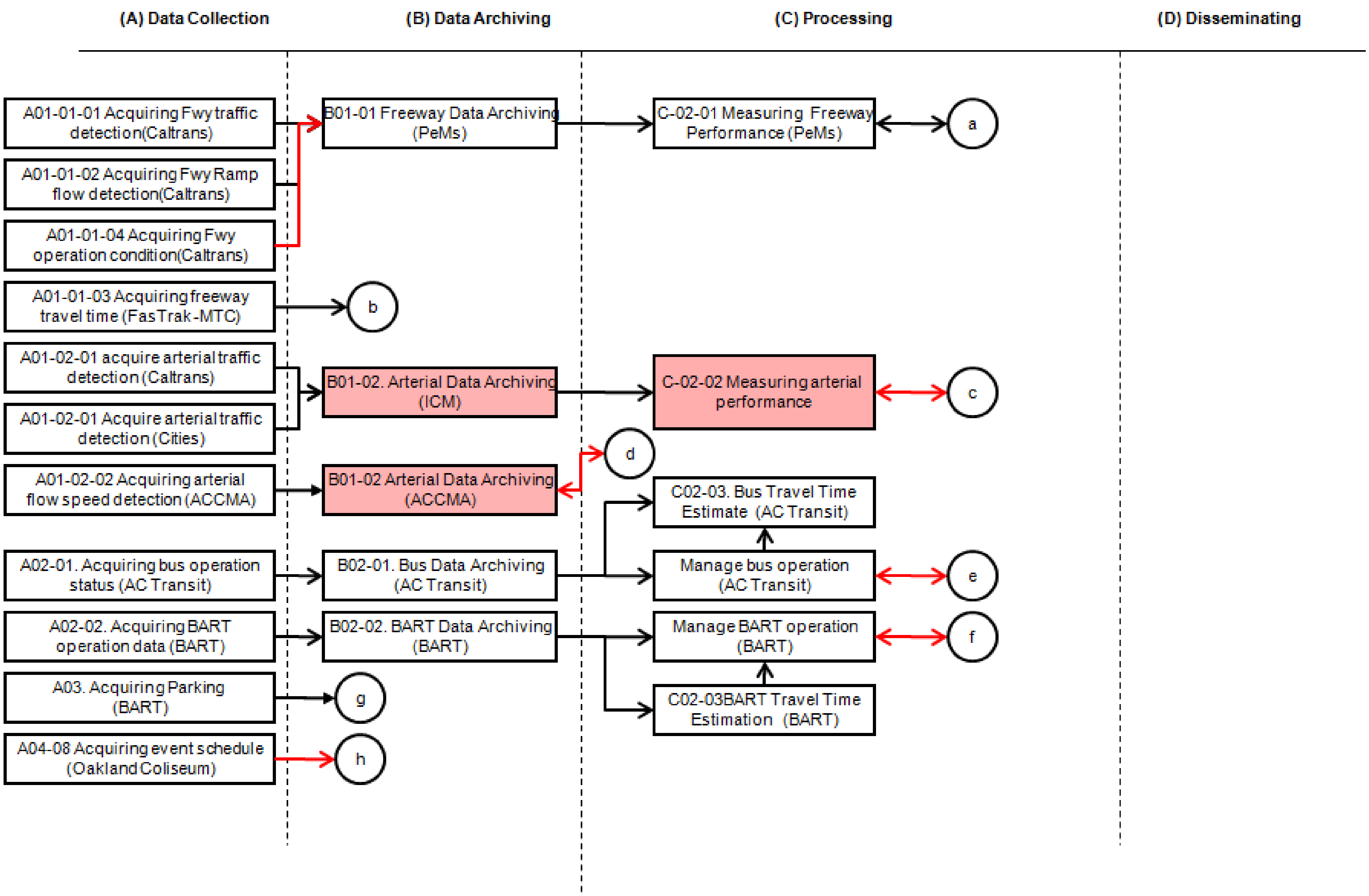
In addition to validating the completeness of the functions, this analysis also helps to:

- Define the appropriate conditions (quantitative or qualitative measures) for each requirement and avoid requirements pitfalls
- Further define data requirements
- Provide the basis for the requirements allocation that guides the system implementation and testing.
- Facilitate the development of interface requirements

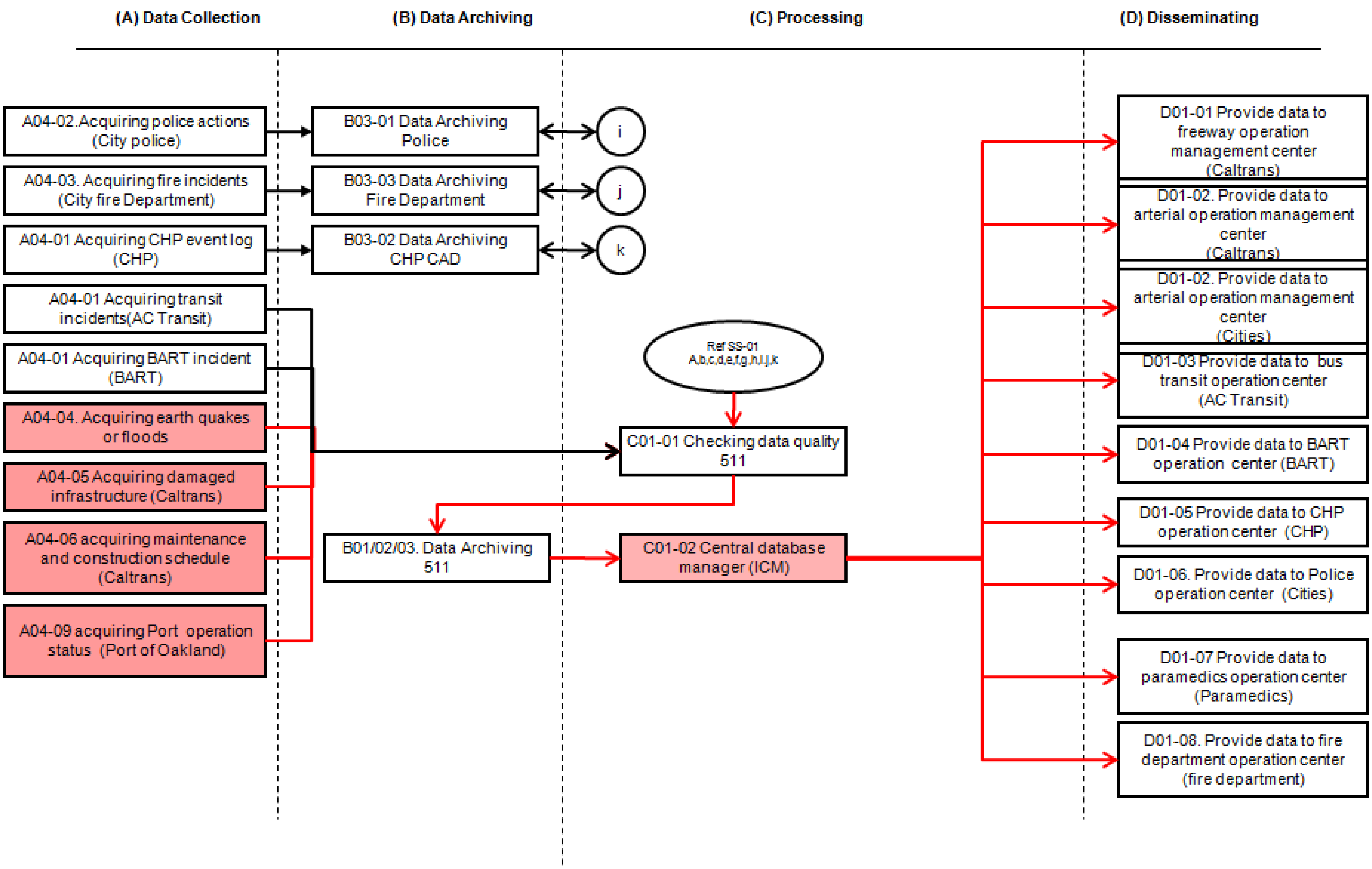
The Figures below show the Functional Black Diagram for the ICMS subsystems. They establish the dependency of the ICMS functions in the context of the existing traffic control system. By means of Functional Diagrams, functions are crossed checked with functional requirements, which become a very useful tool to verify and validate the completeness of the functional requirements.

The functional analysis process has proven to be very effective. Due to the fact that the ICMS will need to be built based upon and integrated with the existing ITS systems, the functional definition and subsystem configuration must be developed in the context of the existing ITS systems. The system analysis method used by the I-880 ICM team put the functional requirements in the context of the existing ITS systems and helped us to discover considerable number of requirement items that were missing or not at the right level. The needs driven requirements process is less structured and it's not easy to come up requirements in the context the existing system designs, conditions and constraints. On the other hands, the needs driven approach also help us to find some gaps from the functional analysis process. The use of the functional analysis and needs driven approaches for the requirements development process provided complimentary means to ensure that the requirements are complete and suitable for implementation.

