USDOT Integrated Corridor Management (ICM) Initiative

ICM Surveillance and Detection Needs Analysis for the Arterial Data Gap

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Integrated Corridor Management (ICM) Initiative

ICMS SURVEILLANCE AND DETECTION

NEEDS ANALYSIS FOR THE ARTERIAL DATA GAP

November 2008

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16. Abstract

The primary objective of the ICM Initiative is to demonstrate how Intelligent Transportation System (ITS) technologies can efficiently and proactively facilitate the movement of people and goods through major transportation corridors that comprise a freeway, arterial street network, and bus and rail transit network.

This report analyzes the need for arterial data within an Integrated Corridor Management System (ICMS), identifies data that is currently available to fulfill the needs, and identifies potential sources of additional data which could be used to fulfill the needs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Executive Summary

An Integrated Corridor Management System (ICMS) is a tool used by transportation network operators to promote continuous optimal operation, to the extent that such operation is possible, on a corridor-wide basis. The focus of this document is on the arterial roadway network and the data that are required to support the management and operations of an arterial network in an ICMS.

In the development of this document, stakeholders from the ICM Pioneer Sites and other interested parties were asked to identify generic and specific arterial data needs related to arterial traffic management activities. Based on the needs that were identified, the data that are currently being used to meet those needs were also identified, as well as any existing gaps in the data that prevent all needs from being met.

This analysis examines what real-time data should be monitored in an ICMS; how the data might be monitored and reported; and how the data will be used to manage corridor-wide performance. These data requirements are compared with current capabilities to determine what additional data are needed and how the data can be obtained in the most efficient and effective manner.

Inevitably, transportation corridors exhibit significant variations in configuration, capacity, and demand between corridors, which can make corridor management solutions complex to define. There is, however, much in common between the events and scenarios that an ICMS will manage and the impacts of transportation events on the corridor, including recurring congestion, incidents, and planned and emergency events. This analysis considers a series of response strategies to these events and scenarios and considers how arterial data will be used in those responses.

The effectiveness of corridor management strategies, including those applied to the arterial network will be assessed through a variety of performance measures. Through the course of this analysis it has become clear that the data needed to manage the arterial network in a corridor-wide context or to evaluate the effectiveness of corridor management strategies may not be readily available through existing or conventional arterial infrastructure. The desired ICMS strategies may require data that existing systems were not designed to collect.

At the beginning of this Needs Analysis, it was assumed that arterial traffic signal systems might provide the majority of the arterial traffic data required for an ICMS. However, as revealed in this document, this may not prove to be the case. Traffic signal systems can be designed to function without collecting any of the data needed for an ICMS. Further, those signal systems that currently collect some of the required data elements do not necessarily collect the data with the time or spatial resolution desired for the ICMS functions, or the systems lack the communications bandwidth or data exchange interfaces required to provide the data to an ICMS in a. timely manner.

This Needs Analysis concludes that there are three potential responses to the identified gaps:

- Modify or eliminate corridor management strategies that are dependent on data that is not readily available from the arterial network

- Modify existing systems to provide the required data on arterial streets
- Augment existing systems with new sensors and/or new data acquisition systems to collect the needed data

Some of the ICM Pioneer Sites and other interested parties are investigating emerging approaches for collecting data using new techniques or technologies. There appear to be several promising potential and future approaches for collecting data, the merits of which are examined in this report. These approaches, along with the tools, techniques, and strategies outlined in the following sections provide a clear picture of how arterial network data can be gathered to support the deployment of an ICMS.

1 Introduction

The Integrated Corridor Management (ICM) Initiative is one of the ten major initiatives sponsored by the United States Department of Transportation (USDOT) Research and Innovative Technology Administration (RITA). The primary objective of the ICM Initiative is to demonstrate how Intelligent Transportation System (ITS) technologies can efficiently and proactively facilitate the movement of people and goods through major transportation corridors. A detailed description of this Initiative can be found in the *Integrated Corridor Management Initiative Program Plan Update,* available on the Web at: http://www.its.dot.gov/icms/.

The ICM Initiative consists of four phases designed to research, document, and implement ICM strategies within corridors utilizing existing ITS assets and identifying innovative approaches to reduce traffic congestion across multiple agencies and/or jurisdictions. Several of the phases will run concurrently.

Phase 1: Foundational Research

Phase 1 included research into the current state of corridor management in the United States and abroad. Initial technical guidance documents were created to assist implementers of ICM as a resource during development of concepts and requirements. During this phase, a multimodal stakeholder group was developed to support the initial and on-going efforts of the ICM Initiative. Phase 1 concluded in early 2006.

Phase 2: Corridor Tools, Strategies, and Integration

Phase 2 includes the development of analytic tools and methods that enable the implementation and evaluation of ICM strategies. The outcomes of this phase will help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that will minimize congestion, improve safety, and help to estimate the benefit resulting from ICM across different transportations modes and traffic control systems.

Phase 3: Corridor Site Development, Analysis, and Demonstration

Phase 3 consists of three stages: concept development, modeling, and demonstration and evaluation.

Stage 1: Concept Development

Eight pioneer sites were selected to develop a Concept of Operations and System Requirements Specification documenting their specific corridor needs for an Integrated Corridor Management System (ICMS). The documents were completed Spring 2008.

Stage 2: Modeling

Three pioneer sites were selected to participate in the Analysis, Modeling, and Simulation (AMS) of their respective proposed ICMS. The AMS began following Stage 1.

Stage 3: Demonstration and Evaluation

Up to four pioneer sites will be selected to implement their ICMS demonstrating the institutional, operational, and technical integration approaches in the field and documenting the implementation issues and operational benefits.

Phase 4: ICM Outreach and Knowledge and Technology Transfer (KTT)

Phase 4 focuses on building an ICM KTT to furnish implementers of ICM and ICMS strategies with a comprehensive set of resources based on research and lessons learned.

Arterial data is critical to the successful implementation of an ICMS. During prior analysis tasks, specific arterial data gaps have been identified. Management of arterial traffic in a corridor depends on the acquisition of data about current conditions in the corridor, the capability to implement various arterial traffic management strategies, and the AMS tools to support the evaluation and selection of strategies appropriate to the current conditions.

The objective of this task is to analyze the arterial data gaps and to determine additional data needs to more accurately predict arterial traffic patterns. This report analyzes the need for arterial data within an ICMS, identifies data that is currently available to fulfill the needs, and identifies potential sources of additional data which could be used to fulfill the needs.

This report is the first step in the overall road map for the arterial data gap. The next step will be to define the requirements for the arterial data and to develop an action plan. After the action plan is developed, there is potential for coordination with a selected demonstration site.

This report is organized as follows:

- **Section 2** provides the concepts and context for ICM Arterial Management and the ICMS capabilities required for supporting the concepts.
- **Section 3** presents the results of the Needs Analysis for the Arterial Data Gap.
- **Section 4** describes an approach for stratifying the data requirements into three time horizons corresponding to the ICM objectives for Arterial Traffic Management.
- **Section 5** identifies the various techniques, approaches, and tools that comprise an ICMS capable of responding effectively to the operational objectives described in Section 4.
- **Section 6** includes a review of approaches currently used or under development to collect arterial data.

- **Section 7** provides an overview of current efforts by pioneer sites and standards organizations to define arterial performance measures.
- **Section 8** summarizes the data gaps that have been identified between that which is readily available, and that which will be required to meet established needs.
- **Appendix A** includes a list of acronyms and abbreviations used within this document.
- **Appendix B** includes a list of the publications and reference documents for this analysis.
- **Appendix C** lists the generic needs established for an ICMS.
- **Appendix D** lists the abstracted needs for ICMS Surveillance and Detection as identified earlier in the ICMS technical integration task.

2 ICM and ICMS Context

This document is an analysis of arterial data which is part of an ICMS corridor. A basic understanding of the ICM concept and an ICMS is necessary in order to adequately analyze the arterial data requirements. This section provides a description of the ICM and ICMS Context.

2.1 ICM Context

ICM is based on four concepts:

1. Corridor modes of operation
2. Strategic areas for ICM
3. Conceptual levels within the corridor
4. ICM environment

2.1.1 Corridor Modes of Operation

The corridor mode of operation refers to the manner in which the corridor ICM manager and/or the transportation network operators are operating the transportation networks that comprise a corridor. There are two major corridor modes:

- Normal mode which constitutes all the actions taken to ensure that day-to-day transportation needs are addressed.
- Event mode which consists of two sub-modes
    - Planned event mode: an event that is known prior to the occurrence which will reduce the existing corridor capacity.
    - Unplanned event mode: an event which increases demand on a corridor network without foreknowledge.

A corridor can be shifted between normal mode and event mode several times during a day or can operate in a single mode for the entire day. In order to shift modes, the corridor manager has to assess the event severity, the impact on the entire corridor, and the expected duration of an event before shifting from normal mode to event mode. The ability of the existing systems to support the shift must also be analyzed.

2.1.2 Strategic Areas for ICM

In order to manage the corridor in an integrated fashion, the corridor manager is required to develop strategies in four areas and implement those strategies. The four strategic areas are:

1. Demand management: addresses the patterns of usage of the transportation networks
2. Load balancing: addresses operating each network to its maximum effectiveness
3. Event response: addresses the response to events based on their duration
4. Capital improvement: addresses the need for improvements to corridor facilities

Control strategies can be developed within the first three strategic areas, establishing actions to implement the strategy. Within the fourth strategic area, recommendations for capital expenditures for facility improvements are developed.

2.1.3 Conceptual Levels within the Corridor

There are three distinct conceptual levels within a corridor. These are:

- The physical level which includes all components that are actually in, on, or under the ground.
- The information and sharing level which provides the tools and information systems that take the data from devices and transform them into information that the transportation system operators can use to make operations decisions about the transportation networks.
- The executive or decision making level which includes the people who make the decisions and the plans, actions, on-the-spot decisions, and controls needed to operate the transportation systems within the corridor.

2.1.4 ICM Environment

The ICM environment consists of the four strategic areas resting upon the three conceptual levels.

2.2 ICMS Context

An ICMS is a tool to help the corridor's transportation network operators keep their networks operating at optimal levels. While it is not possible to keep networks operating optimally all the time, continuous optimal operation is the overall goal. There are two major aspects in the discussion of an ICMS:

- Operational needs
- System architecture

2.2.1 Operational Needs

The ICMS operational needs represent a high-level statement of the capabilities required to implement and operate an ICMS. A generic set of ICMS needs are summarized in Appendix C.

A corridor may be comprised of several transportation modes that collectively move goods and people through the corridor. Within the ICM Initiative, a corridor is recognized if it includes at least three of the following transportation modes:

- Freeway roadway network
- Arterial roadway network
- Roadway with managed lanes
- Bus transit network
- Rail transit network
- Toll roadway network

- Ferry network

The goal of the ICMS is to optimize the use of the transportation resources across all modes of transportation within the corridor. Optimization implies a regulating process that measures performance of a system and modifies the control parameters governing operation of the system in ways that will improve or maintain the performance of the system. This is a simple feedback loop.

In a feedback driven control system, positive feedback tells the system to increase the output value. Negative feedback tells the system to reduce the output value. Optimization is achieved when feedback has driven each control parameter to a state that results in the best possible performance of the system (as described by the performance measures monitored within the system).

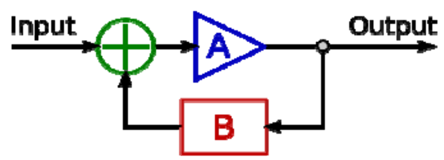

Figure 1 - Simple Feedback Optimization

Optimization therefore implies:

1. The desired performance of the system can be described based on measurable outputs of the system.
2. Performance of the system can be controlled using control measures or strategies that both positively and negatively change the performance of the system.

If a control system automatically uses performance feedback to regulate a system, the controls are considered to be a “closed loop” system. If a control system provides performance feedback information to a human, who must then take action to change the control measures, the system is considered to be an “open loop” system. Complex control systems may use a combination of open and closed loop controls for each control parameter.

