USDOT Integrated Corridor Management (ICM) Initiative

ICM Surveillance and Detection Needs Analysis for the Transit Data Gap

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Integrated Corridor Management (ICM) Initiative

ICMS SURVEILLANCE AND DETECTION

NEEDS ANALYSIS FOR THE TRANSIT 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 transit 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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1 Introduction

The Integrated Corridor Management (ICM) Initiative is one of the ten major initiatives sponsored by the United States Department of Transportation (U.S. DOT) Research and Innovative Technology Administration (RITA). The primary objective of the ICM Initiative is to demonstrate how Intelligent Transportation Systems (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/workplan.htm.

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 ongoing 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 transportation 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 three 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.

Transit data is important to the successful implementation of an ICMS. During prior analysis tasks, specific transit data gaps have been identified. Management of traffic in a corridor depends on the acquisition of data about current conditions in the corridor, the capability to implement various management strategies which may include transit, and the AMS tools to support the evaluation and selection of strategies appropriate to the current conditions. Although parking availability may be a separate issue in some locations, for the purposes of this analysis, the availability of parking as it relates to transit usage will be included.

The objective of this task is to analyze the transit data gaps and to determine additional data needs to more accurately predict transit use patterns. This report analyzes the need for transit 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 transit data gap. The next step will be to define the requirements for the transit 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:

1. **Section 2** provides the concepts and context for ICM Transit Management and the ICMS capabilities required for supporting the concepts.
2. **Section 3** presents the results of the Needs Analysis for the Transit Data Gap.
3. **Section 4** describes an approach for stratifying the data requirements into three time horizons corresponding to the ICM objectives for Transit Management.
4. **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.
5. **Section 6** includes a review of approaches currently used or under development to collect transit data.
6. **Section 7** provides an overview of current efforts by pioneer sites and standards organizations to define transit performance measures.
7. **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.
8. **Appendix A** includes a list of acronyms and abbreviations used within this document.
9. **Appendix B** includes a list of the publications and reference documents for this analysis.

10 **Appendix C** lists the generic needs established for an ICMS.

11 **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 transit data which is needed to support an ICMS corridor. A basic understanding of the ICM concept and an ICMS is necessary in order to adequately analyze the transit 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:

1 Normal mode which constitutes all the actions taken to ensure that day-to-day transportation needs are addressed.
2 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 requires the corridor manager 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:

1. The physical level which includes all field components.
2. The information and sharing level which provides the tools and information systems that take the data from devices and transform the data into information that the transportation system operators can use to make operational decisions about the transportation networks.
3. 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 optimize corridor operations. While it is not possible to keep networks operating optimally all the time, continuous optimization is the overall goal. There are two major aspects in the discussion of an ICMS:

1. Operational needs
2. 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:

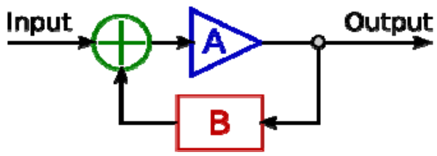
1. Freeway roadway network
2. Arterial roadway network
3. Bus transit network
4. Rail transit network
5. Toll roadway network
6. Ferry network

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).

Optimization therefore implies:

1.



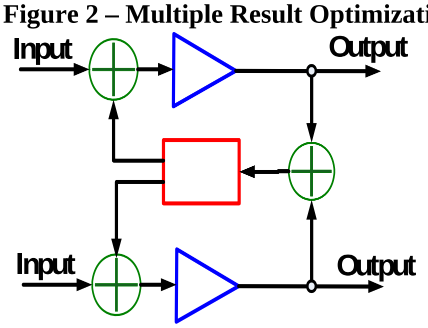
1) The desired performance of the system can be described based on measurable outputs of the system.

Figure 1 – Simple Feedback Optimization

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.

Figure 2 – Multiple Result Optimization



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 at the expense of a two dollar decrease in transit or 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 both outputs, 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.

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 daily operations and record keeping. Often, more baseline information is required for modeling than for daily operations. Modeling and decision support for transit network optimization will require a finer granularity of data than what is needed for simple operational purposes.