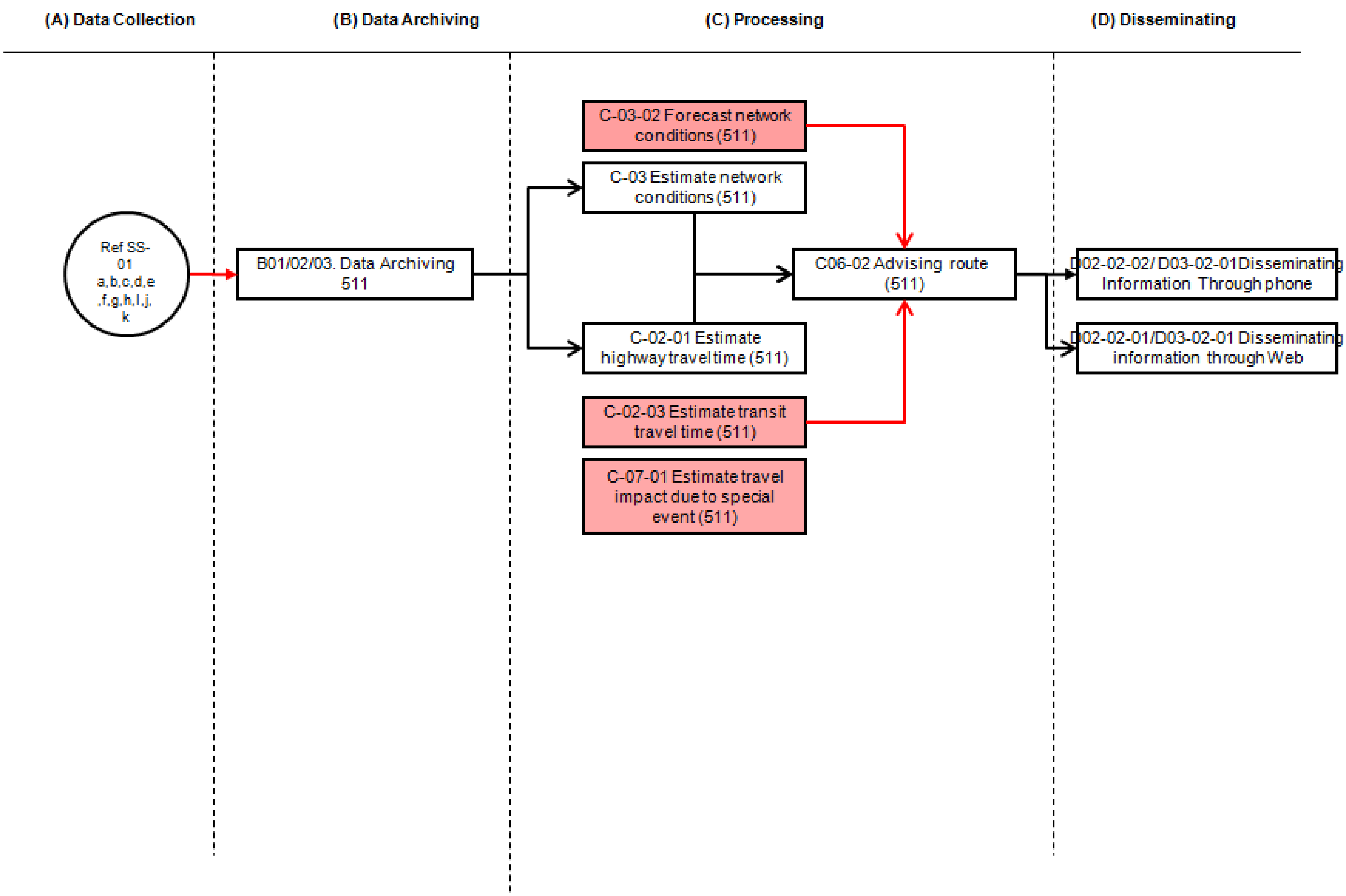
SS-01Information Sharing



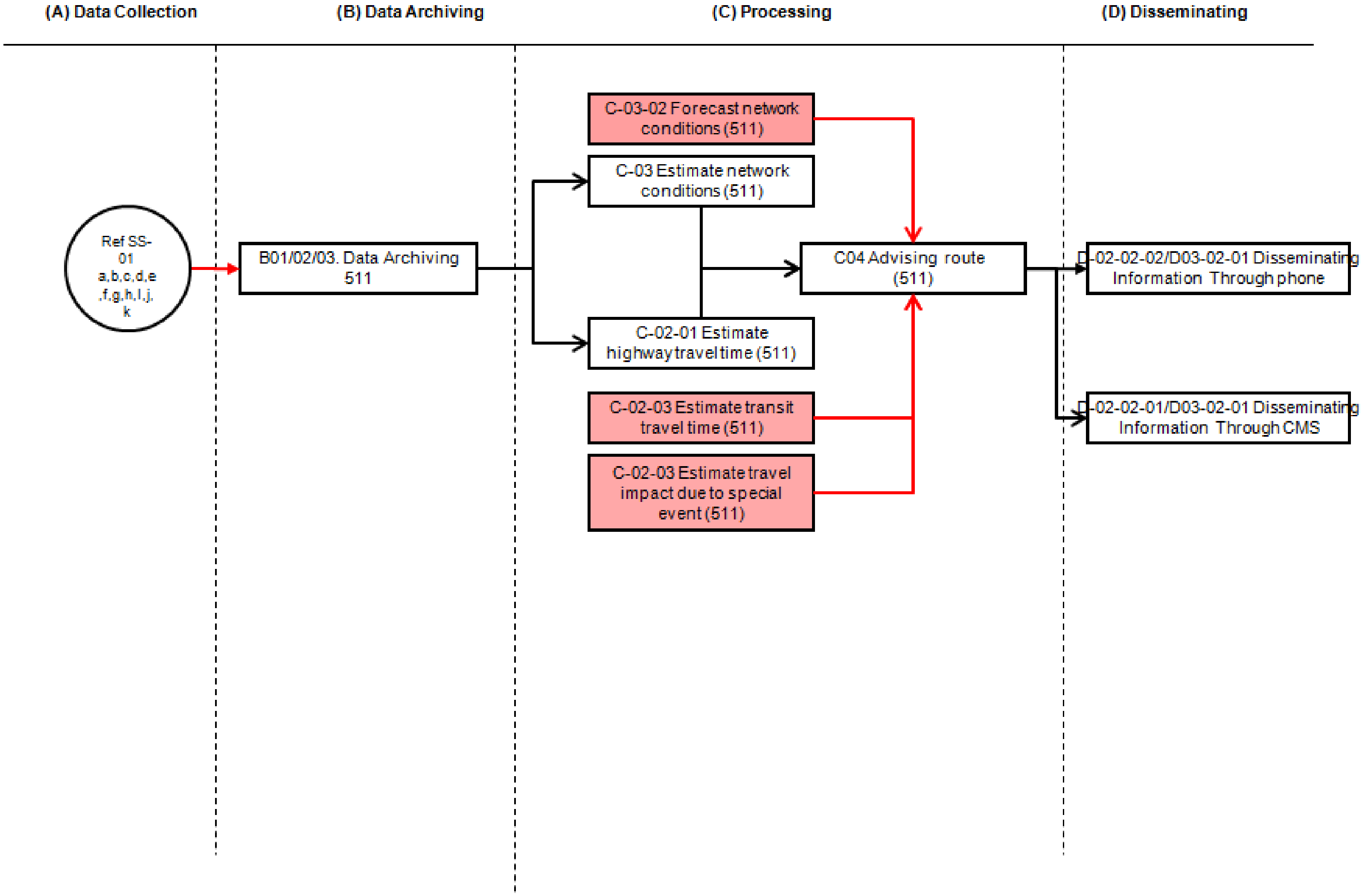
SS-01Information Sharing (Cont'd)



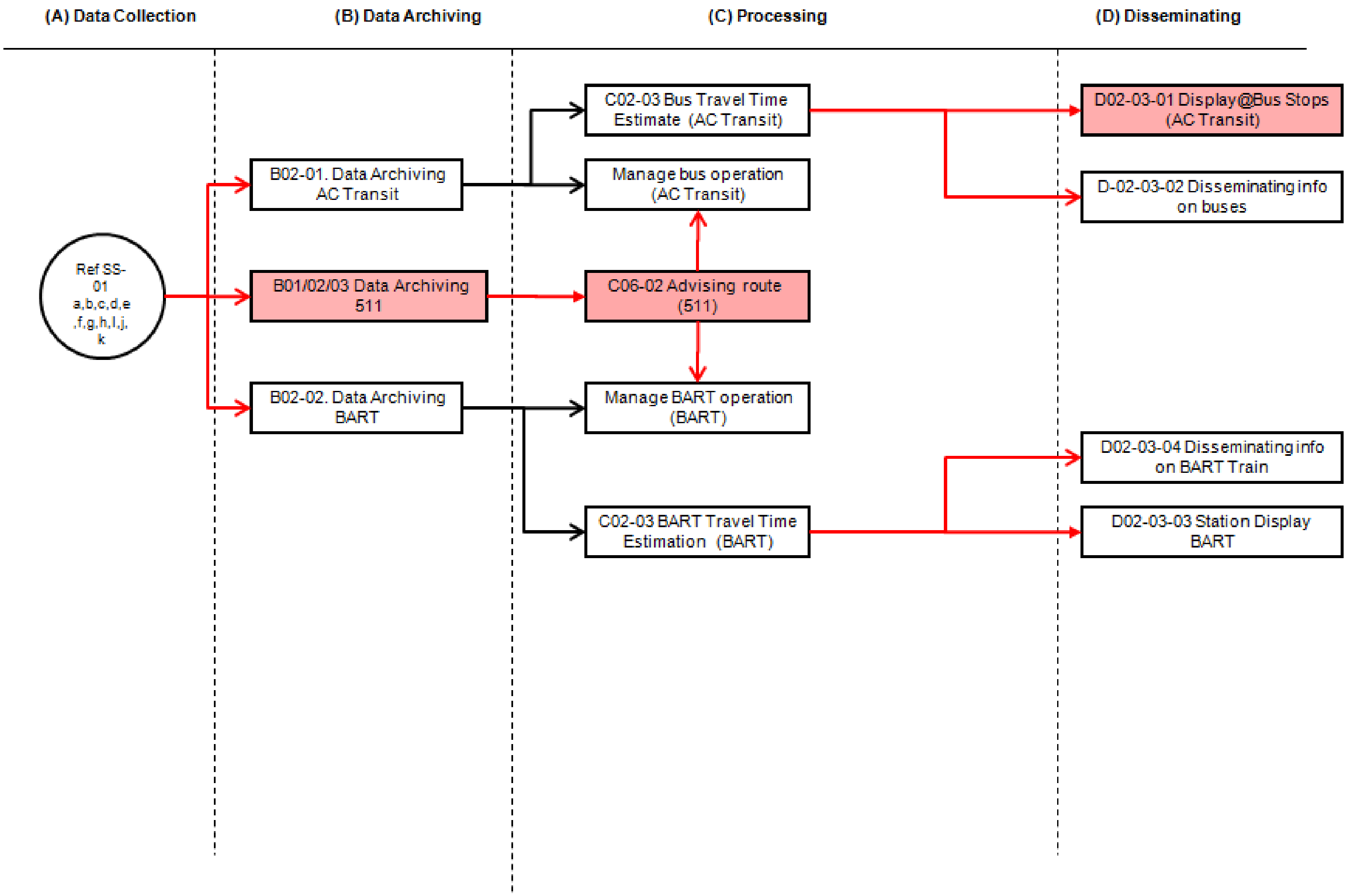
SS-02 Providing Traveler Information Through 511



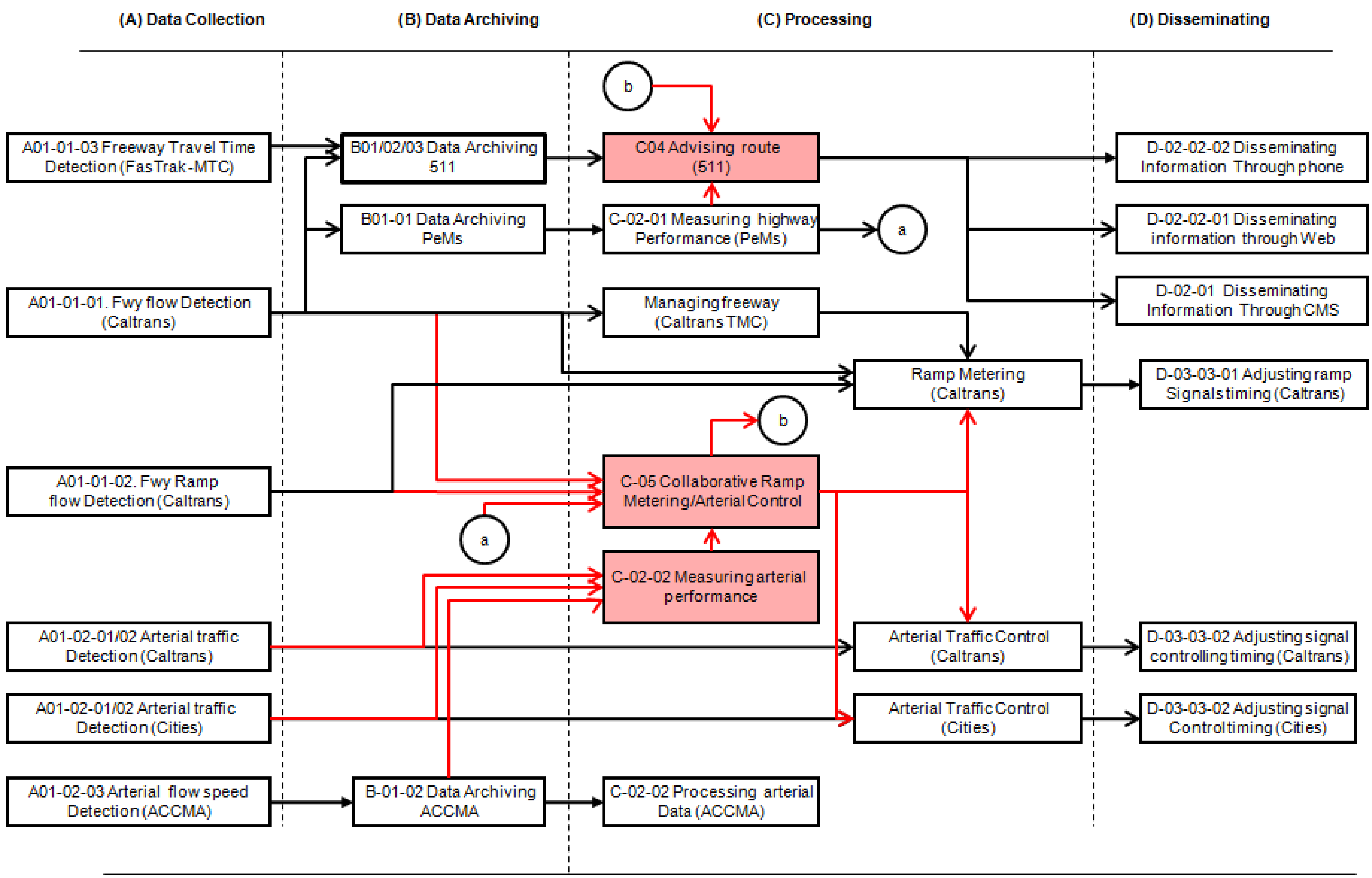
F-03 Providing Information In Real-time to Travelers for En-route Decision Making