Optimization of multiple transportation modes requires a control feedback loop for each transportation mode. If performance of one transportation mode can impact the performance of other transportation modes (and they almost always do), then the feedback must be based on the performance of both systems. There must be a way of describing the value of the desired performance of each system in terms that are common between the systems. Hence, it is acceptable to improve the performance of one system if the change increases the total performance value of all of the inter-related systems, but not acceptable if the total performance value is decreased. Improving the performance of one mode of transportation at the expense of performance of another mode is only acceptable if the Total Net Value of the change is positive. Improving freeway performance by one dollar

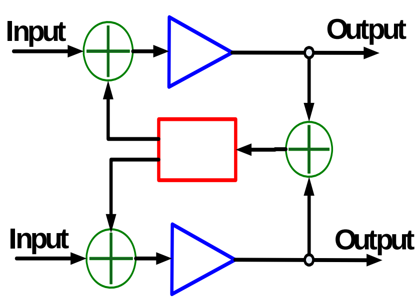

Figure 2 - Multiple Result Optimization

at the expense of a two dollar decrease in arterial performance is not acceptable. This establishes a third constraint on optimization which applies when there are two or more performance goals that must be optimized by the same system:

3. If two or more outputs are to be optimized, the governing feedback must be based on each output, the value of the results must be expressed in common terms, and the governing feedback must be applied to the inputs for all of the controlled systems.

If the system is to be stable, the control algorithm must also model the time it takes from a control change to the time a change in the output can be observed (system latency).

2.2.2 System Architecture

An ICMS typically has three distinct functions that establish how it will work:

1. Input – Information about the current situation or problem to be solved
2. Processing – The rules or algorithms that establish what the system should do given the states of the inputs
3. Output – The results of the processing based on the inputs and processing algorithms

Note that the architecture does not depend on the number or type of inputs, nor on the number of computers that might be required for processing or where the computers might be located. This means that an ICMS can be a centralized or distributed system, closed loop control, open loop control, or a hybrid of both closed and open loop controls.

The ICMS architecture is constrained by the primary goal of optimizing the movement of goods and people through the corridor using the available transportation modes. From the previous section, it is evident that the ICMS must receive inputs in the form of information and operational decisions from every participating transportation mode in the corridor. The ICMS processing algorithms must be capable of determining what should be done based on all of the possible states of all participating transportation modes. The ICMS outputs must be based on optimizing the value of the performance of all of the travel modes to the stated goal of moving goods and people through the corridor.

Simple integration of communications and computing infrastructure will not be sufficient for an ICMS architecture. Sharing information and ITS equipment controls will not constitute an ICMS. An ICMS architecture will require AMS components capable of evaluating multiple travel modes, and decision support or closed loop control components capable of using feedback from the AMS components to make changes in how all of the transportation modes operate. An ICMS requires a common understanding and agreement across all corridor participants as to how "good for the corridor" will be measured. A system where participants will only make changes that benefit the operation of their particular transportation mode is not truly integrated, nor can it be considered an "Integrated Corridor Management" system.

2.2.3 Gap Analysis Context

The preceding sections establish a context for this gap analysis. The analysis is not about data for surveillance and detection for signal systems or about data for signal control outside of corridor management.

This analysis will focus on:

- performance measures for arterial transportation management and the data required to calculate these performance measures;
- data required for AMS systems to evaluate corridor performance relating to arterial traffic;
- data required to assess the impact of strategies and corridor control measures on the performance of arterial systems; and
- data and data acquisition capabilities which are currently available for monitoring arterial traffic.

3 Results of Overall Surveillance and Detection Needs Analysis from Phase 1 of the ICM Initiative

The analysis of the overall surveillance and detection needs for the ICMS operational concepts started with a review of the operational concepts, specifications, and training documents for the ICM Initiative. These include:

- The ICMS Concept of Operations for a Generic Corridor [56]
- The ICMS Foundational Research on Corridor Management Strategies [58]
- The ICMS Surveillance and Detection Needs Analysis [59]
- The ICMS Concept of Operations documents from each pioneer site [39, 12, 26, 29, 42, 51, 61]
- The ICMS System Requirements Specifications from each pioneer site [40, 13, 27, 30, 43, 52, 62]
- The Traffic Control Systems Handbook [22]

3.1 An Example Scenario

The following incident scenario provides an example of how ICM concepts might function in a corridor to coordinate operations within the corridor and enhance the movement of goods and people through the corridor.

In the following scenario, the Freeway Management System (FMS), Arterial Management System (AMS), Transit Management System (TMS), and Public Safety System (PSS) share information about the situation that is essential for making decisions about the incidents. Once the decisions are made, the chosen response must be implemented and information must continue to flow between participants to support the response.

Scenario:

This scenario is based on an incident on Northbound I-01 between 1st and 2nd street interchanges, and at the same time, an incident on Southbound Diablo Rd. between 3rd and 4th Street. Either or both of these incidents could affect the transit 'Purple Route' which runs an express every 30 minutes and a local at a 15 minute delay between express runs. Figure 3 shows the corridor and the locations of the incidents.

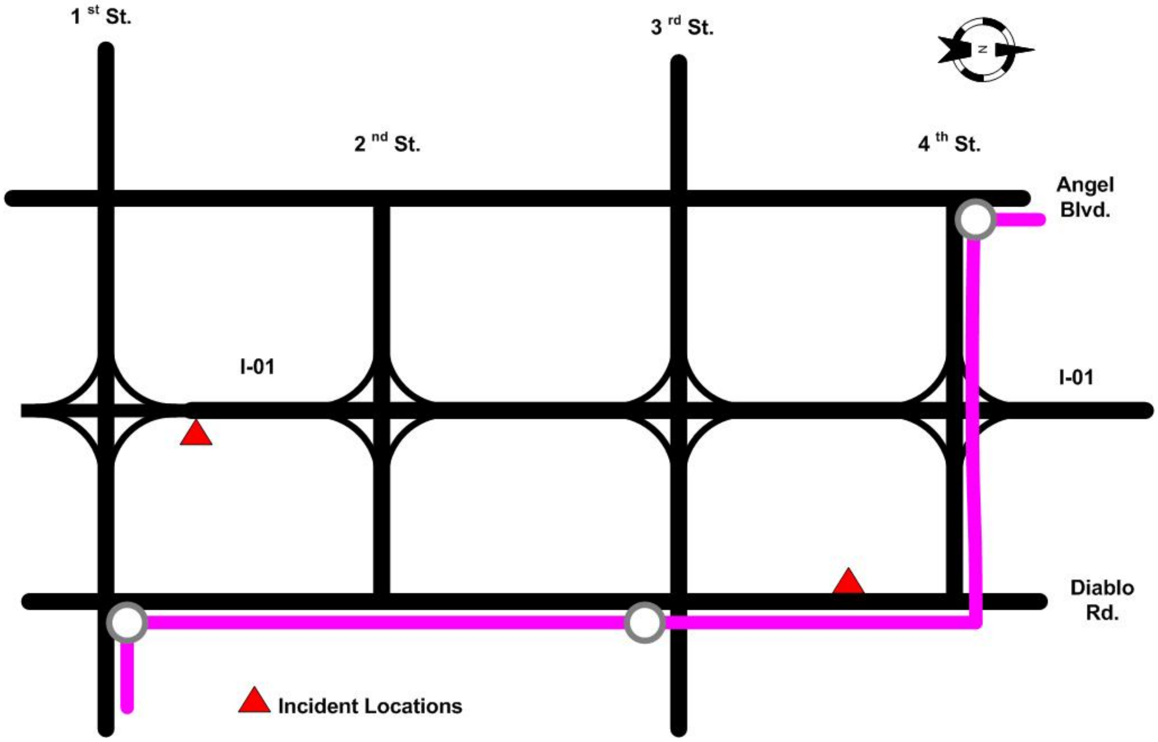

Figure 3 - Example Scenario

ICM Decisions:

The ICM operations personnel will need to collect information about the situation and make some decisions about what should be done. The decisions might include the following:

- Should some freeway traffic be diverted off I-01 to Angel/Diablo arterials between 1st and 2nd St. interchanges?
- Should some arterial traffic be diverted off Diablo Rd. to Angel/I-01 at 3rd and 4th St.?
- Should Purple Route buses be re-routed or assisted around problem areas?
- What information should be given to the public?
- What assistance can be provided to public safety?

To answer these questions and make the associated decisions, some of the information in the following table will be needed by the operations staff and decision support systems. The table shows the possible information sources and who might need the information.

Initial Information Needs:

From	To				
	Freeway Operations	Arterial Operations	Transit Operations	Traveling Public	Public Safety
FMS	• Incident location • Traffic volume affected • Incident duration forecast • Public safety coordination required • Traffic capacity on adjacent freeways	• Incident location • Traffic volume affected • Incident duration forecast • Traffic capacity on adjacent freeways	• Incident location • Incident duration forecast • Travel time forecast	• Incident location • Travel time forecast	• Incident location • Traffic volume affected • Incident duration forecast • Public safety coordination required • Traffic capacity on adjacent freeways
AMS	• Incident location • Traffic volume affected • Incident duration forecast • Traffic capacity available on adjacent arterials	• Incident location • Traffic volume affected • Incident duration forecast • Public safety coordination required • Traffic capacity on adjacent arterials	• Incident location • Incident duration forecast • Travel time forecast • Traffic capacity on adjacent arterials	• Incident location • Travel time forecast	• Incident location • Traffic volume affected • Incident duration forecast • Public safety coordination required • Traffic capacity available on adjacent arterials
TMS		• Signal priority recommendations	• Transit vehicles affected • Alternate route advisory • Signal priority recommendations	• Route changes • Travel time forecast	
PSS	• Cooperative actions required	• Cooperative actions required	• Cooperative actions required		• Crews to respond • Deployment routes • Cooperative actions required

Decisions made:

Based on the severity and expected duration of the incidents, some action will be appropriate. The decision support systems provide information to the operations staff, allowing the following decisions to be made:

- Capacity Northbound on the arterials is enough to allow light vehicles to be detoured around the freeway incident. Drivers on the interstate will be notified of the incident and advised to try Angel/Diablo diversions.
- Capacity Southbound on the freeway and Angel Blvd is enough to allow Diablo Rd traffic to divert to these alternate routes to avoid the arterial incident. Drivers on Diablo will be notified of the incident and advised to try Angel Blvd or I-01 as alternate routes.

- Signal timing along Angel/Diablo routes between 1st and 2nd will be modified to enhance additional traffic flow from the freeway detour.
- Ramp metering system (RMS) timing will be modified to allow traffic onto the freeway at appropriate interchanges for both the I-01 and Diablo Rd diversions. Signal timing at appropriate off-ramps will be modified to allow a higher volume of traffic to exit the freeway.
- The transit express route can be diverted away from both incidents. Local route transit vehicles will run as scheduled, but may require signal priority at some intersections to keep on schedule.
- Public safety crews will be dispatched to both incidents along the best available routes, but may require signal priority at some/all intersections.

Follow-up Information/Coordination Needs:

Implementing the above plan will require a coordinated effort and continued information flow between the participating agencies and notifications to the traveling public.

From	To				
	Freeway Operations	Arterial Operations	Transit Operations	Traveling Public	Public Safety
FMS	• Post incident & detour messages on freeway Dynamic Message Signs (DMS) • Request RMS timing changes	• Request freeway detour messages on arterial DMS • Request traffic signal timing changes		• Post Incident Location and detour info. to web, Instant Messaging (IM), 511, Highway Advisory Radio (HAR) • Update Travel Time forecast	• Identify detour routes • Update Travel Time forecast
AMS	• Request arterial detour messages on freeway DMS • Request RMS timing changes	• Incident Location • Traffic volume affected	• Update Travel Time forecast	• Post Incident Location and detour info. to web, IM, 511, HAR • Update Travel Time forecast	• Identify detour routes • Update Travel Time forecast
TMS		• Request signal priority for specific intersections	• Notify drivers of route/schedule changes	• Post Route /schedule changes to public • Update Travel Time forecast • Update next vehicle arrival messages on Transit DMS	
PSS		• Request signal priority for specific intersections			• Notify Crews to respond • Provide Deployment routes to crews

3.2 Surveillance and Detection Needs

Appendix C includes twenty need statements that reflect the general set of needs for an ICMS based on this review. The following needs represent the key elements of an ICMS deployment that are impacted by gaps in the arterial data:

- Need to understand demand for transportation services (1.2)
  - Need for corridor performance measures (1.2.1)
  - Need for impact assessment tools (1.2.2)
    - Need to collect information about performance and response of the transportation network (1.2.2.1)

These generic needs point to the kinds of surveillance and detection considered necessary for the corridor management activities. Data is needed to measure or calculate performance measures for the transportation services, and data is needed for modeling the transportation services to help operators understand how the transportation systems will respond to the control actions they may undertake.