This analysis will focus on:

1. performance measures for transit management and the data required to calculate these performance measures;
2. data required for AMS systems to evaluate corridor performance relating to transit systems;
3. data required to assess the impact of strategies and corridor control measures on the performance of transit systems; and
4. data acquisition capabilities which are currently available for monitoring transit systems.

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:

1. The ICMS Concept of Operations for a Generic Corridor [31]
2. The ICMS Foundational Research on Corridor Management Strategies [20]
3. The ICMS Surveillance and Detection Needs Analysis [29]
4. The ICMS Concept of Operations documents from each pioneer site [7, 10, 23, 26, 37, 40, 43]
5. The ICMS System Requirements Specifications from each pioneer site [6, 11, 22, 27, 36, 39, 44]
6. The Traffic Control Systems Handbook [15]

3.1 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 transit data:

1. 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 [29]. These detailed needs were summarized as:

2. Needs related to general ICM characteristics
3. Needs related to ICM approaches
4. Needs related to ICM strategies
5. 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.

3.2 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:

Freeway/Tollway Monitoring:

6. Road segment speed (average vehicle distance traveled/time unit) – sampled at 30-120 second intervals, with date/time stamp
7. Road segment volume (vehicles/time unit) – sampled at 30-120 second intervals, with date/time stamp
8. Road segment occupancy (% of unit length lane occupied by vehicles) – sampled at 30-120 second intervals, with date/time stamp

Transit Monitoring:

1. Volume (passengers/route leg) – by time of day and day of week, sampled at each stop, but reported at end of day
2. Fare collected/route leg – by time of day and day of week, sampled at each stop, but reported at end of day
3. Schedule adherence (difference between vehicle actual arrival/departure vs. scheduled arrival/departure) – current and daily summary/route, sampled at 30-300 second intervals, with date/time stamp
4. Vehicle location (with varying degrees of accuracy and update times), sampled at 30-300 second intervals, with date/time stamp

Parking Management Monitoring:

1. Volume (number of vehicles using the parking facility) – current and daily total, sampled as vehicles enter or leave facility, reported daily as either hourly or daily volume
2. Parking spaces remaining – current, sampled as vehicles enter or leave facility, reported daily as hourly and daily counts. In some cases, the current data is displayed at the entrance to the lot.

Arterial Monitoring:

1. Call (vehicle/pedestrian presence) – sampled 0.1 to 0.01 seconds, rarely reported to a central server
2. Volume (number of vehicles passing a point on the roadway during a specified time period) – sampled 0.1 to 0.01 seconds, typically reported as 5 minute summary and archived as hourly totals by time of day
3. Road segment occupancy (percent of time that a point on the roadway is occupied by a vehicle) – sampled 0.1 to 0.01 seconds, most systems report current average per unit time
4. Road segment speed (distance traveled by a vehicle per unit time) – sampled 0.1 to 0.01 seconds, typically reported as 5 minute average
5. Queue length (number of vehicles stopped in a lane behind the stop line at a traffic signal) – sampled 0.1 to 0.01 seconds, typically reported as 5 minute average

6 Headway (time difference between beginning of successive vehicle detections) – sampled 0.1 to 0.01 seconds, typically reported as 5 minute 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 and queue length for the primary control parameters.

It is significant that the latency (time between data sampling and data reporting) differs substantially across current data collection systems. The difference ranges from seconds on freeway networks, to minutes on arterial networks, to daily in the case of some transit network and parking lot data.

It is problematic that some of the data is reported without time/date stamps that would permit the data to be aligned with other information sources for analysis. Problems are also introduced where observations are sampled at one rate and reported as “rolled-up” averages or totals over much longer periods of time. While this practice may save communication or storage costs, it considerably limits the usefulness of the resulting data.

4 Operational Objectives for Transit 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:

1. Demand management
2. Load balancing
3. Event response
4. 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:

1. Current (a.k.a. 'real-time')
2. Planned Event (including pre-planning for emergencies and disasters)
3. 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 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, transit agency operators can respond to unplanned events by making appropriate route changes in order to maintain transit schedules. Depending on the nature, timing, and expected duration of the unplanned event, transit agency operators may be able to coordinate with transportation managers and direct drivers to change modes. In order to affect a mode change, drivers would need to know parking and transit availability. It has been noted that drivers may be more open to mode shift on the initial portion of their trip (i.e., drivers are more likely to shift to transit during the AM peak than the PM peak). This is possibly due to the concern of how and when the driver can get back to where his or her car is parked.