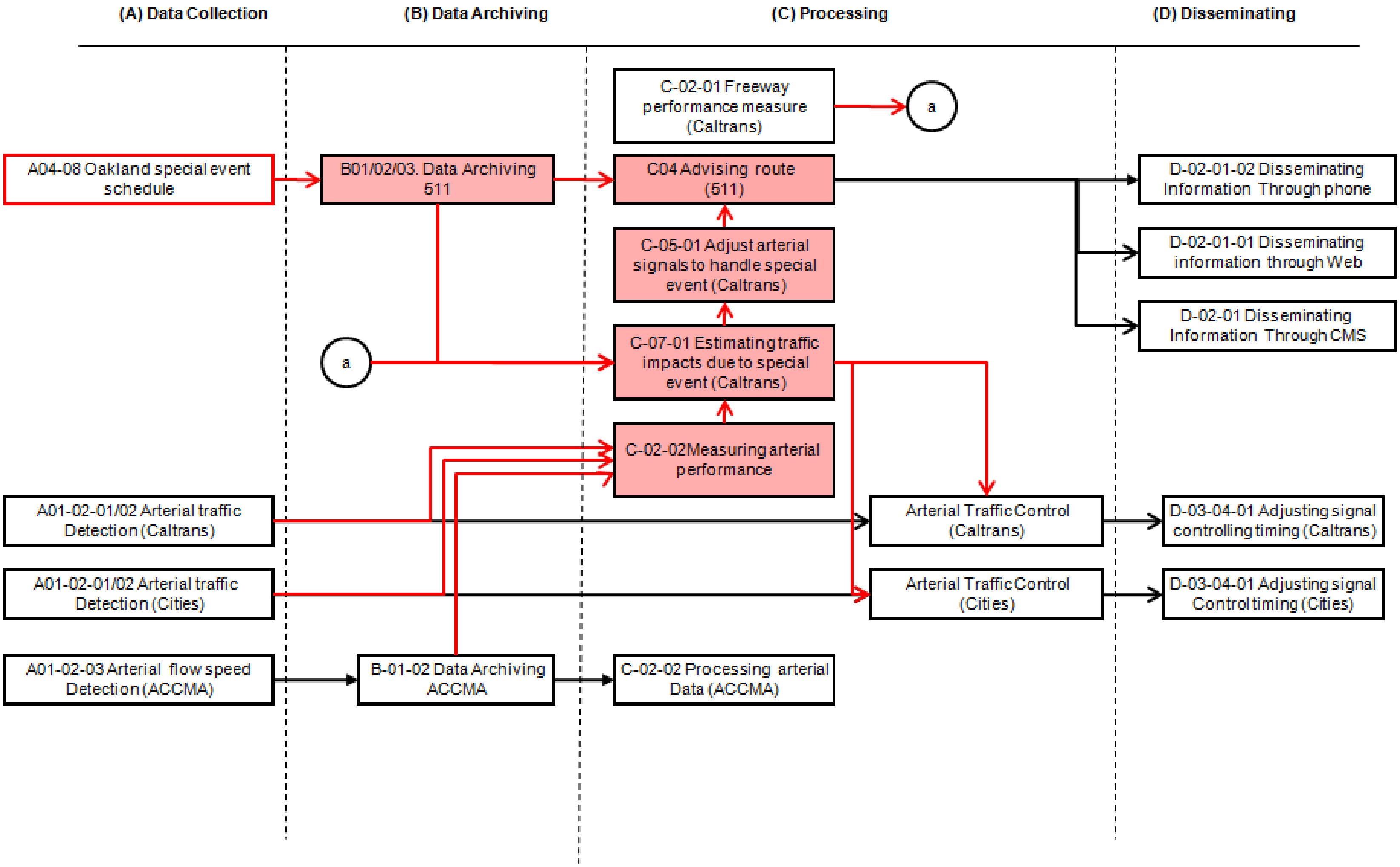
F-04 Presenting Travel Advisory Information in Real-time at Transit Stations and on Transit Vehicles



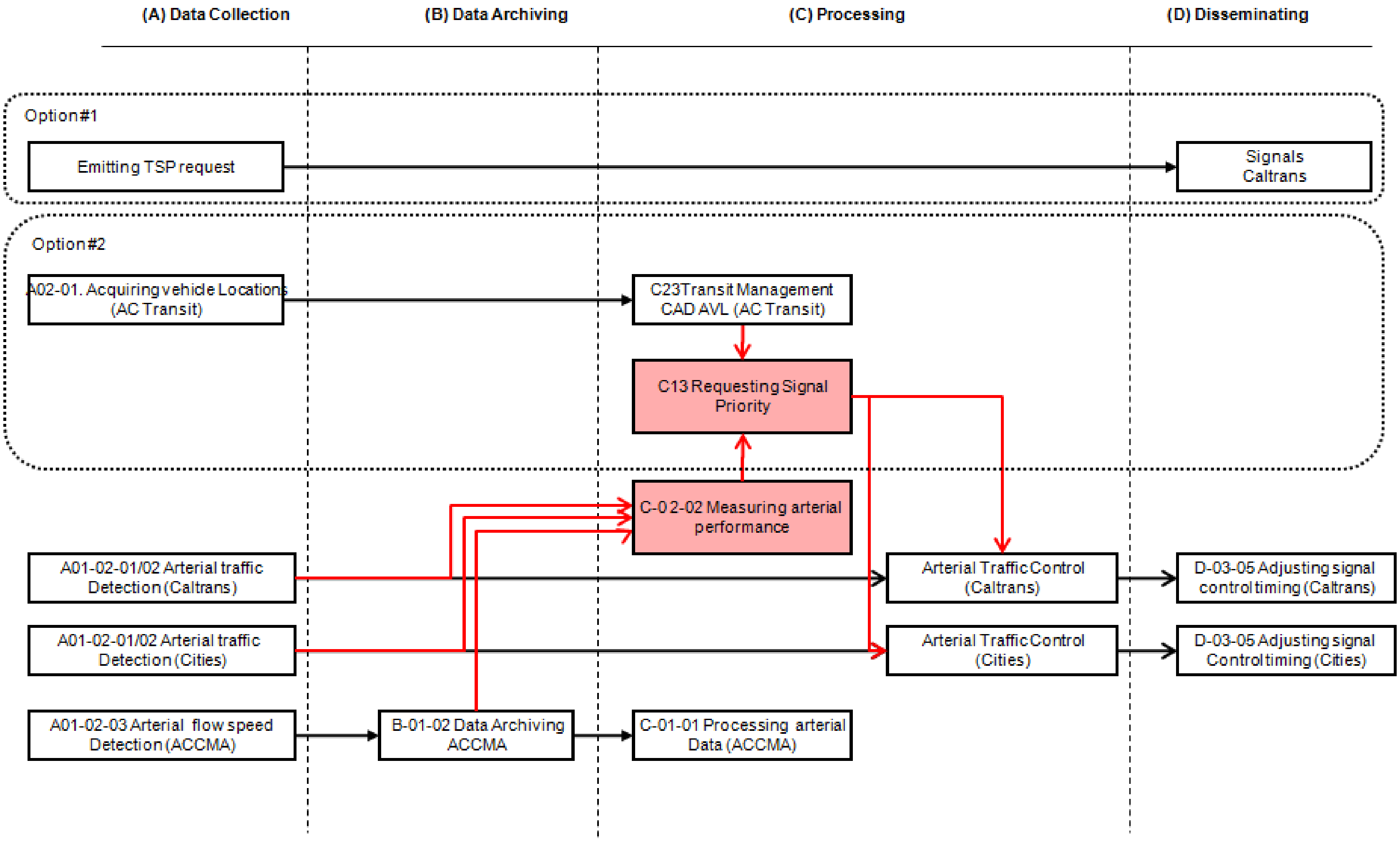
SS-05 Arterial/Ramp Metering



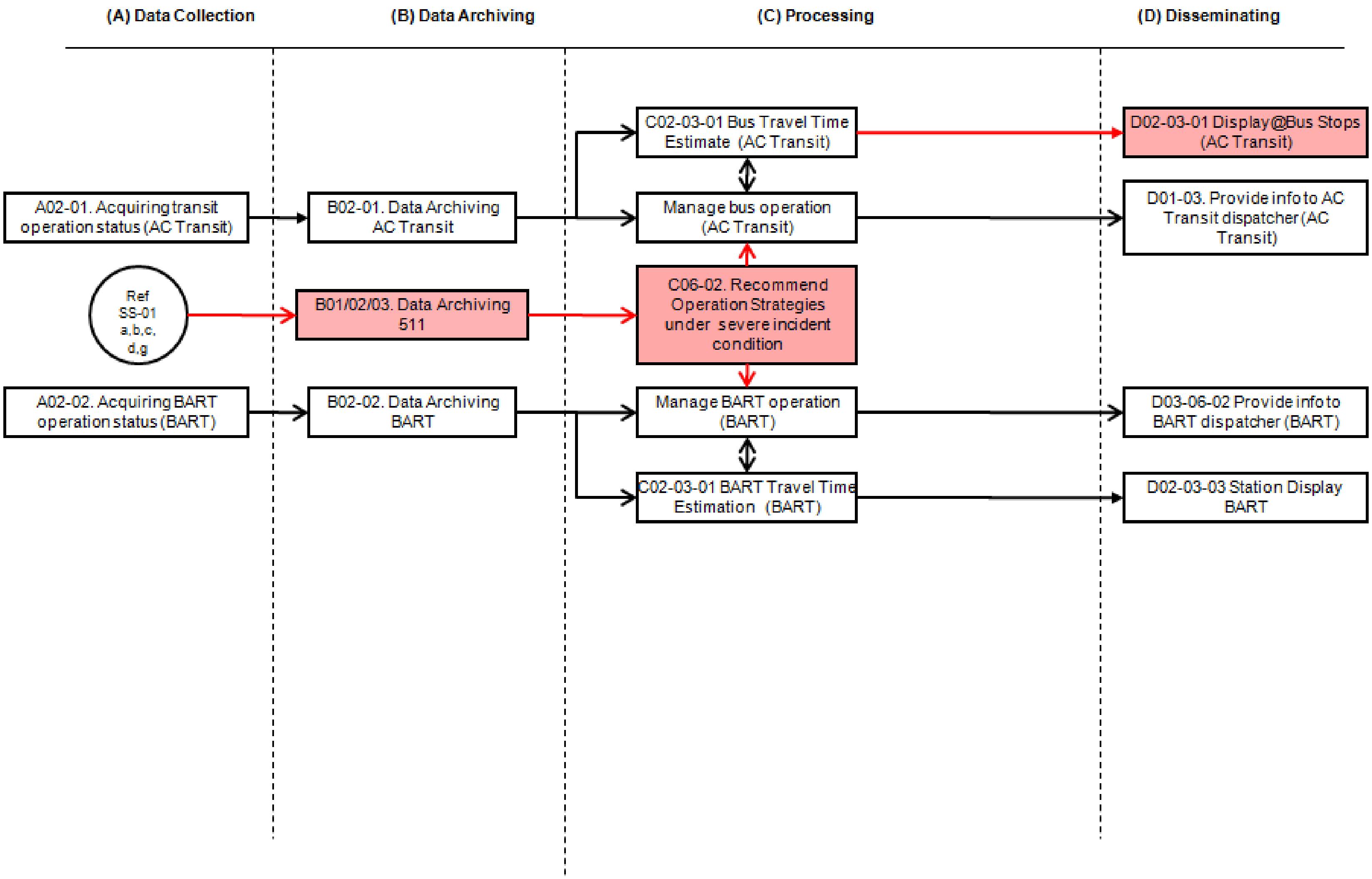
SS-06 Facilitating Arterial Signal Control Systems to Handle Special Events