Appendix D includes thirty-one detailed needs that were identified in the ICMS Surveillance and Detection Needs Analysis [59]. These detailed needs were summarized as:

- Needs related to general ICM characteristics
- Needs related to ICM approaches
- Needs related to ICM strategies
- Needs related to ICM operational data

Analysis of the needs, current methods, and typical data sources indicates that surveillance and detection data must support calculation of current performance of a transportation mode and comparison with the design or ideal performance of the transportation mode being monitored. The system must also be able to identify trends within the data being monitored.

Data needs will vary based on the ICM strategies, the infrastructure within the corridor, the participating agencies, and the types of analysis, modeling, and decision support tools that are implemented. There is no strong consensus at this time about what data is actually needed from arterial systems for ICM implementation. The consensus is equally poor about what performance measures for arterial systems are critical for corridor management.

This is a new operational territory and it may well turn out that the data and performance measures for corridor operations are different from the traditional data and measures used for operation of arterial traffic signal systems.

Appendix E provides a preliminary list of data needs for ICM contrasted with typical data capabilities for operation and planning based on standard operating procedures.

3.3 Current Surveillance and Detection Capabilities

Surveillance and detection measurements for individual transportation modes are generally based on the control needs for managing the systems without regard to impact on other transportation modes. Additional data is collected based on requirements for reporting to local, state, or federal transportation agencies. The following values are typically monitored (although not necessarily in real-time):

Freeway/Tollway Monitoring:

- Road segment speed (average vehicle distance traveled/time unit) – current and by time of day
- Road segment volume (vehicles/time unit) – current and by time of day
- Road segment occupancy (% of unit length lane occupied by vehicles) – current and by time of day

Transit Monitoring:

- Volume (passengers/route leg) – by time of day and day of week
- Fare collected/route leg – by time of day and day of week
- Schedule adherence (difference between vehicle actual arrival/departure and scheduled arrival/departure) – current and daily summary/route

Parking Management Monitoring:

- Volume (number of vehicles using the parking facility) – current and daily total
- Parking spaces remaining - current

Arterial Monitoring:

- Call (vehicle/pedestrian presence)
- Volume (number of vehicles passing a point on the roadway during a specified time period) – current average per unit time and by time of day
- Road segment occupancy (percent of time that a point on the roadway is occupied by a vehicle) – current average per unit time
- Road segment speed (distance traveled by a vehicle per unit time) – current average
- Queue length (number of vehicles stopped in a lane behind the stop line at a traffic signal) – current calculated count
- Headway (time difference between beginning of successive vehicle detections) – current average

It should be noted that in the above list of data monitored, the performance measures that are reported are not generally the values that are used to manage the performance of the transportation modes. For example: volumes are reported on highways, but speed and occupancy are the values used for responsive ramp metering. Passenger volume is reported on transit systems, but current schedule adherence values are the measurements used to control transit signal priority and to make real-time decisions about schedule and route deviations. Daily volume is reported for parking facilities, but signs and access controls are driven off of the number of spaces remaining. Arterial reporting is primarily based on volume and level of service (speed), but local signal controls use call, density, calculated delay, and queue length for the primary control parameters.

3.4 Arterial Signal System Capabilities

As previously noted, an initial premise of this Needs Analysis was that the existing signal control infrastructure may support the arterial data needs for an ICMS. However, some caution should be exercised when discussing the capabilities of arterial signal systems. The state-of-the-art and the state-of-the-practice in any given location may differ greatly. A corridor may include multiple signal systems operated by individual municipal, county, or state jurisdictions. While larger, wealthier jurisdictions may have modern state-of-the-art signal systems; other jurisdictions may have older, even antiquated signal systems.

A modern signal system typically comprises a central server with real-time connectivity to signal controllers at the intersections. Signal systems may control traffic along large arterial corridors or across an entire municipality. In recent years, some systems have been deployed that span multiple jurisdictions and provide coordinated signal control across an entire region. Centralized systems can often support a range of management strategies; ranging from simple monitoring, to active control of signal timing plans, to real-time adaptive signal timing.

Loop detectors used in signal systems are now being replaced more frequently with non-intrusive detectors, such as RADAR or CCTV sensors. While many deployments still use a contact closure from these sensors to signal vehicle presence to the controller, the sensors may support data interfaces capable of reporting additional information, such as speed, volume counts, and occupancy.

In addition to the broadband communication interfaces needed for coordinated control, newer controllers may also have faster processors and more memory. These additional capabilities allow controllers to be programmed to collect and report additional traffic data to their central systems. Many newer devices also support the standard NTCIP protocol for communication with signal controllers. At least three manufacturers currently support an extension of the NTCIP protocol that allows for the collection and reporting of additional data required for adaptive signal systems.

It is becoming more common for newer signal control systems to support data interfaces that allow some traffic information to be shared with other external systems. However, full, bi-directional, center-to-center data exchange interfaces are less common, and, where they exist, are usually the result of site specific requirements rather than a standard product offering.

3.5 Identifiable Gaps

Essentially, the substantial majority of the existing traffic controllers in the US use the same basic structure of cyclic operation, splits, rings, barriers, phases, and overlap information. This information usually comes to the controller in the form of discrete contact closures from a roadway sensor, although a growing number of microwave and video detection systems are capable of providing additional data through serial data interfaces. However, most signal systems are unable to accept the data in this format.

The majority of the status information received is used locally by the controller and then discarded. Memory limitations in the controllers and limited bandwidth for communications links are cited as the primary cause for data deficiencies from the controllers to central systems. Some forms of summary statistics for both phase operation and detector operation are typically available on most traffic controllers, but manufacturers usually implement an averaging mechanism in the controller firmware to conserve memory. Typical implementations provide access to 5-minute or 15-minute averages of traffic volume data for detectors and phase duration data.

Newer systems support centralized collection of phase and detector performance, alarm, and diagnostic information, with update times limited only by the inherent latency of the data collection and communications systems. However, without firmware modifications, these systems are still collecting averaged data rather than real-time data.

4 Operational Objectives for Arterial Data in an ICMS

The overall operational objective for an ICMS is to keep all of the component networks operating optimally all the time. The ICMS allows for the integration of transportation-related data across the corridor. Each agency within the network will have the necessary data and/or control to assist in facilitating the optimal movement of people and goods through the corridor. To manage a corridor in an integrated fashion requires the corridor manager to develop and implement strategies in four areas:

- Demand management
- Load balancing
- Event response
- Capital improvement

These strategies must be supported by the ICMS within the time constraints of the decisions that must be made. The ICMS corridor has three major time horizons for operation. These time horizons are:

- Current (a.k.a. 'real-time')
- Planned Event (including pre-planning for emergencies and disasters)
- Long-term Planning and Optimization

These time horizons correspond to two distinct operating modes for corridors: Normal mode and Event mode. Normal mode is the mode that constitutes all the actions it takes to ensure that day-to-day transportation needs are addressed. Event mode has two sub-modes: Planned Event mode and Unplanned Event mode.

Planned Event mode is the mode where, prior to its occurrence, it is known that an event affecting corridor capacity or travel demand will occur. Capacity may be reduced due to construction, anticipated weather conditions, or a special activity such as a parade. Travel demand may increase due to a large venue activity like a sporting event.

Unplanned Event mode is the mode where an event changes corridor capacity or demand with little or no prior warning. This could be a current event (an incident that reduces capacity) or an emergency situation corresponding to one or more emergency/disaster plans (e.g. an evacuation).

A corridor may shift between Normal mode and Event mode several times during a single day, or even shift from one Event mode to another. In some cases (e.g. during construction or long-term maintenance activities), a Planned Event mode may become the "normal" operation mode.

A corridor does not change modes automatically. Whatever the triggering event, the corridor manager has to assess the *severity* and *impact* on the entire corridor, and the expected *duration* of an event before deciding the operational response. If the severity of an event is low, there may be no need to change operational modes or adopt a new operational strategy.

4.1 Current Time Horizon

The current time horizon is the real-time activity within the corridor. Whether the corridor is in Normal mode or Planned Event mode makes little difference to the corridor operators. The transportation network operators respond to changing conditions by evaluating the surveillance and detection data, sharing event information, and implementing controls to mitigate the impact of the unplanned events on all parts of the corridor. The overall scale of the unplanned event will affect the data needed to meet the operational objectives and large incidents may require more data sharing and coordination than smaller incidents. However, the defining characteristic of the current time horizon remains the same: responses are constrained by the resources at hand and the current capacities of the corridor transportation systems.

Transportation network operators and/or decision support systems may be able to recognize similarity between the impacts of different incidents. Using experience and historical data, in addition to current data, they may be able to take a pre-planned response for another event and use it as a basis for the response to an incident.

Typically, in this operational horizon, operators can respond to unplanned events by making changes to signal timing and ramp metering. Demand on the affected corridor component can sometimes be reduced by notifying the public so that they will change routes, mode of travel, or travel schedules. Coordination with public safety officials may allow for the emergency re-routing of traffic. However, increasing the capacity of the routes is usually not an option.

4.2 Planned Event Time Horizon

The planned event time horizon involves an event within the corridor for which there was prior notification and time to plan the corridor optimization for the event. Pre-planning the response to an event allows the transportation network planners the opportunity to model different responses.

Modeling algorithms will use historical data to validate solutions. This type of modeling may be done with traditional corridor modeling tools or with decision support modeling. The pre-planning exercise allows different agencies within the corridor to work together to optimize the response. In a planned event mode, the ICMS should be capable of evaluating multiple strategies and identifying the likely impacts of each strategy with regard to the performance measures and capacity utilization on all transportation modes within the corridor. If this planning does not identify a strategy that will avoid capacity overloading of one or more of the corridor transportation assets, the corridor participants must understand, in advance, the likely impacts of the selected plan.

During the planning, it may be determined that additional capacity within the affected area is needed and some routes may be designated as one-way for the duration of the event. Transit agencies may respond by providing more high occupancy vehicles and lower cost parking in satellite locations. Public safety agencies and road maintenance agencies will assist during the event with the reconfiguration of roadways.

4.3 Long-Term Planning and Construction Horizon

This time horizon allows the agencies within the corridor to review the current corridor optimization and then determine if there are additional intersections, lanes, transit vehicles, or other ICMS infrastructure needed. Current usage is reviewed and historical data is used to model new configurations. Each configuration is optimized to determine the impact of the proposed modifications and determine which modification has the highest benefit/cost ratio. Long-term planning and construction allow for the building of new pavement, implementation of high occupancy vehicle incentives, and addition of mass transit options.

Long-term planning is usually thought of in terms of capacity planning. To the extent that current and short-term operational decisions are made on the basis of optimizing capacity utilization, long-term planning is an extension of ICM strategies.

4.4 Summary

Demand management, load balancing, event response, and capital improvement are all ways of getting the most "bang for the dollar" out of existing and future investments in corridor transportation capacity. Regardless of how the public measures satisfaction with transportation, transportation providers are investing based on demand for capacity and cost per incremental change in capacity. It is imperative then, that good corridor management depend on measures of capacity utilization, cost of capacity, and the optimization of existing capacity to meet current needs.

Researchers are evaluating performance measurements for traffic signal systems through a variety of approaches. While there is not a clear agreement on what performance measures should be used, there is a growing agreement that improvements in the analysis, modeling, and decision support capabilities for arterial systems will require some basic improvement to the data that is currently available from a controller, as well as changes to data collection methodologies which traditionally have been used primarily for intersection control.