Transit managers have indicated that real-time capacity data may not add significant value to the transit operation. Several reasons were given for this view.

1 First, most transit vehicles are equipped with radio and/or mobile data terminals through which an operator could report a "full vehicle." In some places, parking lot attendants make similar reports by radio when lines at their stop become substantial. Transit management would be able to determine if an additional vehicle and driver were available to add to the route.

2 Second, many transit agencies have limited spare vehicles and drivers.

3 Finally, the amount of time needed to get an additional vehicle to a specific route may be too long to have an effective impact.

Although the lack of additional operators (or drivers) applies to both rail and bus systems, rail systems can often add spare rail cars to current trains to form consists without adding operators (though Federal Railroad Administration rules and union contracts can impose limits on adding cars). This brings into play an additional limitation: rail consists can only be as long as the shortest platforms on the run and cars can only be added at yard locations where the cars are stored. Even with these limitations, rail transit has a significant advantage for meeting increased demand. An additional operator is not necessarily required for more capacity, and rail cars typically have more capacity than a bus.

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.

1 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.

2 Transit agencies may respond by providing more high occupancy vehicles and lower cost parking and shuttles to and from satellite parking locations.

3 In order to add additional capacity, transit agencies may need to schedule and pay overtime to transit vehicle operators.

4 Public safety agencies and road maintenance agencies may need to assist during the event with the reconfiguration of roadways.

4.3 Long-Term Planning and Construction

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 allows for the building of new roadways, 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.

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:

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

The response strategies also have common threads:

1 Information sharing/distribution
   - Coordinate responses to reduce the impact of events on system capacity.
   - Allow traveling public and trip planners to select alternative routes, schedules, and modes of travel based on current or anticipated travel conditions.
   - Share information on transit service regarding incidents, service status, vehicle location, and transit schedules.

2 Improvement of operational efficiency of network junctions & interfaces
   - Signal priority for transit – Give 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 – Optimize existing capacity for enhanced public safety.
   - Multimodal electronic payment – Decrease 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 – Reduce the impact of

events on existing system capacity.

- Coordinate 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.
- Coordinate 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.

3 Accommodation/Promotion of cross-network route and modal shifts

- 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.
- 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 arterial – 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.

4 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, tollway, 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.

5 Management of capacity

- 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.
- 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.
- 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 transit management focuses on obtaining data for person capacity and schedule adherence, it is becoming increasingly apparent that ICMS deployments will be more focused and dependent on 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 transit capacity monitoring is critical to the strategy:

1 **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 capacity data for both transit vehicles and the associated parking facilities, archive this data, and use AMS analysis of the historical data to calculate the remaining un-used capacity within the system.

2 **Improvement of operational efficiency of network junctions & interfaces** – Coordinated operation between freeways, tollways, HOV lanes, arterial roadways, and transit facilities will only be possible if real-time transit capacity and history-based capacity measures are available. This data can be used to give transit vehicles priority if the vehicle is behind schedule and to provide transit hub connection protection. Multimodal electronic payment of HOV, transit, and parking will also improve the efficiency of the network junctions and encourage

commuters to make better transportation choices.

3 **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;
   - non-peak travel periods; or
   - other travel modes.

   This capability will be dependent on the availability of transit and parking capacity and transit vehicle location data at the ICMS to use for modeling and to compare with historical data. This capability is also dependent on the ability to modify transit priority parameters to accommodate a modal shift.

4 **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. This will be used to reroute transit vehicles when necessary. In addition, it is necessary to disseminate pre-trip and en-route traveler information to promote network shifts.

5 **Management of capacity –** Management of capacity is concerned with providing enough capacity to meet demand. Adjusting transit capacity is dependent on the ability to add transit vehicles, adjust headways, modify schedules, or implement lane controls. The use of transit-only lanes, the road shoulder, and signal priority can increase the capacity. Transit capacity can be affected by parking capacity. Strategies to increase parking capacity, such as temporary lots and shuttles, can assist in increasing the transit capacity.