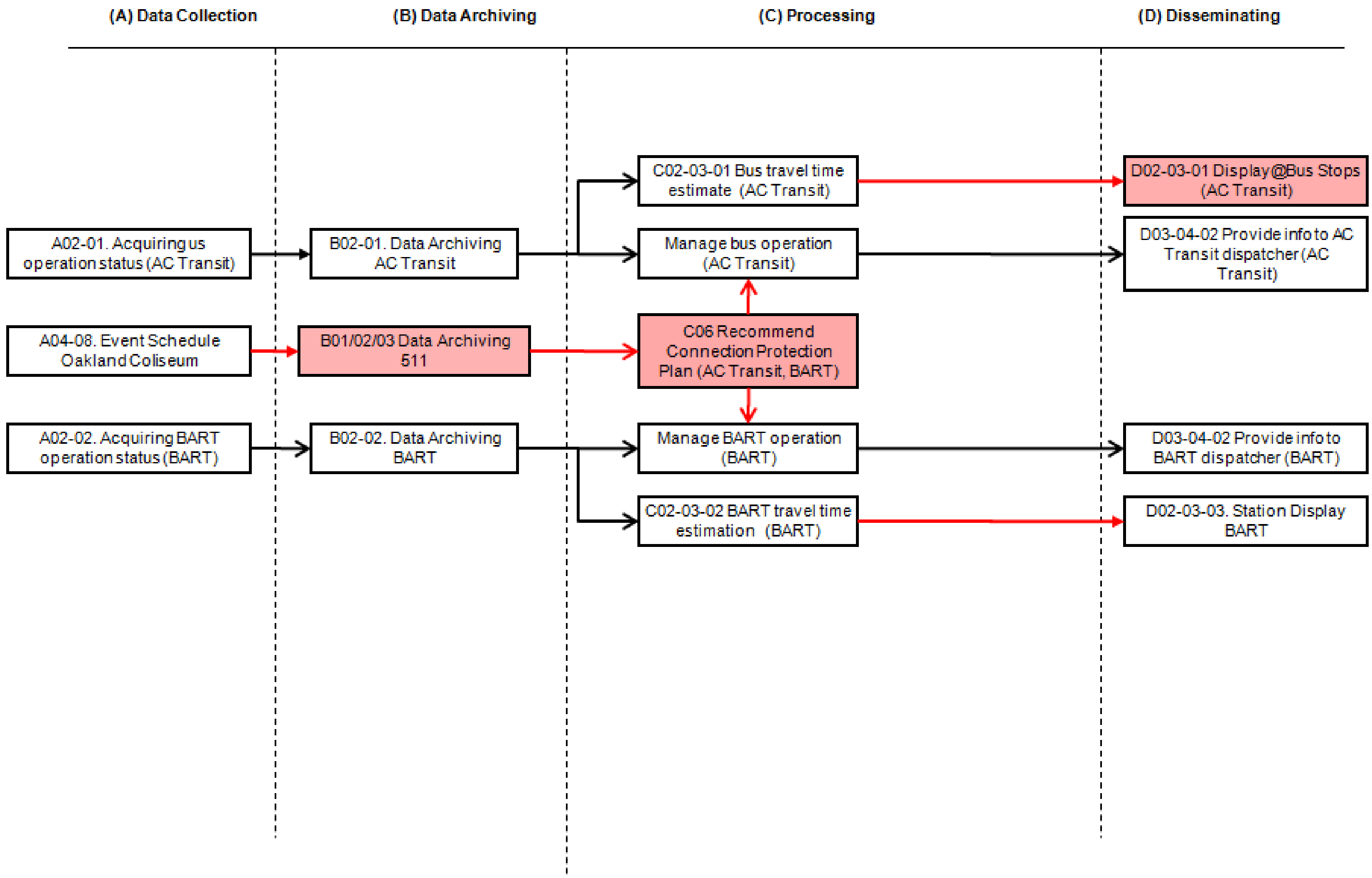
SS-07 Managing Arterial Signal to Provide Transit Signal Priority



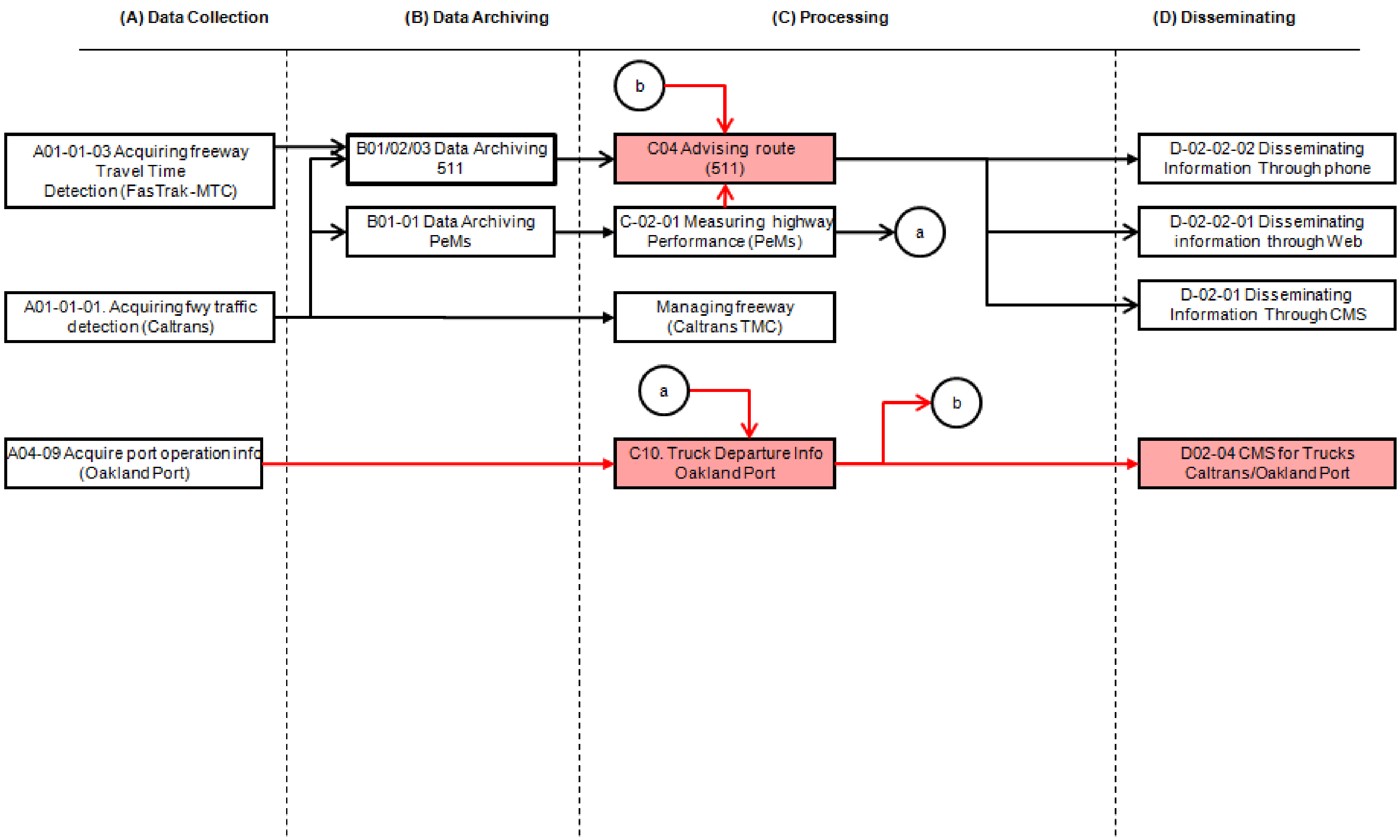
SS-08 Managing Transit Operation under Severe Incident Conditions



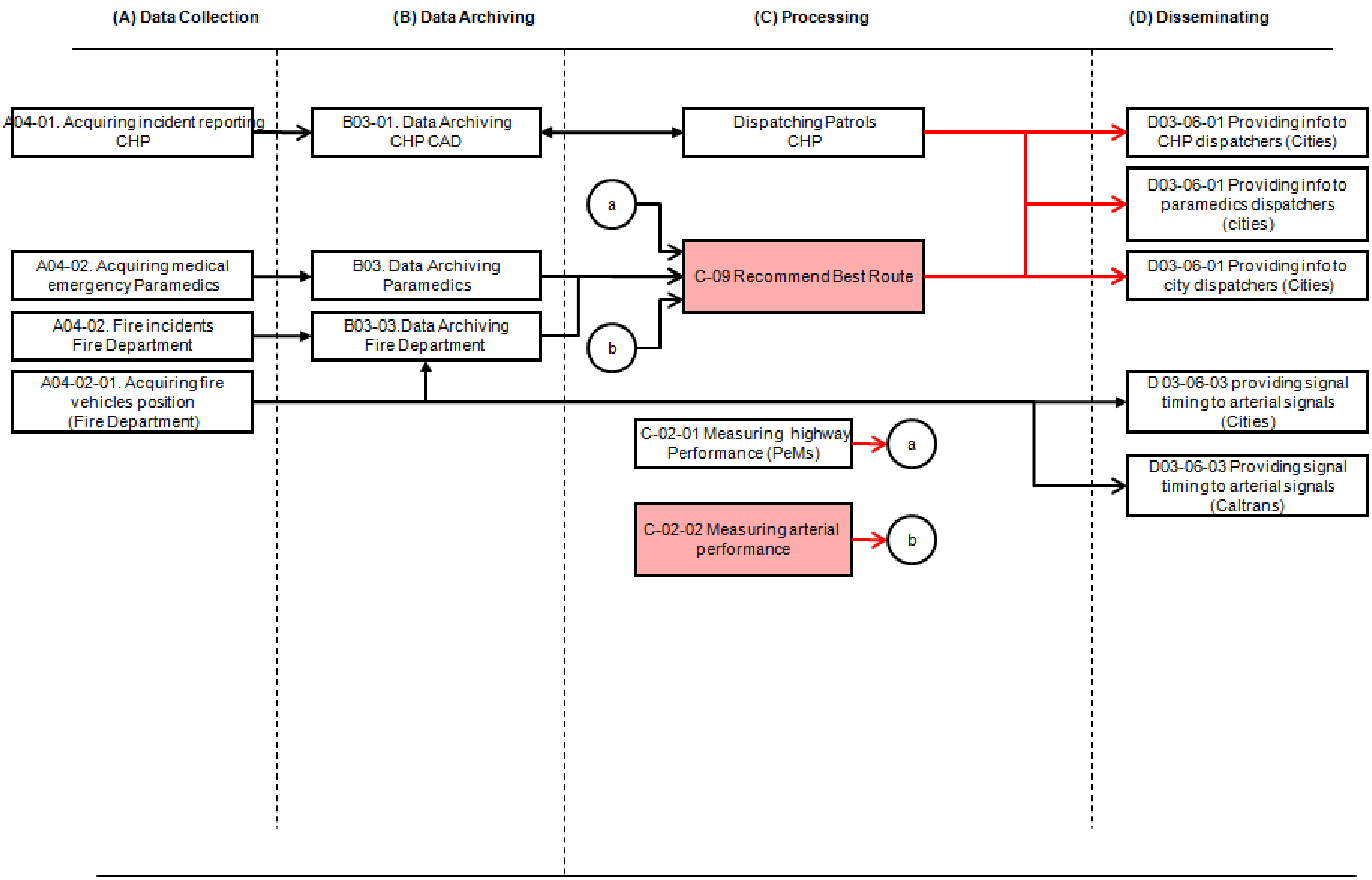
SS-09 Managing Transit Hub Connection Protection for Special Events