1. Data collected or calculated in the controller should be time-stamped and sent to the central system within a few minutes, not averaged or discarded.
2. Firmware should be modified to collect phase, overlap, control mode, detector, and other event information at a significantly finer time resolution. (Controllers typically scan data inputs at 0.1s intervals and some researchers are suggesting sending 1.0s data updates to the central server.)
3. Typical detector configurations may need to be modified to allow finer resolution of intersection volumes by approach and exit. Occupancy and volume need to be collected on a lane-by-lane basis.
4. Additional sensors or modifications to existing sensor configurations may be needed to provide improved speed data (either in the form of travel time or actual measured vehicle speeds)

If it is impractical to implement these changes in existing controllers due to processor, memory, or firmware limitations, it may be feasible to implement separate data acquisition modules that share access to the primary detection devices.

5 Applicable ICM Techniques

Integrated Corridor Management is a complex topic. With seven possible transportation modes (arterial roadway, limited access roadway, roadway with managed lanes, toll roads, transit utilizing roadway right-of-way, transit using separate/exclusive right of way, and waterways), the number of possible combinations and permutations is 2^7 or 128 possible combinations. It is no wonder that no commercial-off-the-shelf (COTS) products for ICMS exist today. Adding to this the variations in configuration, capacity, and demand for each transportation mode in any given corridor, the complexity of corridor management might almost seem insurmountable.

5.1 ICM Strategies

There are some common threads through all of the ICM strategies. The events and scenarios used to justify ICMS deployments have common factors:

- Recurring congestion (capacity overload)
- Incidents (temporary decreases in capacity)
- Planned events (need to temporarily re-allocate capacity from one use to another; divert demand to alternate modes, routes or schedules; and restrict capacity to prevent capacity overload or enhance safety of roadside workers)
- Emergency events (implement pre-planned disaster plans to re-allocate capacity from one use to another, divert demand to alternate modes or routes, or restrict capacity to prevent capacity overload)

The response strategies also have common threads:

- Information sharing/distribution
    - Coordinates responses to reduce the impact of events on system capacity.
    - Allows traveling public and trip planners to select alternative routes, schedules, and modes of travel based on current or anticipated travel conditions.
- Improvement of operational efficiency of network junctions & interfaces
    - Signal priority for transit - Gives higher priority to high occupancy vehicles (HOV) to increase capacity (volume of people moved) of existing assets.
    - Signal pre-emption/"best route" for emergency vehicles – Optimizes existing capacity for enhanced public safety.
    - Multi-modal electronic payment – Decreases capacity bottlenecks by increasing the number of vehicles/passengers that can be processed per hour and facilitate shifts between travel modes and networks.
    - Transit hub connection protection – Decreases travel time (for some) and increases passenger satisfaction to encourage shifts of travel demand to under-utilized transit capacity.
    - Multi-agency/multi-network incident response – Reduces the impact of events on existing system capacity.

- Coordinated operation between freeways and arterials – Coordination of ramp metering with arterial signals keeps freeway capacity restrictions from causing disproportionate arterial capacity restrictions or overloads. Coordination of off-ramp queues with arterial signal systems keeps arterial capacity restrictions from causing disproportionate freeway capacity restrictions or overloads.
- Coordinated operation between arterial traffic and rail transit traffic – Allows better utilization capacity at intersections un-affected by rail operations to mitigate the capacity reduction caused by closed crossings congruent with rail operations.

- Accommodation/Promotion of cross-network route and modal shifts
  - Modify arterial signal timing to accommodate traffic shifting from freeway – Presumably this would allow additional traffic volume to shift from freeways to arterials without allowing the traffic volumes to reach critical limits on the arterial system. The major concern with this strategy, as expressed by stakeholders, is that freeway capacity is usually several times the potential capacity of adjacent arterial roadways, and un-restricted "dumping" of freeway demand on adjacent arterial roadways can result in arterial gridlock (capacity overload).
  - Modify ramp metering rates to accommodate traffic, including buses, shifting from arterials – This could involve giving priority to transit vehicles or HOV traffic to promote higher efficiency transportation modes, but could also involve throttling ramp metering rates to keep arterial traffic from overloading freeway/HOV lane capacities which results in congestion.
  - Modify transit priority parameters to accommodate timelier bus/light rail service on arterials – This should increase the volume of people moving through the corridor while reducing the travel time for transit travelers. This may be implemented as a function of the passenger count and amount of time a transit vehicle must be behind schedule before signal pre-emption is allowed.
- Promotion of Network Shifts
  - Promote route shifts between roadways via en-route traveler information – Similar to the second bullet under "information sharing/distribution" but expressed as a method to reduce demand on a roadway by shifting the traffic volume to alternate freeway, toll-way, or arterial traffic routes.
  - Promote modal shifts from roadways to transit via en-route traveler information devices – Similar to the above strategy, but specifically directed at reducing demand on a roadway by shifting the traffic volume to un-utilized capacity on transit systems.
  - Promote shifts between transit facilities via en-route traveler announcements – Similar to the "information sharing/distribution strategy", but directed at reducing demand on a transit link by shifting the travel volume to alternate transit routes.

  - Re-route buses around major incidents – Similar to promoting route shifts between roadways but directed at transit vehicles.
- Management of capacity
  - Lane use control (reversible lanes/contra-flow) – The strategy reduces one form/direction of capacity in favor of increased capacity in a direction or form that is more efficient or in higher demand.
  - Convert regular lanes to "transit-only" or "emergency-only" – This strategy reduces one form/direction of capacity in favor of higher efficiency transportation modes (transit vehicles) or to promote public safety (emergency vehicles) during emergencies.
  - Add transit capacity by adjusting headways and number of vehicles – This strategy adds capacity (passenger miles per hour) but assumes that the transit agency has the additional vehicles and personnel to provide the capacity.
  - Add transit capacity by adding temporary new service – This strategy can bridge gaps caused by loss of service on other transit routes or where there is a temporary demand surge associated with a planned event. This strategy also assumes that the transit agency has the additional vehicles and personnel to provide the capacity.
  - Coordinate scheduled maintenance and construction activities among corridor networks – This strategy is directed at coordinating activities that will reduce transportation capacity in the corridor so that remaining capacity is sufficient for normal demands, or alternate capacity is provided to accommodate the demand shift from capacity restricted locations.

5.2 ICMS Tools and Techniques

While most of the research being done on arterial traffic management focuses on obtaining data for speed or travel times, it is becoming increasingly apparent that ICMS deployments will be more focused and dependent on volume and capacity data. The underlying truth is that you cannot reliably manage what you cannot measure. The review of the ICM strategies in the preceding section identifies five major strategies that the ICMS must support and how volume/capacity monitoring is critical to the strategy.

- **Information sharing/distribution** – Information sharing to coordinate responses and reduce the impact of events on system capacity will depend on the capability to monitor and model the impact of events on system capacity. This dependency means that it will be critical for ICMS implementations to collect real-time volume data, archive the real-time volumes, and use AMS analysis of the historical data to calculate the remaining unused capacity within the system. At least three cities are publishing arterial transportation data on web sites, using maps to display traffic volume or traffic congestion measures.

- **Improvement of operational efficiency of network junctions & interfaces** – Coordinated operation between freeways, tollways, HOV lanes, and arterial roadways will only be possible if real-time arterial volume and history-based capacity measures are available. Volume and capacity data can be used to assess the impact of arterial detours for freeway events, manage the impact of ramp metering queues on arterial traffic, and optimize signal timing based on system-wide conditions.

- **Accommodation/Promotion of cross-network route and modal shifts** – This capability focuses on changing demand (volume) on one part of the network by shifting the volume to other routes or travel modes. This capability will be dependent on the availability of current speed and volume data at the ICMS to use for modeling and to compare with historical data.
- **Promotion of network shifts** – This capability will also be dependent on the availability of current speed and volume data at the ICMS to use for modeling and to compare with historical data.
- **Management of capacity** – There is no consensus in the industry at this time about how to calculate or measure capacity. Since you cannot manage what you cannot measure, it is essential to ICMS deployments to find a way to measure capacity on a real-time basis. The most promising research published on this problem seems to indicate that managing capacity on arterial networks will require collection of real-time speed and volume data at managed intersections and the capability to model the speeds and volumes on the remainder of the network where live data is not available.

5.3 Pioneer Site Techniques

Seven of the eight pioneer sites identified collection of volume data on arterial roadways as a critical element of their planning and all of the sites identified collection of arterial speed data as a critical element. Only one pioneer site has identified a data acquisition rate at this time. Minnesota is planning to modify signal controller software to report speed and volume data at least once every two minutes. Three sites identified additional performance data that will be collected specifically to evaluate signal timing.

Most of the sites plan to collect arterial volume data by modifying existing signal system controller software to collect and report speed and volume data. In some cases, loop configurations are being modified to facilitate the data collection.

Arterial speed data will be collected from signal systems, cell phone probes, Automatic Vehicle Location (AVL) data from transit vehicles, and Automatic Vehicle Identification (AVI) data from toll tags or car license plates. Speed data will be collected and archived as either miles/hour, travel time for specific segments, or both.

With regard to the ICM strategies identified in Section 5.1, the pioneer sites provided the following information:

Information Sharing, Accommodation/Promotion of cross-network route and modal shifts, and Promotion of network shifts - Several sites indicated that mode shifting is not feasible at present because the volume/congestion information about adjacent arterials is not available to drivers who might otherwise decide to exit a freeway in favor of an arterial route during freeway congestion. Most of the sites plan to share congestion, volume, or travel time data with the public as a way to encourage mode, route, or departure time shifts. One site is considering using the ICMS to evaluate management strategies involving use of HOV lanes.

Improvement of operational efficiency of network junctions & interfaces – All of the sites had at least one strategy dependent on improving coordination between ramp metering and arterial signal systems or improving arterial signal timing to reflect a response to congestion on the freeway system or in other areas of the arterial system. Two sites indicated that the data would also be used to coordinate transit priority between vehicles and signal systems.

Management of capacity – All of the pioneer sites had at least one strategy relating to capacity management. None of the sites have prior experience with capacity management (unless one includes ramp metering as a capacity management strategy). As a result, there was no clear consensus about how capacity management would be measured, monitored, or controlled.

It should be noted that capacity management on arterials may be especially complex. Since the capacity of an intersection is a function of the signal phase and timing, capacity may need to be calculated based on real-time data such as the green times, which are not always accessible in real-time at the operations center.

All of the sites had strategies for shifting travel demand away from modes or locations with capacity problems, but none of the sites have clearly expressed how they plan to compare capacity on transit vehicles with vehicle capacity on roadways. No clear decisions were expressed about how to compare HOV capacity with traffic on other roadway segments. Only one site recognized that it would be useful to try and collect data about how many occupants were in the vehicles traveling on HOV lanes as well as passenger counts on transit vehicles so that person-miles of travel performance measures could be calculated accurately.

Where signal priority for transit vehicles was included as a management strategy, priority was based on schedule adherence criteria, and no mention was given as to weighting signal priority based on the number of passengers carried by the transit vehicle or the number of vehicles that would experience travel delays as a result of the signal pre-emption. At least one pioneer site is looking at whether it makes sense to include the passenger count and service status of the transit vehicle as a part of the evaluation process for signal pre-emption.

Figure 4 shows the techniques that are proposed by the pioneer sites and the data needs that relate to each technique. The number of sites implementing each technique is shown in parentheses.

● Necessary ○ Good to Know	Lot Utilization	Vehicle Location	Vehicle Speed	Passenger Count	Link Speed	Link Volume	Phase/ Timing	Volume L/R/T	RMS Timing	Incident/ Congestion
Information Sharing										
Real-time Data (7)	○	○	○	○	○	○	○	○	○	○
Incident Coordination (8)					○	○		○		●
Pre-trip Info. to Public (7)	●	●	●		●					●
En-route Info. to Public (8)	●	●			●					●
Improve Efficiency of Junctions										
Transit Signal Priority (6)		●	●	○						
Coordinate RMS/ Signals (2)						○	●	○	●	
Coordinate Signals/ Rail Transit Crossings (2)		●	●				●			
Promote Cross-Network Route/Mode Shifts										
Modify Signal Timing (7)					○	●	●	●		
Modify RMS Rates (2)						○	○	○	●	●
Modify Signal Priority (6)		●	●	○		○	○	○		
Direct Travelers to Alternate Networks (6)	●			●	●	●	○	○	○	●
Direct Travelers to Alternate Routes (6)					●	●	○	○	○	●
Detour Buses Around Incidents/ Congestion (1)		●	●		○	○				●
Add Transit Capacity (4)	●	●	●	●	○	○	○	○		○
Add Parking Capacity (3)	●									
Restrict Ramp Access (1)					○	●	○	●	●	●

Figure 4 - Corridor Management Techniques and Data Requirements

6 Arterial Data Gathering Approaches

6.1 Standard Arterial Data Gathering Approaches

The most common data gathering approach for arterial data is the collection of traffic volume data using pneumatic tube counters. This data is used for traffic studies and is usually single-use, single-purpose data.