5.3 Pioneer Site Techniques

The pioneer sites identified collection of transit data as an important element of their planning. All of the pioneer sites have some transit vehicles with Automatic Vehicle Location (AVL). Most of the sites have, or are planning to have, complete AVL coverage on all transit vehicles. Several sites have bandwidth or other communication limitations that restrict how much and how often data can be collected from the transit vehicles. Vehicle location data on rail transit is not necessarily acquired using global positioning equipment as is done on bus transit. Several of the rail transit systems rely on sensors that detect when a vehicle passes a monitored location along the railway.

The AVL data is used to determine speed and schedule adherence. All of the sites have implemented Automatic Passenger Counters (APC) and are using the data to determine ridership and available capacity (although not in real-time). Most of the pioneer sites collect APC data at the end of the day.

The sites identified a need for multimodal electronic payment for tolls, parking, and transit. At this time, multimodal electronic payment is used primarily for the benefit of the consumer. Some agencies use electronic payment data for determining or validating ridership statistics. Most of the pioneer sites collect payment data at the end of the day.

Most of the sites plan to collect transit data by expanding the transit AVL capability, in order to determine travel time and schedule adherence. Many of the sites indicated a need for parking lot utilization information and the ability to provide the information to the traveling public.

Three of the sites specifically outlined transit performance requirements. These performance requirements included overall system performance measures such as the quality of service from the passenger's point of view and route level performance measures. Route level performance measures include travel time, trip mileage, wait time, dwell time, speed, and passenger load. Most of the sites plan to monitor delays and schedule adherence, though these were not specifically cited as transit performance measures.

All of the sites had at least one strategy to improve the efficiency of network junctions. Two sites indicated that the data would also be used to coordinate transit priority between vehicles and signal systems.

Some of the sites had implemented Automatic Passenger Counters on some of the transit vehicles. However, the data from these devices appeared to be used for historical purposes.

Several sites indicated that en-route mode shifting is not feasible at present. Vehicle operators are the primary information source for passengers, but operators lack the necessary information to compare travel times between the modes and to determine availability of parking. This represents two problems: getting the right information to travelers in a timely manner, and being able to analyze and predict sudden increases in passenger demand quick enough to make an effective response. Transit vehicle operator observations alone may not be enough to allow transit agencies to act in time to accommodate a sudden increase in demand.

The sites have found that mode shifting for planned events is feasible and transit providers are able to accommodate the extra capacity demand with pre-planning. 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. Many of the sites indicate that congestion data is used internally to determine the need to modify transit routes due to an incident.

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. 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 using signal priority. No mention was given to monitoring the operational status of the transit vehicles. For example, an empty bus dead-heading to the start of a route or a bus headed to a timed transfer point might merit additional consideration for signal priority.

6 Transit Data Gathering Approaches

6.1 Standard Transit Data Gathering Approaches

In the past, the standard transit data gathering approach was the driver reporting to a dispatcher via a radio system. The driver was the eyes and ears of the transit agency and could report his current location, current capacity, and any additional required information. This method allowed the transit dispatch center to have current information but did not provide for the retention of historical data for analysis and modeling.

Today, many transit agencies have equipped their vehicles with AVL technology. Most transit agencies are using AVL based on global-positioning satellites. Some rail transit systems still depend on sensors that report when vehicles pass certain locations within the rail network.

The global-positioning data can provide the timestamp, location, speed, and direction of travel of the vehicles each time the data is reported. Reporting frequency varies from agency to agency and ranges from 30 seconds to 5 minutes. In most systems, the data is not only available for current operations but is also archived for planning. This data allows the transit agency to maintain schedules. Based on the positions reported, vehicle travel times can be calculated. The computerization allows the agency to address vehicle failures, monitor schedule and route adherence, and can also be used to trigger specific automatic audio and visual announcements on the vehicle.

About 10% of the vehicles in a transit fleet are typically equipped with Automatic Passenger Counters which count the number of passengers getting on and off the bus/train at each stop. Some fleets are moving to 100% coverage of their fleet, but this is more the exception than the norm at this time. APC data is typically downloaded to a server at the end of each day, and is not usually available while the vehicle is in operation.