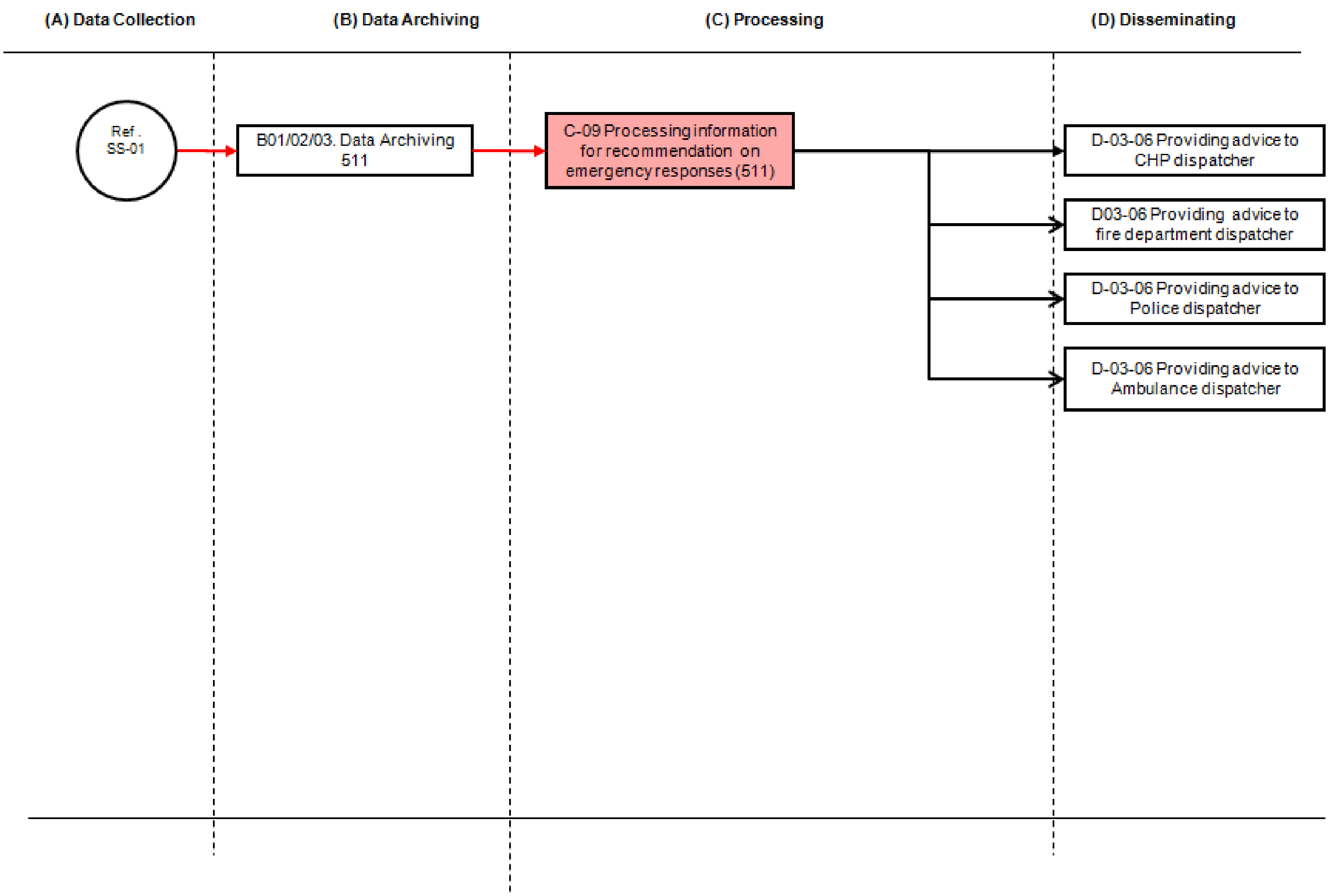
SS-10 Advising Truck Operators and Drivers About Port Delay and Estimated Travel Time



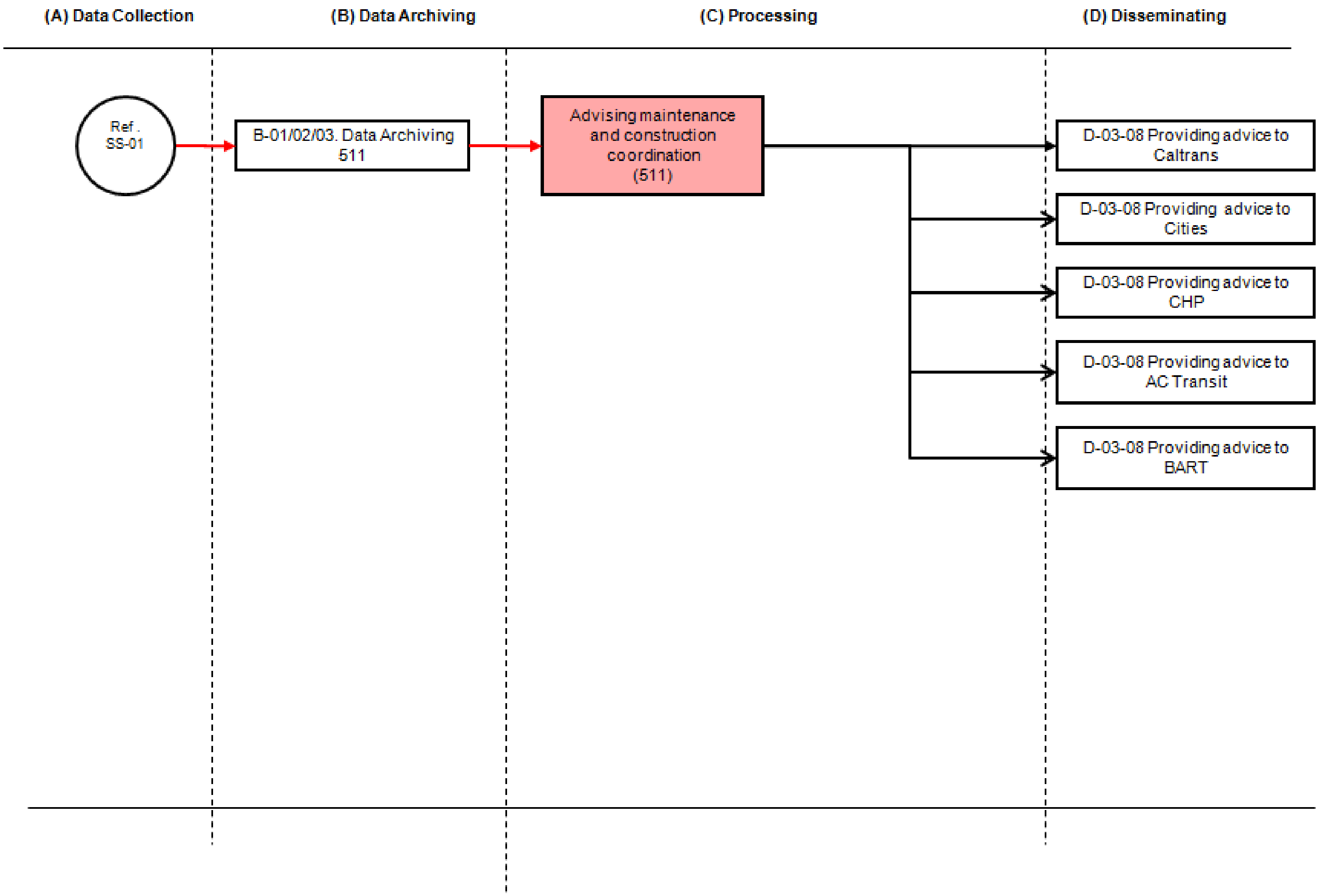
SS-11 Providing Emergency Vehicle with Signal Pre-emption and Best Routing Recommendations



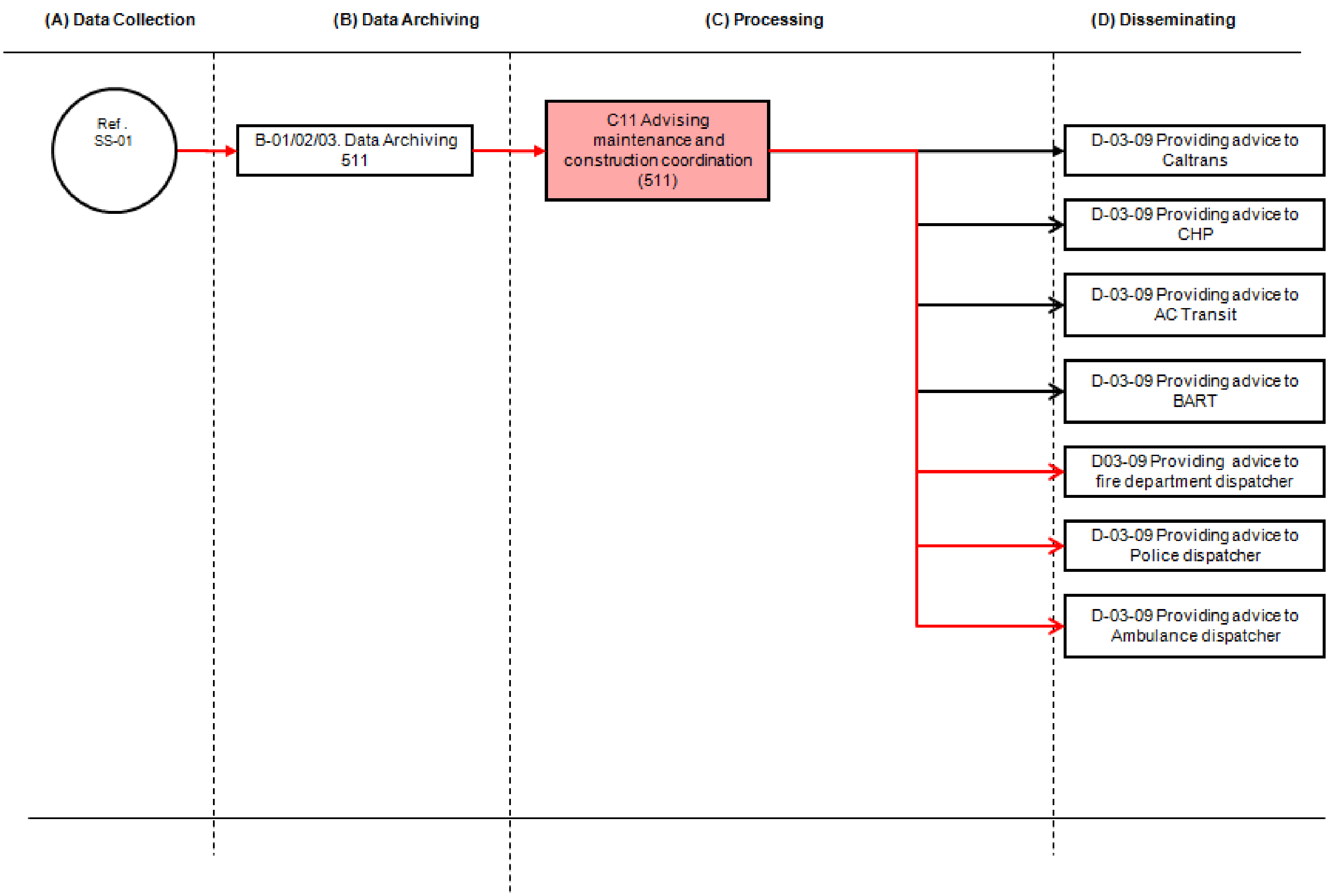
SS-12 Facilitate Rapid Incident Response



SS-13 Supporting Maintenance and Construction Coordination



SS-14 Supporting Coordination of Construction Work During Emergencies



5. 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, the characteristics of the data and the method a data is produced. Note that the data are referenced in the functional requirements.

Table 5.1 ICM Data Requirements

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DF	Freeway data					
DF-01	Freeway travel time	511	Minutes	Every 30 seconds	Error less than 20% of total travel time	Derived
DF-02	Freeway travel speed	Freeway TMS and PeMs	miles/hour	Every 0.5 mile	Errors of 5 mph or less.	Both Direct measurement and filtered data using PeMs
DF-03	Freeway traffic volume	Freeway TMS and PeMs	Vehicle/lane/hour	30 seconds	Errors less than 20% of the total count	Calculated
DF-04	Freeway Occupancy	Freeway TMS and PeMs		Every 0.5 mile	Error less than 20% of total count or less.	Calculated
DF-05	Freeway traffic sensor status	Freeway TMS and PeMs	Functional/ nonfunctional	Every 0.5 mile	Detectable for 90% of the sensors	Calculated
DF-06	Freeway ramp volume	Freeway TMS and PeMs	Vehicle/lane/hour	At freeway on-ramp	Error less than 20% of total count or less.	Calculated

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DF-07	Freeway ramp sensor status	Freeway TMS and PeMs	Functional/ Nonfunctional	Every 0.5 mile	Detectable for 90% of the sensors	Calculated
DF-08	Current condition of freeway operations system	Freeway TMS	Functional/ Nonfunctional	Every 60 seconds	Can detect 100% system failures that cause interruption of system operation	Calculated
DF-09	Current messages on variable message signs	Freeway TMS	Functional/ nonfunctional	Every 60 seconds	Can detect power related CMS failures	Processed
DA	Arterial data					
DA-01	Arterial presence traffic volume	Caltrans, cities, ACCMA	Vehicle counts	Every 60 seconds	Error less than 20% of the total count	Derived
DA-02	Arterial advance traffic volume	Caltrans, cities, ACCMA	Vehicle counts	Every 60 seconds	Error less than 20% of the total count	Derived
DA-03	Arterial traffic signal status	Caltrans, cities	none	Every 60 seconds	Cycle splits and offsets and whether the signal is operational, with latency of no more than 20 s	Derived
DT	Transit data					
DT-01a	Transit bus location	AC Transit CAD AVL	GPS coordinates	Every 120 seconds from AC Transit CAD/AVL	Within GPS error (~15 meters)	Derived