Although daily demand profiles can be constructed from data obtained by signal systems, the aggregation of data in the controllers usually destroys the fine detail required for optimization and performance monitoring of the signal systems.

Traffic signal systems traditionally relied on time of day-based timing plans. In their simplest forms, these signal systems could operate without any traffic data input. As the sophistication increased, traffic responsive systems were developed that required presence detection for the through and turn lanes and queue length detectors to establish approximate traffic volumes on each approach. When multi-intersection coordinated signal systems were deployed, additional data such as speeds, headway, and road segment occupancy were added to the data collected by the signal systems. The traffic data acquired by sensors associated with signal systems was used for signal control, but was not typically archived or even sent back to a traffic management center for display.

The advent of regional signal coordination initiatives made it more common for the data from signal systems to be collected and archived at a traffic management center. Most of the data that is archived is intended for statistical analysis, performance reporting, or planning. The data are usually “rolled up” into hourly, daily, and monthly summaries. The data collected is pre-purposed for signal control or reporting, which has resulted in some short-cuts in the design of the data collection devices and local processing [28].

Since the signal systems only need presence detection for turn lanes and through lanes, detection is not always sensed by individual lanes. All of the left turn lanes, for example, may be ganged and input to the system as a single digital input. Queue detectors may be configured to detect that the queue has backed up to a certain point, but may not be configured to collect an accurate count of the vehicles in the queue from the monitored approach. The volume counts collected for signal control tend to focus on signal specific issues (i.e. turn counts, queue clearance, etc.). The data may or may not be specific to lanes, and in many cases only the 5 to 60 minute summaries of the data are sent back to the center. Figure 5 shows the typical sensor placement for arterial signal systems. Many arterial systems are operated without the placement of the queue sensors that are labeled 4, 5, and 6 in the figure.

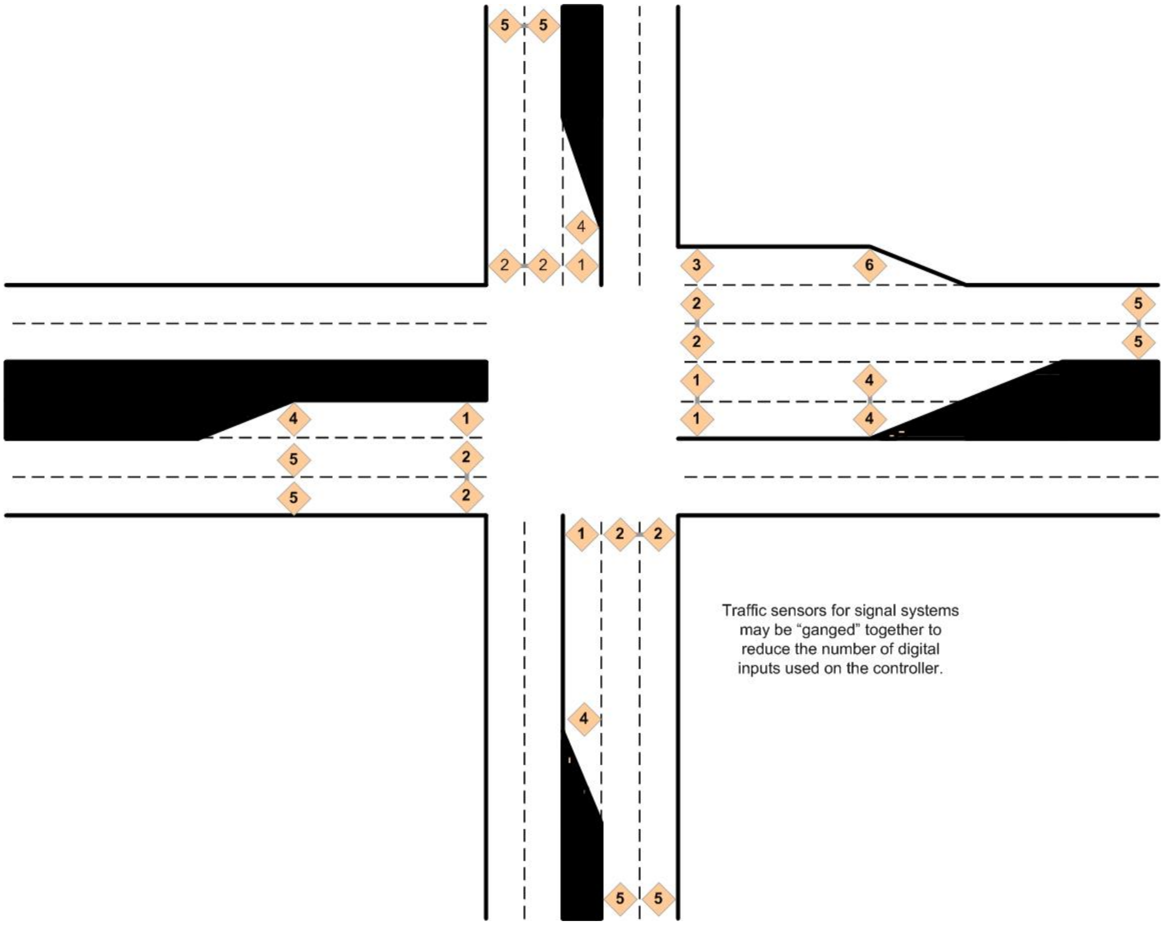

Figure 5 - Typical Arterial Data Sensor Placements

The resulting data gap for operations is a result of two factors in this typical data gathering approach:

- The data is "coarse" – Real-time operations and optimization will need data specific to each lane of travel. An ICMS will need speed, volume, and occupancy data for each lane of travel. The scan/reporting times for data collection will need to change. The ICMS will need fresh data every 5 to 30 seconds. The data can be rolled up to longer time spans as needed by the ICMS or AMS software, but the reverse is not true. Data summaries of 5 to 60 minutes from the field cannot be "un-rolled" to provide real-time data.
- Location, location, location – The ICMS will need data from places where traditional signal systems do not collect data. While a few systems today collect speed data, the debate in the AMS community seems to indicate the speed data currently collected by arterial systems is not adequate, and will need to be supplemented by adding speed detection capabilities at additional locations. A similar debate about volume data indicates that additional volume count locations will be needed to support ICMS operational goals.

The most common factors cited for the absence of real-time traffic data for arterial systems are [33]:

- The lack of existing automated surveillance equipment on many arterials
- The lack of data collection capability within the intersection controllers currently operating many traffic signal networks
- The lack of communications capability and/or sufficient communications bandwidth within existing traffic signal control systems
- Insufficient technical knowledge about how to convert available data into meaningful information
- Insufficient financial and staffing resources to remedy the above conditions

The arterial data which is generally collected includes data from a vehicle detection unit and status data from a signal controller. A variety of different methods are currently used to detect a vehicle on arterials and gather data:

- Inductive loop detectors and micro-loops
- Video imaging
- Radar

While inductive loop detectors are still the most common detector, there is a strong move nationally toward replacing inductive loops with non-intrusive detection systems.

6.2 Emerging Approaches for Arterial Data Gathering

Several of the pioneer sites will be experimenting with novel technologies to collect data that would otherwise not be available to existing arterial systems. Most of these efforts are aimed at obtaining speed or travel time data.

Travel times on tollways can be calculated by using toll-tag monitoring or vehicle license plate recognition technologies. At least one site will be investigating putting toll-tag sensors on freeways and arterials to obtain travel time data.

Several sites will evaluate using AVL data from transit vehicles to calculate travel times. The Minnesota pioneer site will also be evaluating the use of cell phone probe data to calculate speeds and travel times on arterial roadways.

Cellular phone tracking is another mechanism that can be used to identify vehicles by using information about cell sector changes to estimate the location of the vehicle. This information must be matched with road segment data in order to provide more meaningful speed and travel time data [24].

About half the pioneer sites will take additional steps to modify existing arterial traffic sensors and signal system software to allow these existing assets to collect additional data.

Modifying existing signal system sensors to collect additional data is a viable option because the cost is relatively low and the data that can be collected couples well with the needs of existing and planned arterial modeling software. Most traffic sensors for signal systems are only used to measure vehicle presence. With minor modifications, the same sensors can collect speed, volume, and occupancy data (as most systems currently do on freeway systems) and from this data headway, density, turning time, queue clearance failure, and arrivals during red can be calculated. With the addition of supplemental sensor locations within or near the intersections (see Figure 6), additional metrics can be estimated including segment travel times, segment functional capacity, and average speed, volume, and occupancy for arterial segments.

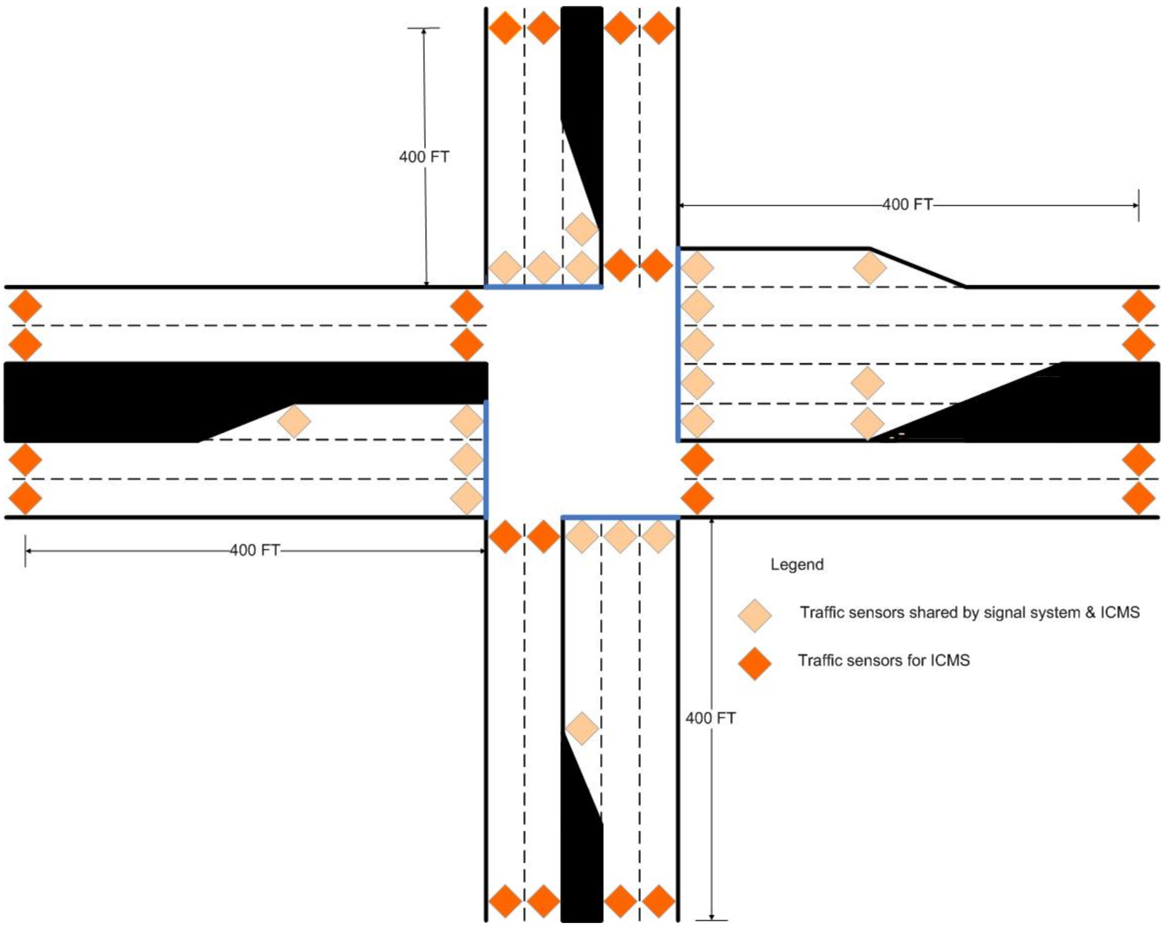

Figure 6 - ICMS Arterial Intersection Sensor Configuration

There is by no means a consensus about the usefulness or viability of adding additional sensors at intersections or at mid-block. The best place to measure speed, or even the best way to measure speed, has not been resolved. Some prefer to measure travel times rather than simple speed.