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DT-01a	Transit bus location	ICM Data acquisition system	GPS coordinates	Every 2 seconds from ICM data logging system	Within GPS error (~15 meters)	Derived
DT-02	Transit bus time to arrival at next bus station	Next Bus	Minute	Every 60 seconds	20% of the time to arrival	Calculation
DT-03	Transit bus ridership data	AC Transit CAS AVL	Rider	Every 120 seconds	Less than 10% of the total measured ridership	Derived
DT-04	BART train location	BART CTC	km/mile from a reference location	Every 2 seconds	Error less than 10% of the distance traveled	Calculated
DT-05	BART train time-to-arrival at the next station	BART ATC	Minute	Every 30 seconds or less	Error less than 10% of the time to arrival	calculated
DT-06	BART ridership	Fare collection system	Rider	Every entry	Error less than 1% of the total riders	Derived
DT-07	Parking availability at major parking facilities	BART parking management system	Space	Every 60 seconds	Error less than 1%	Derived
DI	Incident data					
DI-01	Freeway incidents	Caltrans, CHP	None	Less than 5 minutes after incident occurs	Location, type of incidents, Validated report	Reporting
DI-02	Arterial and local incidents	Caltrans, cities, ACCMA	None	Less than 5 minutes after incident occurs	Location, type of incidents, Validated report	Reporting

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DI-03	Transit incidents	AC Transit, BART	None	Less than 5 minutes after incident occurs	Location, type of incidents, Validated report	Reporting
DI-05	Natural disasters	USGS through stakeholders agencies	None	Forecast if possible; reports less than 10 minutes after the disaster occurs	Location, disaster type (e.g., earthquake, flood), Validated report	Reporting
DI-06	Damaged infrastructure	Caltrans, cities, BART	Infrastructure name, location	Immediately	No later than one hour after damage occurs	Reporting
DI-07	Planned road closure	Caltrans, cities, BART	Infrastructure name, location, road closures	After road closure plans are developed	90% correct for 24 hours notice	Derived
DI-08	Maintenance and construction schedule	Caltrans, cities, BART	Location and time	After maintenance schedule are developed	90% correct for 24 hours notice	Derived
DI-09	Condition of emergency response	CHP, police, fire	None	During the emergency response	Delay no longer than 5 minutes	Derived
DPF	Processed data-Freeway					
DPF-01	Freeway travel time advisory	Caltrans, PeMs, 511	Minutes	Update every 30 seconds	Error less than 20%	Processed
DPA	Processed data-Arterial					
RPA-01	Arterial travel time advisory	Caltrans, 511	Minutes	Update every 30 seconds	Error less than 20%	Processed
	Processed data-Transit					

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DPT-01	Bus Time-to- Arrival	AC Transit, 511	Minutes	Every 60 seconds	Error less than 10% of time to arrival	Processed
DPT-02	Bus trip time estimate info	AC Transit, 511	Minutes	Every 60 seconds	Error less than 10% of the travel time	Processed
DPT-03	BART Time-to-Arrival	BART, 511	Minutes	Every 60 seconds	Error less than 10% of time to arrival	Processed
DPT-04	BART trip time estimate info.	BART, 511	Minutes	Every 60 seconds	Error less than 10% of the travel time	Processed
DPT-05	Transit connection info	AC Transit, BART, 511	Minutes	Every seconds	Error less than 10% of the travel time	Processed
DPR	Processed data- Route selection					
DPR-01	Alternative route travel time info	Caltrans	Minutes	Update every 60 seconds	Error less than 20% of travel time	Processed
DPR-02	Alternative route advice	511, Caltrans	Highway number	Update every 60 seconds	Alternative route	Processed
DPR-04	Travel time about alternative route	511, Caltrans	Minutes	Update every 60 seconds	Error less than 20% of total travel time	Processed
DPR-03	Parking availability info	BART	number of parking space	Update every 60 seconds	Error less than 1% of the total parking space	Processed
DPI	Processed data- Incidents					

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DPI-01	Highway incident location	511, CHP, Caltrans,	location	Update every 60 seconds	Within 60 seconds of receiving an inquiry	Processed
DPI-02	Highway incident severity	511, CHP, Caltrans	Level (1-5)	Update every 60 seconds	Within 60 seconds of receiving an inquiry	Processed
DPI-03	Duration of incident	511, CHP, Caltrans	Minutes	Update every 60 seconds	Within 60 seconds of receiving an inquiry	Processed
DPI-04	Transit incident	BART, AC Transit	Minutes	Update every 60 seconds	Within 60 seconds of receiving an inquiry	Processed, or inputted
DPI-05	Traffic condition near incidents	511, Caltrans, ACCMA	Level (1-5)	Updated every 60 seconds	300 seconds after incident occurs	Processed
DPI-06	Congestion location	511, Caltrans, ACCMA	Location	Updated every 60 seconds	300 seconds after incident occurs	Processed
DPI-07	Speed slowdown location	511, Caltrans, ACCMA	mph or kph	Updated every 60 seconds	300 seconds after incident occurs	Processed
DPCM	Processed data – construction and maintenance					

ID	Data Element Name	Source of data	Unit	Frequency of data from source	Characteristics, such as accuracy, validity, timing, and capacity	Calculation or algorithm used to derive data value
DPCM-01	Construction and repair work info	Caltrans, cities, BART	none	Once	Location and time (minutes) Within 60 seconds of receiving an inquiry	Processed
DPSE	Processed data - Special event					
DPSE-01	Estimate attendance of special event	Oakland Coliseum	People, vehicles	Once	5 hours prior to the event	Processed
DPSE-02	Traffic impact info	Caltrans, 511	Minutes, for travel time delay	Once	2 hours prior to the event	processed
DPSE-03	Connection protection recommendations	AC Transit, BART	None	Every 120 seconds	The error of predicted arrival is less than 2 minutes	Processed
DPER	Processed data – emergency response					
DPER-01	Best route recommendation for emergency vehicles	511	none	Upon request	Graphic and descriptive	Processed
DPER-02	Maintenance and construction schedule info	Caltrans, cities and transit agencies	none	hourly	Schedule may change but will be updated	Developed by related agencies
DPPO	Processed data -- Port operation					
DPPO-01	Port access delay info	Port of Oakland	Minute	60 seconds	Error less than 15 minutes	Processed

6. 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 depicted in Figure 2.3 through Figure 2.10 in Section 2.5. These interfaces between the new ICM elements and the existing ITS systems will apply the interface standards and protocols adopted for these existing systems. Table 6.1 provides interface requirements. Note that the letters 'a' through 'x' in the requirement names (e.g., RIa) are defined in the Figures 2.3 to Figure 2.10. Interface 'x' refers to existing interfaces, which are not re-specified in the ICM interface requirements. Interface requirements in most of cases refer to the Interface Control Documents (ICD) that the existing ITS systems use. ICDs are already available for some of the ITS systems while ICDs for other systems will need to be created prior to the development of the I-880 ICM system. The ICM ICD will reference the ICDs for the existing systems and will clearly define the requirements for the interfaces between newly established ICM elements and the existing ITS systems.

Table 6.1 Interface Requirements List

ID	Requirement	Subsystems that the interface requirement supports	Physical Interface Requirements	Protocol Requirements	Notes	Criticality
IR-a	The ICMS database manager shall maintain two way communication with freeway TMS	SS-01 SS-02 SS-03 SS-04 SS-05 SS-06 SS-07 SS-08 SS-10 SS-11 SS-12 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	The interface requirement and communication protocol are defined by "Data Dissemination Architecture for 511" [17] and TravInfo® Open Messaging Service (TOMS) [18]	H
IR-b	The ICMS database manager shall maintain two way communication with Freeway PeMs	SS-01	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	Communication link already exist between 511 and PeMs	H
IR-c	The ICMS database manager shall maintain two way communication with CHP emergency response CAD	SS-01 SS-11 SS-12 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	Communication link already exist between 511 and CHP emergency response CAD	H

IR-d	The ICMS database manager shall maintain two way communication with AC Transit ACS	SS-01 SS-02 SS-03 SS-04 SS-07 SS-08 SS-09 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	Communication link is being developed between 511 and AC Transit ACS.	H
IR-e	The ICMS database manager shall maintain two way communication with BART CTC	SS-01 SS-02 SS-03 SS-04 SS-08 SS-09 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	Communication link is being developed between 511 and BART CTC.	H
IR-f	The ICMS database manager shall maintain two way communication with MTC 511	SS-01 SS-02 SS-03 SS-04 SS-05 SS-06 SS-07 SS-08 SS-09 SS-10 SS-11 SS-12 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	511 already uses the said interface and protocols.	H
IR-g	The ICMS database manager shall maintain two way communication with Caltrans arterial TMS	SS-01 SS-02 SS-03 SS-04 SS-05 SS-06 SS-07 SS-11 SS-12 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		H

IR-h	The ICMS database manager shall maintain two way communication with cities arterial TMS	SS-01 SS-02 SS-03 SS-04 SS-05 SS-06 SS-07 SS-11 SS-12 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)	This is optional	H
IR-i	The ICMS database manager shall maintain two way communication with ACCMA arterial data system	SS-01 SS-11 SS-12	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		H
IR-j	The ICMS database manager shall maintain two way communication with Oakland Coliseum	SS-01	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		H
IR-k	The ICMS database manager shall maintain two way communication with Port of Oakland Freight Management System	SS-10	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		H
IR-l	The ICMS database manager shall maintain two way communication with Fire/Police/Paramedics departments	SS-01 SS-13	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		H

IR-m	The arterial TMS shall maintain two way communication with Arterial CMS	SS-02 SS-03 SS-04 SS-06	The communication between arterial TMS and CMS shall use frame relay or wireless communicaton	The arterial TMS shall communicate with CMS using the Caltrans existing center-to-CMS protocols		H
IR-n	The BART CTC maintain two way communication with rail station ICM signage	SS-02 SS-03 SS-04 SS-08	The communication between BART CTC and ICM signage shall use wire communication	The ICMS communicate with signage shall be XML-formatted data via the Java Message Service (JMS)		H
IR-o	The Transit ACS shall maintain two way communication with bus transit station signage	SS-02 SS-03 SS-04 SS-08	The communication between AC Transit ACS and station signage shall use wireless communication	The ICMS communicate with signage shall be XML-formatted data via the Java Message Service (JMS)		H
IR-p	The arterial TMS shall maintain two way communication with freeway TMS	SS-05	The communication between arterial TMX and freeway TMS shall frame relay or wireless communication	The arterial TMS shall communicate with CMS using the Caltrans existing center-to-center comm protocols		H
IR-q	The Freight Management Center shall maintain two way communication with ICM signage	SS-10	The communication between ICMS subsystems and ICMS database manager shall use Internet connection	ICMS subsystems shall communicate with ICMS database manager XML-formatted data via the Java Message Service (JMS)		

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Appendix A: Performance Characteristics Analysis

A.1 ICM Factors Contributing to Achievable Reduction of Traffic Congestion and Travel Time

Users of the I-880 corridor experience significant congestion during all time periods. The table below summarizes congestion trends for three years for the freeway portion of the corridor.

	Northbound Direction				
Year	AM Peak	Mid Day	Evening and Early AM	PM Peak	Total Daily
2003	1,499	1,237	552	2,547	5,835
2004	1,124	1,067	360	2,317	4,867
2005	1,331	1,434	285	2,351	5,402
	Southbound Direction				
Year	AM Peak	Mid Day	Evening and Early AM	PM Peak	Total Daily
2003	1,924	1,397	276	2,249	5,846
2004	1,728	1,427	291	2,375	5,821
2005	1,678	1,848	232	2,444	6,202
	Total Corridor				
Year	AM Peak	Mid Day	Evening and Early AM	PM Peak	Total Daily
2003	3,423	2,634	828	4,796	11,682
2004	2,852	2,494	651	4,691	10,688
2005	3,009	3,282	517	4,795	11,604

Table A.1 Congestion Trend for I-880

Of course, travel time and congestion are strongly correlated. When congestion is high, so is travel time. When congestion diminishes, travel times are reduced. Whereas transportation practitioners sometimes focus on total congestion as measured by aggregate delays, individuals (i.e., customers) focus on travel times. This is an important distinction, since a 10 percent reduction in delay often translates into one or two minutes of travel time reductions. Although such reductions do not always seem significant to individuals, they do reflect impressive performance improvements overall. Over time, without such improvements, individuals would eventually experience significant travel time increases.

The exhibit on the next page depicts the travel time distribution on the I-880 corridor in the southbound direction for 2005. Notice the two peaks during the AM and PM peak periods respectively. Also note the variability of travel time over the year. Although the mean travel time is around 46 minutes during the AM peak period, many travelers experience much higher travel times. So when travel times are analyzed, it is important to consider both the mean travel times and the overall distribution of travel times.

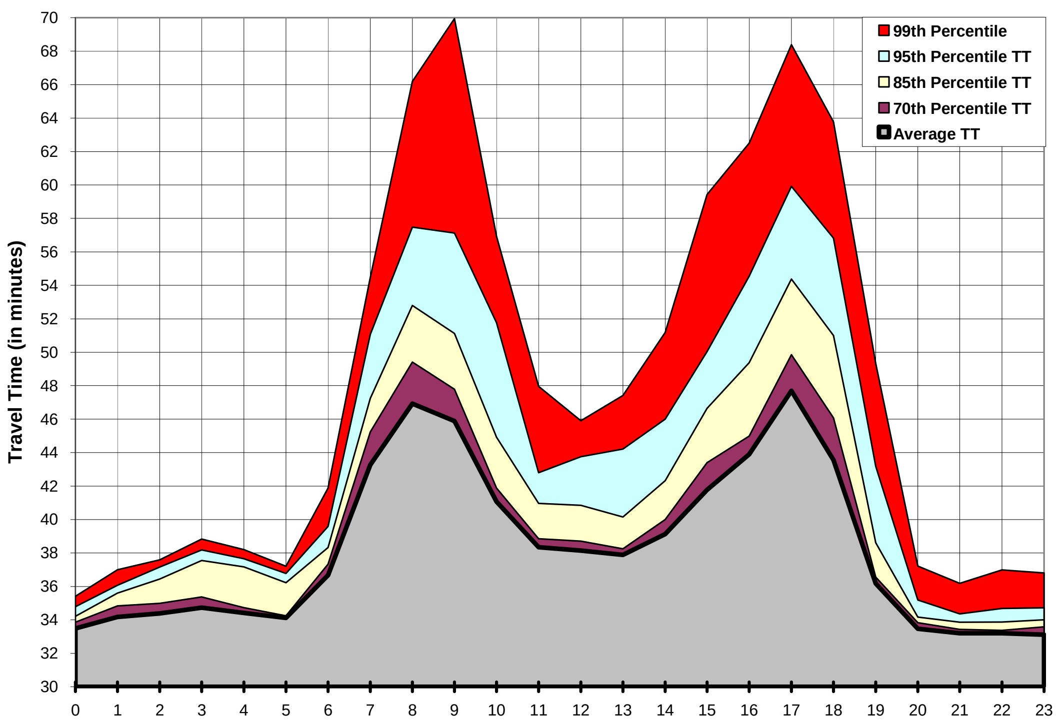


Figure A.1 Travel time along I-880 corridor

(Source: PeMS, https://pems.eecs.berkeley.edu/)

The proposed ICM strategies are estimated to reduce congestion as follows:

- Reduction of overall delay by 10 percent
  - Computed as total hours of delay, broken down by facility, mode, and bottleneck area
- Peak period contraction by 10 to 15 percent
  - Computed by bottleneck area as the length of the period where speeds are below 35 miles per hour
- Improvement of reliability by 10 percent
  - Computed by the travel time index (the 95th percentile of travel time distribution)

These are admittedly lofty goals, especially on a congested urban freeway. However, our experience suggests that these goals are attainable. These goals only translate into 2-3 minutes in mean travel time reductions, but much more for some travelers. Implementation must take into consideration several critical factors:

Performance measurement – implementation of the ICMS is expected to be iterative. To fine-tune the different systems and business processes, continuous measurement is critical. Given the detection in place on the freeway and critical arterials, practitioners will be able to evaluate their actions in almost real-time.

Focus on known bottlenecks – congestion reduction has to focus on the causes of the recurrent and non-recurrent delays. Recurrent delays are caused by known bottlenecks already identified by the region (refer to ICM Concept of Operations for a more detailed discussion of known bottlenecks). Many of these bottlenecks relate to high traffic flow merges at several locations. Strategies such as the integration of arterial signal and ramp metering systems should focus on these bottleneck locations in order to achieve significant improvements in overall congestion.

Cross-training – integration of existing systems represents the technical aspect of the ICMS. However, to properly utilize integrated systems, practitioners in charge of one system must be trained to better understand the other systems to better understand the ramifications of their actions. For instance, ramp metering staff should be trained on the systems that control the signal timing of the arterials, and vice versa. Such training will be included in the implementation plans for all ICM strategies.

Demand Management Monitoring – The proposed ICM strategies address traffic management (e.g., arterial signal integration with ramp metering), traveler information (e.g., travel time estimates for trucks at the ports), incident management (e.g., faster detection of incidents and causes thereof), and increased transit ridership (e.g., signal prioritization). All these strategies, to some extent, deal with demand management. Understanding changes in demand characteristics will therefore be critical to properly implementing the ICM strategies. Demand management metrics to monitor will include: flow rates, truck volumes under different conditions, average time to clear incidents, transit ridership, ramp waiting times, and average bus speeds. The ICMS implementation team will develop a detailed monitoring plan for these and other pertinent metrics to evaluate the effectiveness of these strategies.

Risks to Implementation

The primary risks to implementing the ICM strategies can be summarized as follows:

- Technical – integrating multiple systems requires careful analysis and detailed functional specifications

- Institutional – Systems do not improve performance on their own. Business processes have to be revised to incorporate these new capabilities. Agencies that focus only on "their" system and refuse to consider overall mobility improvements will not achieve the desired results.

- Funding – too many transportation technology projects under-estimate the total funding requirements and end up reducing the true functionality needed to improve system performance.

The remainder of this section focuses on specific strategies that aim to improve incident management, mode split, and safety. Note that these strategies all contribute to congestion and travel time reductions as well.

A.2 ICM Factors Contributing to Balance of Demand Freeway and Arterial Highways

The I-880 arterial corridor network, approximately 45 mile long, has 174 traffic signals and 15 metered ramps among some 60 on and off ramps. A preliminary analysis has been performed by the I-880 ICM team to evaluate the potential benefits of coordination between freeway ramp metering and arterial traffic management. The network was coded in *NetZone*[1], and evaluated for three control scenarios in a 3.5-hour peak period:

[1] *NetZone* is a corridor modeling toolbox developed by Professor Michael Zhang's research group at University of California at Davis.

1) Base case: the original control schemes imported from the Paramics traffic control files (ramp control is pre-timed)

2) Base case without ramp metering: we kept the control schemes for intersections established in the base case but disabled ramp metering.

3) Base case with ALINEA ramp metering: we used the local, traffic responsive ramp metering algorithm ALINEA to control the 15 metered on-ramps. The control gain in ALINEA is set to 70 veh/hr.

In all the three cases, we also introduced various levels of intelligent route guidance:

a) no route guidance (0%), where all travelers would choose their free-flow shortest path(s).

b) 100% route guidance, where all travelers would periodically re-route to their current shortest routes based on updated travel times

c) 50% route guidance, where half of the travelers would follow the fixed shortest paths obtained from free-flow travel times and half of the travelers would acquire real time traffic information and periodically reroute based on the updated travel times in the network.

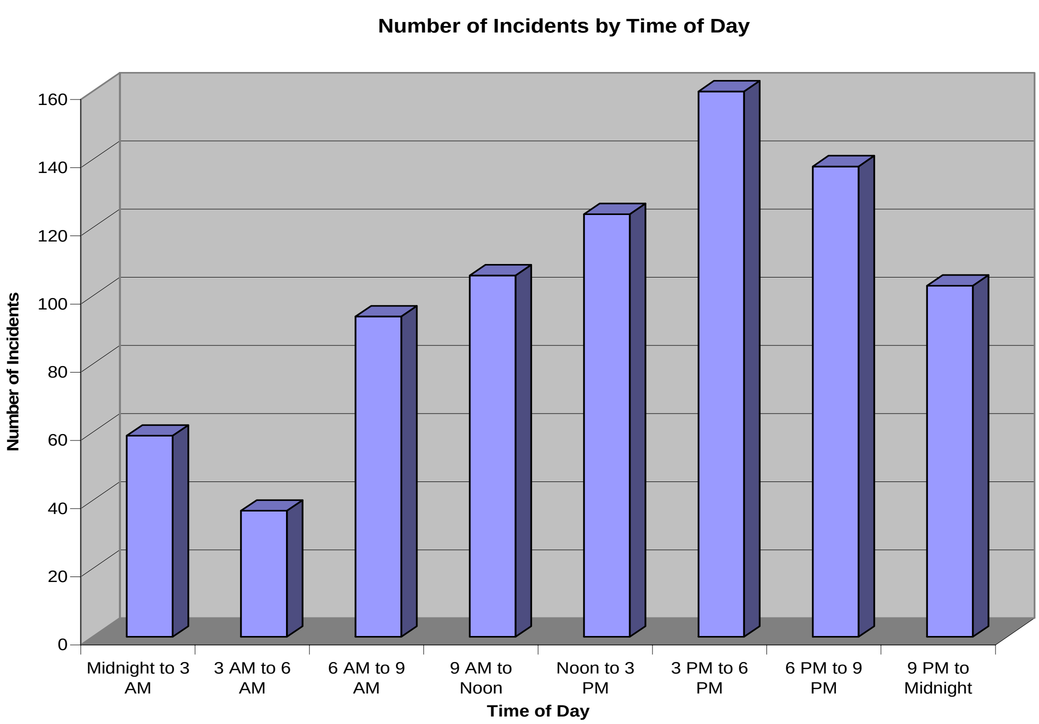
The primary results of network performance are shown in Table a.2. It is clear from these results that real-time traffic information, when distributed discretionally, is most effective in improving corridor performance (up to 34% travel time savings), while for the same level of information provision, ramp metering can generally improve corridor performance, but not to the extent obtained from route guidance. Signal coordination, which could further improve network performance, is not tested here due to limitations in the current version of *NetZone*.

Table A.2 Network performance under various control schemes

Scenarios		Total travel time (hrs)	Total travel delay (hrs)	Avg. travel time (min.)	Avg. travel delay (min.)	Avg. travel speed (mile/hr)
0%	1	148083.48	103809.74	39.13	27.43	19.84
	2	140564.74	96291.01	37.14	25.44	20.90
	3	141367.15	97093.42	37.35	25.65	20.78
50%	1	98165.98	53365.14	25.94	14.10	30.07
	2	99313.12	54455.49	26.24	14.39	29.70
	3	98462.97	53650.06	26.02	14.18	29.96
100%	1	116998.11	70215.46	30.91	18.55	25.76
	2	120477.39	73511.47	31.83	19.42	25.05
	3	122515.10	75788.03	32.37	20.03	24.60

A.3 ICM Factors Contributing to Achievable Improvements in Incident Detection and Efficient Incident Management

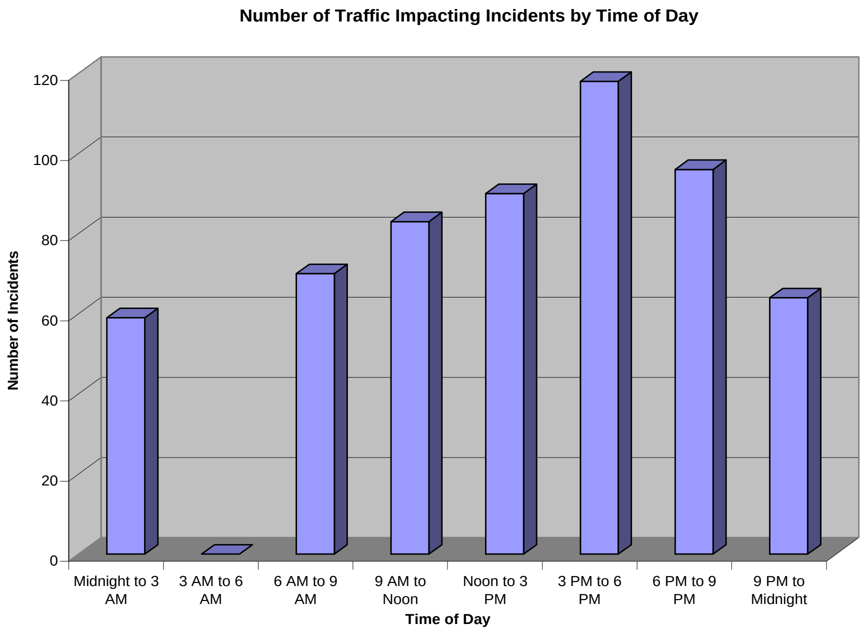
Based on the TASAS accident database and California Highway Patrol (CHP) logs the average number of daily I-880 incidents is over 100, with many of them occurring in the afternoon, corresponding to high traffic volumes and high levels of congestion. The chart in the following figure shows number of incidents by time of day based on a one-year sample of accident data on I-880.