Some researchers advocate mid-block speed measurement and volume counts but others note that these measurements can produce travel times that do not include the effects of the signals at the intersections. Since adding sensors at mid-block can be expensive, some researchers have proposed adding detectors at 400 feet from the intersection, far enough away to minimize intersection effects but close enough to allow existing controllers to be connected to the detectors.

Some work has been done using the detectors at the stop line to calculate speed, but the problems of how to deal with vehicles that are stopped or just starting to accelerate into the intersection in these calculations has led to disappointing results. Better results have been obtained by adding detectors at the exits to the intersection, where vehicles are presumably closer to their free-flow speed. Combining vehicle counts at these sensors with the counts at the stop line, volume can be reported by through, left turn, and right turn classifications that are more accurate in intersections with permissive turn configurations. This detector configuration also supports more accurate counts of the number of vehicles served per cycle.

Figure 7 shows a comparison of the characteristics associated with various sensor locations that are being considered for arterial data collection.

Legend
● Good
◖ Fair
○ Poor

Sensor Location	Cost	Signal Control	Signal Performance	Queue Length	Speed	Volume	Occupancy
Stop Line	●	●	○	○	○	◖	○
Approach	●	●	●	●	○	◖	◖
Exit	◖	○	○	○	◖	●	◖
400 Ft	◖	○	○	○	●	●	●
Mid-block	○	○	○	○	●	●	●

Figure 7 - Characteristics of Various Sensor Locations

6.3 Potential/Future Approaches

6.3.1 Controller Modifications

Several research projects are focusing on modification of the traffic controller logic and reporting capabilities. One example is the Federal Highway Administration (FHWA) work on the ACS-Lite adaptive control system which focuses on collecting time-tagged sensor and signal phase data in one second slices for analysis and optimization of the signal timing. This project includes forward thinking use of National Transportation Communication for ITS Protocol (NTCIP) communication standards and methods to make the data retrieval compatible with low-speed communication networks that are most frequently found in today's signal systems.

Four controller manufacturers have implemented this data collection and reporting capability in NTCIP controllers. Field trials have shown that it is possible to use the finer granularity and temporal fidelity of the data to measurably improve traffic performance.

6.3.2 Vehicle Infrastructure Integration (VII) Probe Data

Vehicle probe data is data is collected within each vehicle and broadcast to roadside equipment for assimilation and analysis. Data gathered includes information about the vehicle operation such as speed, braking, windshield wiper state, ambient temperature, etc.

The advantages of this method are:

- Information is available on a per vehicle basis
- Data beyond speed, volume, and occupancy can be collected

The disadvantages of this method are:

- Need high percentage of vehicles with instruments installed
- Need devices installed along roadway to receive data
- Privacy concerns of public

VII represents an enormous potential for ICMS data [49, 50]. The Michigan Department of Transportation's Data Use Analysis and Processing (DUAP) project is exploring how VII data could be used for ITS applications in a Department of Transportation (DOT) environment. One of the early findings from this effort is that even simple statistical analysis of the VII data over large areas can identify significant changes in traffic conditions without requiring detailed modeling of the roadways.

6.3.3 Passenger Vehicle Global Positioning Systems

Passenger vehicle global positioning systems (GPS) are another way to collect arterial data [38]. Each vehicle would be equipped with a GPS unit. The unit is able to communicate with satellites to record time of day and latitude/longitude. A time interval in the one-second range will provide a clear representation of the path that the vehicle moves. The collected data can be analyzed to determine travel time and travel speed. GPS has an advantage over the electronic Distance-Measuring Instruments (DMI) because it can easily be associated with the geographic information systems (GIS) for analysis where DMI cannot be directly associated with GIS.

The advantages of vehicle GPS are:

- Data can be associated with GIS
- Allows for extraction of traffic signal delay
- More popular

The disadvantages of vehicle GPS are:

- Need high percentage of vehicles with GPS
- Privacy concerns of public

6.3.4 Electronic Distance-Measuring Instruments

Electronic DMI can be used to measure speed and land distance based on the sensing of pulses produced in vehicles [38]. An electronic DMI sensor is connected to the vehicle's transmission. As the vehicle is moving, pulses are received by the sensor. This method is used more for studies and planning than in a real-time application. The data is typically recorded to a portable computer and then uploaded.

The advantages of this method are:

- Ability to identify areas of delay
- Source of data for fuel consumption and emissions analysis

The disadvantages of this method are:

- Data is dependent on the driving characteristics of the driver
- Privacy concerns of public

6.4 Summary of Data Gathering Approaches

Table 1 contains a summary of the types of data that can be collected or estimated using the data gathering approaches discussed in this section.

Table 1 – Data Available from Data Collection Approaches

Device	Data Directly Measured	Data Calculated from Measured Values
Inductive Loop Detectors	Vehicle Presence	Speed Volume Occupancy Headway Density Incident detection Vehicle volume arriving on red Turning time Signal cycle failure
Video Imaging	Vehicle Presence Speed Volume	Occupancy Headway Density Incident detection Vehicle volume arriving on red Turning time Signal cycle failure
RADAR/LIDAR	Vehicle Presence Speed Volume Occupancy	Headway Density Incident detection Vehicle volume arriving on red Turning time Signal cycle failure
Automatic License Plate Recognition	Travel Time	Average speed
Cellular Phone tracking	Average speed/segment	Estimated Volume/segment Incident Detection Travel Time
Transit Vehicle AVL	Speed Average speed/segment Travel Time	Schedule adherence
Automatic Vehicle Identification	Vehicle presence Travel time Average speed/segment	Trip origin/destination
Passenger Vehicle Global Positioning System	Speed Average speed/segment Travel Time	Trip origin/destination
Electronic Distance-Measuring Instruments	Average speed/segment	
VII Probe Data	Presence Speed Roadway conditions Weather conditions	Average speed/segment Travel Time

7 Arterial Data Types and Performance Measures

7.1 Overview of NCHRP Arterial Performance Measures

The Highway Capacity Manual [55] states that the arterial level of service is based on the stopped delay per vehicle at a signalized intersection. Calculating this measure requires knowledge of the signal phase and the number of vehicles in each lane group on a second by second basis. Table 2 shows the standard information for Arterial LOS [55].

Table 2 – Arterial Levels of Service

Level of Service	Stopped Delay Per Vehicle (Seconds)
A	≤5.0
B	>5.0 and ≤15.0
C	>15.0 and ≤25.0
D	>25.0 and ≤40.0
E	>40.0 and ≤60.0
F	>60.0

The National Cooperative Highway Research Program (NCHRP) has projects under way to refine the arterial performance measures. NCHRP Project 3-79 [7] has several research tasks that focus on real-time performance measures for arterial traffic. The focus of this effort is to identify methods for measuring, calculating, and modeling the LOS performance measures in real-time.

Of particular interest in this research is the work contracted with Purdue University on performance measurements using Input-Output measurements and hybrid techniques for calculating performance measurements using the incoming and outgoing volumes of traffic at individual intersections. These techniques are of interest to ICMS deployments because their focus is on collecting traffic volume data as a means of modeling the current LOS performance measures.

While real-time traffic volumes by segment and intersection are not performance measures of primary interest to the NCHRP 3-79 project, this data, acquired as a byproduct, may be of value to ICMS deployments as a way to measure arterial capacity and the elasticity available for transit pre-emption or capacity shifting from highway to arterial modes.

Several recent publications from the NCHRP have discussed the importance of performance measures. Guidance from NCHRP Report 551 [8] identifies the following criteria for performance measures:

- Policy Driven Measures
  - Be sensitive and responsive to policy objectives
  - Convey meaningful information about the transportation system
- Strategic Perspective Measures
  - Be able to be forecast

  - Relate to an economic as well as a technical dimension
  - Reflect a combination of outputs and outcomes
- Consideration of Options and Tradeoffs
  - Be sufficiently sensitive to reflect impacts of a broad range of options, and potentially, modes
  - Help to relate system impacts to factors under the agency's control and to identify impacts of factors not under the agency's control
  - Be applicable to scenario testing or "what-if" analysis
  - Provide a clear indication of changes in impacts due to different proposed investments, funding levels, and resource allocations
  - Enable a linkage analytically between budget and performance while considering the requirements of the Governmental Accounting Standards Board (GASB) 34 modified method
  - Be able to relate project outcomes to the program level
- Feedback Measures
  - Provide information enabling managers to understand problems and suggest solutions
  - Be able to be monitored economically on a periodic basis
  - For performance measures dealing with system operations and management, be able to be monitored and provide useful feedback in real-time
- Measures Across Organizational Units and Levels
  - Be developed for technical as well as managerial and executive levels within the organization
  - Be of a mathematical form that permits aggregation or "rolling up" where appropriate

It should be noted that many traffic engineers do not consider the performance measures defined in the Highway Capacity Manual to be the performance measures of choice for arterial traffic. Many favor the use of volume/capacity ratios for a performance measure. Even this measure becomes problematic when traffic approaches saturation (v/c=1).

7.2 Pioneer Site Performance Measures

Many of the pioneer sites expressed a need for the ability to coordinate ramp metering with adjacent traffic signal controls as a means to improve the performance of both the arterials and the freeways. In order to coordinate these, there must be unused capacity on the ramp and the adjacent traffic signal cycles must be operating such that the arterial has capacity to handle the volume while the ramp meters the vehicles onto or off of the freeway. Performance measures that were identified to assist with this coordination were:

- Vehicle speed
- Intersection approach volumes
- Ramp queues
- Link and spot speeds
- Link and ramp capacity

Each site identified improvement in overall throughput of the corridor as a desired performance measure. In order to demonstrate improvement, the current level of corridor throughput must be calculated across all modes of transportation and all segments of roadway. The following surveillance and detection capabilities as defined in Section 3.2 are needed to calculate the improvement:

- Freeway and Tollway Monitoring
- Transit Monitoring
- Arterial Monitoring

In addition to corridor throughput, each pioneer site identified specific performance measures for the corridor that were desired. These included:

- Travel time including mean, maximum, buffer, and range
- Vehicle speed
- Travel delay time and predictability
- Incident duration and frequency
- Fuel consumption savings
- Pollutant emissions savings

Some of the pioneer sites identified specific performance measures for the freeway, transit, or arterials. The performance measures identified for arterials included:

- Arterial speed based on AVL
- Arterial volume and occupancy
- Arterial capacity
- Arterial segment specific measures which include:
    - traffic volume
    - travel speeds and times
    - level of service
    - vehicle miles and vehicle hours traveled
    - person-miles and person-hours traveled
    - number of incidents and incident rate
    - number of fatalities and fatality rate
    - number of injuries and injury rate
    - incident response and incident clearance time

The key factors in the quality of service, as defined in NCHRP 3-79, are identified as the average speed and the number of stops. Traffic performance monitoring tools use vehicle counts, speeds, and signal status data as inputs in determining the performance of the traffic on a particular segment or link.

7.3 Performance Measures for ICMS

Performance measures figure heavily in the design of arterial transportation systems. Most arterial planning is based on current demand and forecasts of future demand based on demographic measures such as population growth, population shifts, new construction, and economic forecasts of fuel costs. These studies are essentially a demand forecast which is then equated to a capacity requirement. The modeling exercise is focused on determining where to add capacity, how much capacity to add, and how to add the required capacity in the most cost-effective way.

Current models that handle multiple transportation modes typically use a cost per unit of additional capacity as a measure of comparison between alternatives involving multiple modes of transportation within the planning model. As a performance measure for planning, incremental cost of construction for equivalent capacity works for comparing multiple transportation modes.

Incremental cost of construction does not work for real-time management or event planning. This difference between construction planning and operational planning establishes a time-event horizon between construction planning and operational planning and management. Real-time management and event planning must be based on the assets at hand. This means that controls and strategies for operation of corridor assets must be based on using existing assets without exceeding capacity limits.

The forward-looking nature of event planning allows operations staff to move or re-allocate existing transportation resources. For example, real-time responses do not usually result in mode shifts:

- Real-time responses to incidents call for messages on existing Dynamic Message Signs and Highway Advisory Radio in addition to information broadcasts to the public through the media, text messaging, and the Internet.
- Lanes may be closed, and even entire roadways may be closed. In the case of incidents involving transit, schedules may be disrupted or routes dropped for a short time.
- For incidents lasting less than an hour or two, route shifting and travel plan changes are the primary responses to the reduced capacity caused by the incident.

Event planning may involve substantial modifications to the deployment of equipment, and the allocation of lanes, roadways, intersections, and other capacity-related assets. The differences between events (construction, parade, or large venue event) and disaster planning (evacuations, road closures due to flooding, weather, or roadway damage) are more a matter of degree than method. For example, planning can involve capacity changes such as:

- Event related timing plans can be implemented on arterial signal systems
- Intersections can be closed and detour routes established to modify conventional traffic patterns
- Lanes or whole roadways can be closed and detour routes established
- Lanes or roadways can be blocked and put into contra-flow operation to expand capacity in desired directions
- Transit vehicles can be added and/or diverted from established routes to expand transit capacity between desired locations
- Temporary parking areas can be opened to facilitate additional transit capacity

- Portable Dynamic Message Signs and Closed-Circuit Television (CCTV) cameras can be deployed to key locations to provide additional surveillance and direct communication with travelers

The goal of incident management is to keep an incident from cascading into a situation where there is a substantial loss of capacity at a critical time, but incidents do frequently result in major congestion. The goal of ramp metering is to smooth out traffic density and manage volume to avoid recurring congestion on highways (without causing equally detrimental congestion on arterial roadways). The goal of transit priority-based signal strategies is to quickly move people in high occupancy vehicles without creating traffic problems for people in other vehicles. None of these goals are conflicting unless, and until, they negatively impact the capacity of other transportation modes. Viewed as a common goal to maximize the utilized capacity to move goods and people through the corridor, a common feedback value can be derived that is suitable for evaluating and managing use of the corridor transportation resources. This concept establishes a basis for Integrated Corridor Management that can usually be agreed upon by all participants:

> **Integrated Corridor Management should be based on the concept of reducing or avoiding capacity overloading on all corridor transportation modes and maximizing the volume of people and goods moved through the corridor for any given transportation demand.**

To achieve this goal, the ICMS must have two of the following three data types available for arterial roadways:

- The usable capacity (from design or historical data) for each intersection and road segment
- The current traffic volume for each intersection and road segment
- The remaining unused capacity (usable capacity minus current traffic volume)

An effective measure for usable capacity would likely be derived from measured traffic volumes just prior to onset of recurring congestion. The difference between the design capacity and the usable capacity would provide a measure of elasticity.

7.4 Performance Measures for Arterial Management

Arterial networks are highly interconnected meshes of nodes (intersections) connected by road segments. The capacity on the arterial network is a function of the capacity of the intersections and the capacity of the interconnecting road segments. The intersection capacity is a function of geometry, road friction, signal timing, vehicle size, and the number of vehicles in each approach lane. Arterial road segment capacity is a function of geometry, road friction, vehicle size, number of vehicles in each lane, and average speed of the vehicles. Like freeway capacity, the onset of congestion can result in a drop in functional arterial capacity.

To establish real-time monitoring of arterial performance, an ICMS will need the capability to collect current data about speed, volume, and queue lengths at intersections on a lane by lane basis [3]. In work done by Portland State University in 2007, the arterial signal systems were evaluated for their ability to collect 17 different arterial performance measures. The work in this investigation demonstrates that relatively good performance data can be obtained. This study confirmed that data needs to be collected and sent to an operations center at least once per signal cycle. The study also identified a barrier – that the current generation of signal control hardware is generally incapable of the required level of performance and communication.

One last issue may also need to be considered: the above performance measures treat all vehicles the same. Strictly speaking, high occupancy vehicles and high capacity freight haulers should be given a different weighting factor, as they represent a more efficient movement of people and goods than a single occupancy vehicle used to transport an individual or a small quantity of goods. Signal priority for a loaded transit vehicle makes sense in these terms, but signal priority for an empty transit vehicle may be counterproductive.

7.5 Data for Impact Assessments

Impact assessments are modeling tools that attempt to determine capacity utilization for a given scenario or control algorithm. For planning purposes, the model can be evaluated over a range of values for capacity and under differing conditions to establish a profile of the impact across a range of conditions. Whether the planning is for construction or for a special event, an impact profile can help identify which strategies provide the most desirable outcome.

Impact assessment for real-time control or decision support has different requirements. First, the only input conditions of interest are the current conditions. The only alternative actions or control modes that need to be evaluated are the ones that can be implemented immediately. Responses are usually time constrained. An operator does not have a lot of time to review a complex profile of results.

Data for real-time impact assessment must be timely and accurate. The performance measures discussed in the previous section may be suitable for impact assessments, providing that the measures are current enough to accurately reflect the situation under assessment. The assessment itself must be calculated quickly enough that the recommended control actions are based on input conditions that have not changed substantially.

One interesting phenomenon has been observed relating to traffic impact assessments. Forecasting for weather and usage forecasting for power, natural gas, and water are routinely published. The accuracy of these forecasts is rarely affected by public reaction to the forecasts. Traffic forecasts frequently result in a “self-defeating prognosis” [4]. Forecasting congestion in a specific area often results in people avoiding the area (given the choice) and the shift in traffic may be enough that the congestion does not materialize. The shift may also be enough that congestion *does* occur in another location where no congestion was forecast.

While this is good, in the respect that many ICM strategies are based on changing the public behavior, the public may stop responding to ICM strategies if they do not believe that the forecasts are accurate enough to be trusted.

8 Summary of Arterial Data Gaps

In this analysis, several information gaps have been identified:

- Traffic signal systems represent the majority of real-time data collection in most arterial transportation systems.
- Most traffic signal systems do not support transferring data to a central system for analysis or sharing with other systems.
- Most traffic signal systems do not collect the types of data required for ICMS.
- Most traffic signal systems do not support the data collection granularity required for ICMS. Speed, volume, and occupancy data are needed per lane on a 1-2 minute collection cycle. Many signal systems aggregate sensors across multiple lanes (as was illustrated in Figure 5) and most aggregate data into hourly summaries before uploading the data to central servers.
- Modification of traffic signal systems to provide the desired data usually requires modifications to the sensor connections, to the controller, and to the controller software. This may not be feasible in many corridors.
- Alternative data collection methods are limited to providing speed or travel time data which cannot easily be used to derive critical capacity factors such as traffic volume, occupancy, headway, and density.
- Speed and travel times are well suited to public dissemination, but speed and travel times do not predict capacity problems; they only identify the location once the capacity failure has occurred.
- The granularity of AVL and AVI data may not be a good match for operational needs. The travel time and speed data from these systems can represent 5-15 minute or longer time spans. Both techniques also offer limited coverage of the arterial network.
- The cell phone probe data has not had a good record of providing detailed traffic data on small arterial segments. This does not mean that the data is not useful, but that it may be useful in different ways from more traditional traffic sensor systems. The statistical methods being explored with the DUAP project may provide additional useful ways to use the cell phone and other probe data.

From the AMS portion of the Initiative, it will be critical to learn which types of data are essential to modeling the corridor, and what granularity of data is required for the AMS tools to be accurate and useful. From the pioneer site deployments, it will be important to learn which types of data gathering measures are effective and produce useful information for operations as well as the public.

The ICMS projects each have a unique modeling approach and different goals for how the modeling part of the ICMS will integrate with the operational and planning aspects of their corridor management strategy. This diversity should provide good insights into what can and cannot be done with arterial data to manage corridor capacity.

Researchers are evaluating performance measurements for traffic signal systems through a variety of approaches. While there is not a clear agreement on what performance measures should be used, there is a growing agreement that improvements in the analysis, modeling, and decision support capabilities for arterial systems will require some basic improvement to the data that is currently available from a controller:

1. Data collected or calculated in the controller should be time-stamped and sent to the central system, not averaged or discarded.
2. Firmware should be modified to collect phase, overlap, control mode, detector, and other event information at a significantly finer time resolution. (Controllers typically scan input data at 0.1s intervals and some researchers are suggesting sending 1.0s data updates to the central server.)
3. Typical detector configurations may need to be modified to allow finer resolution of intersection volumes by approach and exit. Occupancy and volume need to be collected on a lane-by-lane basis.
4. Additional sensors or modifications to existing sensor configurations may be needed to provide improved speed data (either in the form of travel time or actual measured vehicle speeds)

If it is impractical to implement these changes in existing controllers due to processor, memory, or firmware limitations, it may be feasible to implement separate data acquisition modules that share access to the primary detection devices.

It may be necessary to investigate new ways of collecting data from intersections using the existing sensors, but bypassing the signal controllers. It may be possible to piggyback COTS data acquisition equipment on the existing sensors without disruption to the signal system. This would allow intersections with older controllers to participate in the ICMS data collection at a lower cost than replacement of the signal system. Adding processor power to intersections may also be less risky than modifying controllers to collect more data than the original controller specifications required.

APPENDIX A – Acronyms

AMS	Analysis, Modeling, and Simulation
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CCTV	Closed-circuit Television
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
DMI	Distance-Measuring Instrument
DMS	Dynamic Message Sign
DOT	Department of Transportation
DUAP	Data Use Analysis and Processing
FHWA	Federal Highway Administration
GASB	Governmental Accounting Standards Board
GIS	Geographic Information System
GPS	Global Positioning System
HAR	Highway Advisory Radio
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
IM	Instant Messaging
ITS	Intelligent Transportation System
KTT	Knowledge and Technology Transfer
LIDAR	Light Detection and Ranging
LOS	Level of Service
MOE	Measure of Effectiveness
mph	Miles per hour
NCHRP	National Cooperative Highway Research Program
NTCIP	National Transportation Communication ITS Protocol
RADAR	Radio Detecting and Ranging
RITA	Research and Innovative Technology Administration
RMS	Ramp Metering System
RWIS	Road Weather Information System
USDOT	United States Department of Transportation
VDS	Vehicle Detection Sensor
VII	Vehicle Infrastructure Integration

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APPENDIX C – Generic ICMS Needs

1 – Need to optimize the supply and demand for transportation services within the corridor. Operations need to manage the supply of services to match demand. Assessing the availability of service during periods of varying demand involves knowing about either permanent or non-permanent changes to service availability and methods to make additional services available on either a permanent or temporary basis. These services include mass transit services and motorist assist services.

1.1 – Need to share control of devices within a corridor – Operators within a corridor need to be able to share information from, and control of, ITS devices within a corridor in order to manage supply and demand for transportation services. Devices may include HOV/HOT lane controls, DMS, HAR, CCTV, VDS, and RWIS roadside equipment, and video switches in operations centers. Control sharing rules should be established through institutional agreements among the equipment owners in the corridor.

1.2 – Need to understand demand for transportation services – This includes evaluation of alternatives for responding to changes in demand whether temporary or long-term. This requires collection of information about the volume of people who are demanding their services and the origin and destination of their trips. This also requires collection of information about willingness of travelers to shift from one network or mode to another based on conditions or incentives.

1.2.1 – Need for corridor performance measures – Measures are needed to evaluate how well a corridor is operating.

1.2.2 – Need for impact assessment tools – Maintenance and operation departments need to assess the potential impact of actions under consideration. This can be an assessment of long-term or short-term changes. The tools need to consider both intra-network and cross-network effects to deliver the net effect on corridor operations.

1.2.2.1 – Need to collect information about performance and response of the transportation network. – Data needs to be stored in an accessible data structure so that it can be used by analytical and/or predictive processes that support other needs. The analytical tools will need both current and historical information for analysis.