(Source: PeMS TASAS)

Figure A.3 Statistics of Incidents for I-880

Based on CHP logs, incidents that most likely impact traffic represents 70 percent of all I-880 incidents reported. The chart in the following figure shows number of traffic-impacting incidents by time of day on I-880.



(Source: PeMS TASAS)

Figure A.4 Traffic Impacting Incidents on I-880

Between 5 and 15 collisions occur daily on I-880. These collisions are major sources of non-recurrent congestion on I-880 depending on the time of day these collisions occur, on the number of vehicles involved, and on the number of lanes blocked. The following figure shows number of collisions on I-880 from 1999 to 2004 based on TASAS data.

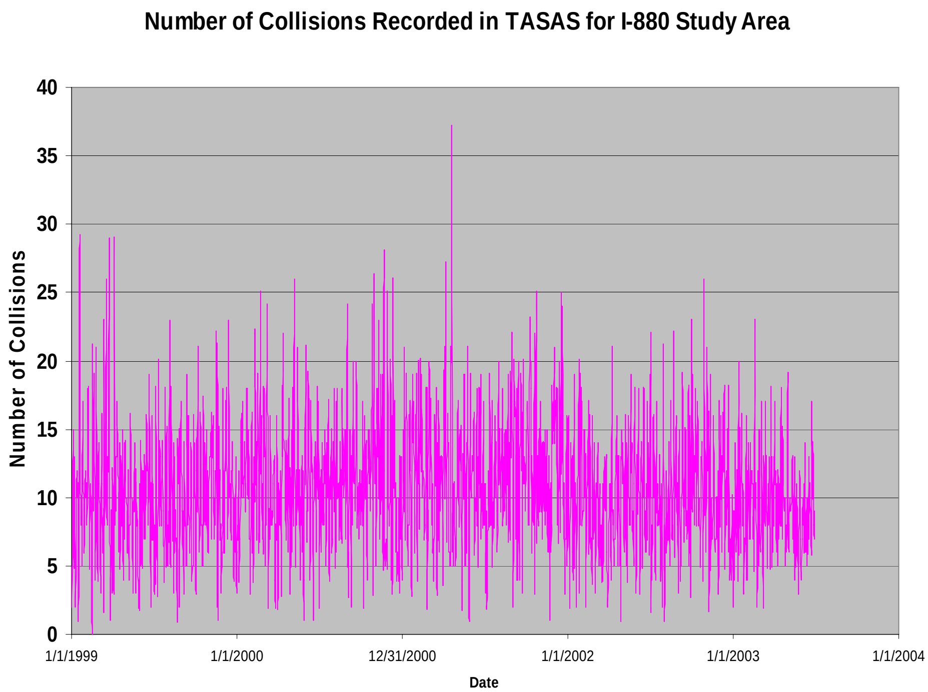


Figure A.5 Number of Collisions on I-880

The current incident management operation on I-880 includes: a) the Freeway Service Patrol (FSP) provides incident response 6-10 AM and 3-7 PM, and b) BAIRS (Bay Area Incident Response System) provides incident response outside of FSP hours.

The objectives of ICMS include improving incident detection, verification, response, and clearance. Possible ICM improvements in the area of incident management include:

- Improve response time for supervisors to come to incident scene and verify conditions
- Provide special heavy-duty incident response trucks (either roving or stationary) to assist with removal of trucks or in case on multi-vehicle accidents
- Improve accuracy of incident logging at CHP CAD system
- Improve integration between freeway and arterial operations
- Improve integration between freeway and transit operations
- Improve incident information including location, number of lanes blocked, etc.

Range of expected improvements in incident detection and efficient incident management resulting from ICMS deployment

The proposed ICM strategies are estimated to reduce incident–related congestion as follows:

- Reduction of overall incident delay by 10 percent
  - Computed as total hours of incident delay, broken down by facility, mode, and bottleneck area
- Improvement of travel time reliability by 10 percent
  - Computed by the "buffer index"

The following table summarizes observed improvements in incident detection and efficient incident management, throughout the country. Sources of this information are also provided in the table.

Table A.3 Expected Improvements in Incident Detection and Management

Expected improvements in incident detection and efficient incident management	Source
San Antonio - System decreased incident response times by: • 21% for major accidents • 19% for minor accidents	from ITS Benefits: Continuing Successes and Operational Test Results - Mitretek
Philadelphia (TIMS): • 40% decrease in incidents • 55% reduction in freeway closure time • 8% reduction in incident-severity rate	from Draft ITS Benefits: 1999 Update, March 1999, Mitretek Systems for FHWA ITS Joint Program Office
Houston (TranStar): • 5-minute average freeway incident time savings • 30 minutes savings for major freeway incidents	from Draft ITS Benefits: 1999 Update, March 1999, Mitretek Systems for FHWA ITS Joint Program Office
Northern Virginia - Estimates of reduction of incident duration for all incidents is: • 6 minutes (if use CCTV and cellular phone in response vehicles) • 9 minutes (if use CCTV, cellular phone and GPS in response vehicles) • 13 to 19 minutes (if use CCTV, cellular phone and GPS and CAD in response vehicles)	from Incident Management and Intelligent Transportation Systems Technology: Estimating Benefits for Northern Virginia, March 1998 - G. Maas, M. Maggio, H. Shafie, and R. Stough, George Mason University

National (urban) - A reduction in incident notification time from 5.2 minutes to: • 2 minutes would result in a 15% decrease in urban interstate fatalities • 3 minutes would result in a 11% decrease in urban interstate fatalities	from ITS Benefits: Continuing Successes and Operational Test Results - Mitretek

Risks to Implementation

Risks and factors from a technical implementation standpoint include:

- Integration of Fire Department CAD system to the 511 and East Bay SMART Corridors program
- Installation of Mobile Data Terminals (MDT) on all fire departments apparatus
- Improve accuracy of incident logging at CHP CAD system

Risks and factors from an institutional implementation standpoint include:

- Logistics of coordinated response among agencies for incident management will require detailed interagency agreements
- Better coordination between supervisors responsible for incident verification

A.4 ICM Factors Contributing to Achievable Improvement in Safety

In addition to improving delay and the reliability of travel time, proposed ICM strategies are expected to also improve safety on the I-880 corridor. The proposed ICM strategies are estimated to improve safety as follows:

- Reduction of overall number of crashes by 10 percent

The following table summarizes observed improvements in safety, throughout the country. Sources of this information are also provided in the table.

Table A.4 Expected Safety Improvements

Expected safety improvements	**Source**
National - Accident savings of 42% for deployment of basic metropolitan ITS infrastructure (297 metro areas)	from ITS National Investment and Market Analysis, 1997 - Apogee and Wilbur Smith
Accident statistics for fatalities: • 36% from off-road accidents involving rollover or collision with fixed objects • 18% from angle collision • 17% from head-on collision • 5% from rear-end collision • 2% from sideswipe	from Intelligent Vehicle Highway Systems Operational Benefits – Mobility 2000 - March 1990
Ramp metering reduces freeway accidents by 20 to 40%	from Intelligent Vehicle Highway Systems Operational Benefits – Mobility 2000 - March 1990
San Antonio - System decreased: • Injury accident occurrence by 15% • Secondary accidents by 30% • Total accidents by 35% • Accident rate by 41%	from ITS Benefits: Continuing Successes and Operational Test Results – Mitretek
National • Transit improvements decreased fatalities by 10% • Traffic management improvements decreased accident rate by: o 15% on freeways o 9% on arterials	from ITS National Investment and Market Analysis, 1997 - Apogee and Wilbur Smith
National - Freeway management combined with incident management programs can reduce accidents by 15% to 50% in congested areas	from Freeway Management Systems - USDOT, available at www.its.dot.gov/tcomm/itibeedoc/fms.htm
National - Crash reduced by 24% to 50%	from Transportation Planning and ITS: Putting the Pieces Together - FHWA, 1998
National - Crash reduced by 15% to 50%	from ITS Benefits: 2001 Update - Mitretek and Ramp Metering: A Review of the Literature - Arnold
California - Crash reduced by 20% to 50%	from Ramp Metering Status in North America: 1995 Update – FHWA
Minneapolis/St. Paul - Crashes increase by 26% in peak period when meters were turned off	from Twin Cities Ramp Meter Evaluation, prepared for Minnesota Department of Transportation by Cambridge Systematics, February 2001

Risks to Implementation

Risks and factors from a technical implementation standpoint include:

- Difficulties in obtaining reliable data to perform meaningful crash rate and conflict analysis

Risks and factors from an institutional implementation standpoint include:

- Better coordination among agencies responsible for sending vehicles and equipment for incident management
- Interagency coordination to provide more rapid dissemination of accurate and timely traveler information
- Local cities and Caltrans failing to agree on a mutually acceptable ramp metering strategy

A.5 ICM Factors Contributing to Mode Shift

In addition to improving delay, reliability of travel time, and safety proposed ICM strategies are expected to also improve mode shift on the I-880 corridor. The proposed ICM strategies are estimated to improve mode shift as follows:

- Additional mode shift of 2-4% of total corridor trips in response to traveler information about recurrent and non-recurrent congestion

The following table summarizes observed improvements in mode shift, throughout the country. Sources of this information are also provided in the table.

Table A.5 Expected Mode Shift

Expected mode shift	Source
San Francisco Bay Area (survey): • 12.5% of commuters who heard of congestion prior to departure changed their departure time • 28.6% chose alternate routes • 7.1% changed mode • 39.3% did not change behavior because they did not believe it would help	from Traveler Response to Traffic Information on an Incident: A Case Study of the US-101 Corridor in the San Francisco Bay Area - Ronald Koo, Harvard University and Youngbin Yim, University of California at Berkeley
Seattle (Traffic Reporter) (PC-based graphical, interactive, real-time, traveler info system): • 16% surveyed willing to change departure time, route, or travel mode before departure • 40% willing to change departure time and route • 21% willing to change route • 23% unwilling to change departure time, route, or travel mode	from "Traffic Reporter: A Real-Time Commuter Information System" in Applications of Advanced Technologies in Transportation Engineering, Proceedings of the Second International Conference, August 1991 - Edited by Y. Stephanedes and K. Sinha
Seattle/Boston (surveys) - When provided with better traveler information, 5% to 10% change travel mode	from ITS Benefits: Continuing Successes and Operational Test Results – Mitretek
San Francisco Bay Area (TravInfo) • Of the participants who seldom ride transit, 35% indicated that the likelihood of taking transit increased after they received information while 50% of frequent transit riders said the same • Of the participants who called for transit information, 14.3% of transit riders (2 people), switched to a personal vehicle as a result of receiving transit information	from TravInfo Evaluation: A Study of Transit Information Callers - Youngbin Yim, Ronald Koo and Jean-Luc Ygnace
Atlanta - About 65% of all survey respondents said they altered the routing, timing, destination, or mode as a result of the device	from Atlanta Traveler Information Showcase 1996 Fact Sheets, October 1996 - Walcoff & Associates, Inc., October 1996

Risks to Implementation

Risks and factors from a technical implementation standpoint include:

- Upgrade existing 511 system to improve user access especially to real-time information about service interruptions and connection problems of transit
- Integration of multiple existing systems (of all modes) into a unified system that can utilize all traffic information and disseminate the information to public and transit agencies in a timely manner
- Development of reliable models to predict near-future conditions as a result of mode shift
- Development of reliable methods to automatically generate alternative transit route and transfer locations based on real-time transit conditions

Risks and factors from an institutional implementation standpoint include:

- Transit agencies may need to consider appropriate access control schemes for available parking to control demand during normal operations, including parking pricing and reservation systems
- There is a need for updating operations guidelines to incorporate enhanced interagency coordination strategy for information delivery
- The proposed ICM strategy is more complex than the current approach; more training of traffic and transit operations personnel for response planning will be needed
- Transit agencies should be flexible enough for real-time adjustments in their capacity to become adaptive to problems or changes in other systems