1.2.2.1.1 – Need to collect and archive information from permanent data collection installations in the corridor. As current information is collected in the corridor, it should be archived in a location and format that is useable by the analysis, modeling, and simulation tools.

1.2.2.1.2 – Need to collect and archive information from temporary data collection installations in the corridor It may be too expensive to collect all information needed on a regular, current basis. Some information may need to be collected for a period of time and stored as "typical" or historical reference information. "Typical" information can be used in place of continuous instrumented information, and historical information can be used as a basis for comparison between past and current conditions.

1.2.2.1.3 – Need for current information – The ICMS and system operators need current information about conditions within the corridor. This information includes travel volumes on networks within the corridor, travel times on networks, location and effect of events that impact capacity, and a measure of unused capacity on each network within the corridor.

1.2.2.1.4 – Need to have quality physical infrastructure – The ITS components need to be reliable, available, maintainable (and well maintained), extensible, and interoperable.

1.2.2.2 – Need to have descriptive information about corridor infrastructure - Certain static information is needed by operators and systems in order to perform required tasks. This information may include geographic, geometric, descriptive, or restrictive information about the transportation infrastructure and the ITS infrastructure.

1.2.2.3 – Need to monitor the physical status of the ITS and transportation infrastructure – Operations and maintenance staff need to have information about the operational status of the infrastructure in order to plan maintenance and make decisions about which resources can be used in response to new conditions that may arise.

1.2.3 – Need to collect and process information in a timely manner – Information needs to be collected and processed within time frames consistent with the need for timely information. Processed information needs to be current enough for the system and operators to use as a basis for decisions and actions required to regulate and manage the transportation networks. Information must be current enough for transportation network users to make timely and appropriate decisions about time, route, and modes of travel.

1.2.3.1 – Need to have a quality information processing infrastructure – The ICMS sub-systems and components need to be reliable, available, maintainable (and well maintained), extensible, and interoperable.

1.2.3.2– Need to present understandable information – System operators and public users need information to be presented in formats that are easy to understand and relevant to the decisions that need to be made. This applies to visual and audio information presentation, use of appropriate contexts (map displays for geographic information, visual clues such as color, shape, blink) to convey states, and use of tabular and graph presentations to show relationships between parameters.

2 – Need for coordination with other corridor participants – To convey planned changes in operational status and to convey current near-real-time conditions.

2.1 – Need for transportation system operators and public safety organizations to coordinate – There is a need for coordination on a real-time basis for incidents requiring response by two or more organizations.

2.2 – Need for standard definition of customary actions – This identifies a set of pre-planned actions and the circumstances that would trigger those actions. This also implies shared access to the information required to identify the circumstances to the level necessary to establish which actions are required, and associated response information such as location.

2.3 – Need to have competent and well-trained staff – This applies to the proper operation and maintenance of systems, and training in interpreting the information provided and determining the most effective actions to take when circumstances require non-customary action.

3 - Need for communication with transportation network users. Operators need to communicate with users to let them know the existing conditions in the transportation network and what alternative travel modes are available. Active communication sends information to users: HAR, DMS, text messaging, email, etc. Passive communication makes information available but users must seek out the information: media outlets, traffic web sites, travel web sites, 511 systems.

APPENDIX D – ICMS Surveillance and Detection Needs

The following table lists the abstracted needs identified for ICMS Surveillance and Detection in the ICMS technical integration task [59].

ID	Abstracted Need	Reference
Needs related to general ICM characteristics		
SD-001	**Surveillance and detection in an ICMS should cover all networks.** Typical networks in an ICMS include freeways (including HOV, HOT, reversible, transit-only, and emergency vehicle-only lanes), arterial and other surface streets, and transit facilities (bus and rail); the junctions between them, including freeway on- and off-ramps; and associated facilities such as park-and-ride lots.	Implementation Guide [36] p 13 Generic ConOps [56] p 16, 19, 35 ICM Technical Systems Integration Focus Group
SD-002	**Surveillance and detection in an ICMS should cover all modes**. Modes in an ICMS will include autos, buses, and rail transit.	Generic ConOps [56] p 19, 35
SD-003	**Surveillance and detection in an ICMS should support integrated operational approaches by the agencies.**	ICM Approaches and Strategy [58] p 4 ICMS Requirements [57] p 14
SD-004	**Surveillance and detection in an ICMS should support real-time, automated data sharing between agencies.**	Implementation Guide [36] p 13, 27
Needs related to ICM approaches		
SD-005	**Surveillance and detection in an ICMS may support load balancing across the network to utilize any spare capacity.**	Generic ConOps [56] p 16 Implementation Guide [36] p 23
SD-006	**Surveillance and detection in an ICMS may support real-time route shifts.**	Generic ConOps [56] p 16 Implementation Guide [36] p 3, 23 ICM Technical Systems Integration Focus Group ICMS Requirements [57] p 14
SD-007	**Surveillance and detection in an ICMS may support real-time mode shifts.**	Generic ConOps [56] p 16 Implementation Guide [36] P 3, 23 ICMS Requirements [57] p 14

ID	Abstracted Need	Reference
Needs related to ICM strategies		
SD-008	**Surveillance and detection in an ICMS may support real-time travel demand management.**	Implementation Guide [36] p 3
SD-009	**Surveillance and detection in an ICMS may support the provision of a network-wide, real-time holistic view of the corridor for the traveler, both pre-trip and en-route.**	Generic ConOps [56] p 16, 19 Implementation Guide [36] p 23
SD-010	**Surveillance and detection in an ICMS may support network-wide, real-time traffic monitoring.**	Implementation Guide [36] p 3
SD-011	**Surveillance and detection in an ICMS may support the real-time monitoring of recurring and non-recurring congestion.**	Implementation Guide [36] p 3 ICM Transit Focus Group Meeting ICMS Requirements [57] p 14
SD-012	**Surveillance and detection in an ICMS may support network-wide, real-time response to incidents, events, and emergencies, including those caused by weather conditions.**	Generic ConOps [56] p 16, 19, 40, 43,55 Implementation Guide [36] p 3 ICM Transit Focus Group Meeting ICMS Requirements [57] p 14
SD-013	**Surveillance and detection in an ICMS should support efficient bus and rail transit operations.**	Generic ConOps [56] p 16, 19 Implementation Guide [36] p 23 ICM Transit Focus Group Meeting ICM Approaches and Strategy [58] p 7
SD-014	**Surveillance and detection in an ICMS should support the ease of use of bus and rail transit services, including associated facilities such as park-and-ride lots.**	Implementation Guide [36] p 23 Generic ConOps [56] p 19 ICM Approaches and Strategy [58] p 7

ID	Abstracted Need	Reference
SD-015	**Surveillance and detection in an ICMS may support network-wide, real-time transit system monitoring, including recognition of the different operating segments in the system, such as local versus express service.**	Generic ConOps [56] p 19, 40 Implementation Guide [36] p 3, 23 ICM Transit Focus Group Meeting ICMS Requirements [57] p 14
SD-016	**Surveillance and detection in an ICMS may support transit hub connection protection.**	Generic ConOps [56] p 16 Implementation Guide [36] p 23
SD-017	**Surveillance and detection in an ICMS may support transit priority and emergency vehicle pre-emption at traffic signals.**	Generic ConOps [56] p 16, 19 Implementation Guide [36] p 23 ICMS Requirements [57] p 14
SD-018	**Surveillance and detection in an ICMS may support network-wide, variable transportation pricing and payment strategies, including those affecting highways, transit services, and parking facilities.**	Implementation Guide [36] p 3, 23 ICMS Requirements [57] p 14
SD-019	**Surveillance and detection in an ICMS may support variable lane operations, such as reversible lanes, contra-flow systems, transit-only and emergency vehicle-only lanes, and use of shoulders as travel lanes.**	Implementation Guide [36] p 23 ICMS Requirements [57] p 14
SD-020	**Surveillance and detection in an ICMS may support the implementation of variable speed limits.**	Implementation Guide [36] p 23
SD-021	**Surveillance and detection in an ICMS may support the implementation of variable truck restrictions.**	Implementation Guide [36] p 23 ICMS Requirements [57] p 14
SD-022	**Surveillance and detection in an ICMS may support real-time special event management.**	Generic ConOps [56] p 37
SD-023	**Surveillance and detection in an ICMS may support the coordinated operation of ramp meters and arterial signal systems.**	Implementation Guide [36] p 23

ID	Abstracted Need	Reference
SD-024	**Surveillance and detection in an ICMS may support the coordinated operation of arterial signal systems and at-grade rail crossings.**	Implementation Guide [36] p 23
SD-025	**Surveillance and detection in an ICMS may support the ability to determine in real-time when operating conditions on any part of the network return to normal.**	ICMS Requirements [57] p 14
SD-026	**Surveillance and detection in an ICMS should support the utilization of corridor assets by multiple agencies, including the resolution of conflicting requests from agencies.**	Implementation Guide [36] p 23, 32
Needs related to data		
SD-027	**Surveillance and detection in an ICMS should provide the data types required for the various ICM operational approaches.**	ICM Approaches and Strategy [58] p 7 Implementation Guide [36] p 17 Generic ConOps [56] p 55 ICMS Requirements [57] p 14, 18 ICM Technical Systems Integration Focus Group
SD-028	**Surveillance and detection in an ICMS should support the provision of the required data in a consistent form to the agencies.**	ICM Approaches and Strategy [58] p 7 Implementation Guide [36] p 23 Generic ConOps [56] p 19
SD-029	**Surveillance and detection in an ICMS may support data archiving.**	ICM Technical Systems Integration Focus Group
SD-030	**Surveillance and detection in an ICMS may support the provision of required data to analysis, modeling, and simulation (AMS) activities.**	ICM Sample Data List p 4, 6 ICM AMS Methodology [2] p 3-2, 3-4
SD-031	**Surveillance and detection in an ICMS may support the provision of required data for performance measurement.**	Generic ConOps [56] p 16, 19, 72 Implementation Guide [36] p 16, 25 Analysis Modeling & Simulation Focus Group ICM AMS Methodology [2] p 3-4

APPENDIX E – ICM Data Needs

Data needs will vary based on the infrastructure within the corridor, the participating agencies, and the types of analysis, modeling, and decision support tools that are implemented. There is no strong consensus at this time about what data is actually needed from arterial systems for ICM implementation. The consensus is equally poor about what performance measures for arterial systems are critical for corridor management.

This is a new operational territory and it may well turn out that the data and performance measures for corridor operations are different from the traditional data and measures used for operation of arterial traffic signal systems.

Table 3 shows a comparison of data typically collected for modeling arterial systems, and the data that may be required for analysis, modeling, and decision support in corridor management systems.

Table 3 - Analysis, Modeling, and Decision Support Data Needs

	Beginning		End		Intersection		Mid Block		Source		Sink	
	Typical	**ICM**	**Typical**	**ICM**	**Typical**	**ICM**	**Typical**	**ICM**	**Typical**	**ICM**	**Typical**	**ICM**
Volume	M	M	M	M	M	M	E	E	M	M	M	M
Density	C	C	C	C	C	C	C	C	C	C	C	C
Speed	C	C	C	C	C	C	C	C	C	C	C	C
Classification	D	D	D	D	D	D	D	D	D	D	D	D
heading	E	E	E	E	E	E	E	E	E	E	E	E
Queue Length	C	C	C	C	C	C	C	C	D	D	D	D
O-D	E	E	E	E	E	E	E	E	E	E	E	E
Turns	N	N	N	N	M	M	N	N	M	M	M	M
Block Cap	C	C	C	C	C	C	C	C	C	C	C	C
Trip O-D	N	N	N	N	N	N	N	D/E	N	N	N	N
Tolling/Pricing	M	M	M	M	M	M	M	M	M	M	M	M
HC	E	E	E	E	E	E	E	E	E	E	E	E
Nox	E	E	E	E	E	E	E	E	E	E	E	E
PM	E	E	E	E	E	E	E	E	E	E	E	E
O3	E	E	E	E	E	E	E	E	E	E	E	E
Transit Route	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E
Transit Schedule	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E
Priority	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E	M/C/E
Transit Occupancy	M	M	M	M	M	M	M	M	M	M	M	M

D - Desirable Not Collected
M - Measured
C - Calculated
N - None
E - Extrapolated

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