Transit operators are also interested in parking lot utilization at or near transit routes. Current techniques for monitoring parking availability vary widely.

Many agencies own and operate their own park-and-ride facilities. Some park-and-ride lots are provided and maintained by the Department of Transportation (DOT) at major interchanges. Many of these lots are an asphalt or gravel parking area and parking is free. These lots may be monitored for safety by local law enforcement but the available capacity is typically unmonitored. In some municipalities, commuters are able to park at shopping centers. These lots are generally private property and there is no distinction between commuter and shopper usage.

In major metropolitan areas, parking garages and controlled-access lots are available for transit riders. These parking facilities are located near the transit stops. The operations of these lots may be contracted to a parking management company. Many of these facilities are monitored electronically and data is available to the parking management company about the parking space availability. The parking management company may provide the data to the transit agency.

Incidents involving transit vehicles are usually reported to dispatch using mobile radio.

Other incidents in the corridor that might affect transit schedules or routes are usually discovered and reported when the vehicles encounter the problem area. Major construction detours and event planning are usually coordinated in advance. However, transit operators are not always aware of minor road maintenance which may impact the transit vehicle's ability to remain on schedule.

6.2 Emerging Approaches for Transit Data Gathering

An emerging approach for transit data gathering is the use of Mobile Data Terminals (MDT). Depending on the transit agency, the functions of the MDT include some or all of the following:

1. Download driver manifest
2. Collect data on driver actions
3. Record passenger counts both boarding and alighting
4. Provide security alarm and retention of buffered video
5. Collect route and schedule adherence data
6. Collect vehicle location data
7. Provide automatic visual and audio announcements
8. Collect fare data
9. Provide messaging between dispatch and vehicle

In the case of paratransit vehicles, data on assistive devices, attendants, and companions may also be gathered. While some agencies may have the communication infrastructure to transmit the information while the vehicle is on route, many agencies upload the data when the vehicle returns to the garage at the end of the day. The data collected can be analyzed to determine schedule adherence, passenger wait time, passenger crowding, speed and delay analysis, and passenger load. The results allow transit management to observe trends and make modifications to optimize the transit system.

Some transit agencies have started deploying a wireless infrastructure and thus providing Wi-Fi access for riders as a method to boost ridership. Wi-Fi is used for data transmission between buses and the transit management center both en-route (at stops) and at the end of the day.

Some agencies are using vehicle area networks to provide connectivity between vehicle devices and applications. The data gathered is used to improve both safety and efficiency. The system supports video surveillance and allows a bus operator to stream video to public safety when needed. The network also gathers maintenance-related data which can help improve the efficiency of the vehicle.

Several critical trends are also emerging regarding how transit information is provided to the public. These strategies involve trip planning, next transit vehicle arrival information, and parking information.

Most agencies have (or are currently planning) web sites that provide fare, schedule, and route information. This is supplemented with trip planning software that allows the traveler to enter starting location, destination, and desired departure or time of arrival. The system will then process the information supplied by the traveler and provide driving, parking, transit route, and walking directions for the requested trip.

Arrival times for transit vehicles are being posted on signs at stops, and next stop and arrival times are posted and announced on the vehicles. Several transit agencies are also providing the next arrival time information on web sites or making the information available through text messages or cellular telephone-based information services.

Sites are also providing more information about the locations, cost, and availability of parking at park-and-ride facilities through their web sites. In a few cases, message signs along freeways or major arterial routes are being used to remind drivers of the park-and-ride option, direct them to parking lots, and give active counts of parking spaces remaining at the nearest lot.

6.3 Potential/Future Approaches

Currently transit management relies on statistical information to determine the scheduling of transit vehicles. Any need for additional vehicles is determined by the vehicle operator from observation of the passenger load on the vehicle and the number of waiting passengers at the transit stops. If there is a major incident within the ICM corridor which requires a mode shift by travelers, the availability of current transit data is important to the determination of the unused capacity within the ICMS. This data includes:

1. Current passenger counts which would allow the transit managers to determine where additional resources are needed to assist in handling increased transit load.
2. Real-time parking availability data so that travelers could be directed to transit locations with available parking capacity.
3. Transit data during the incident time which allows the transit managers the ability to determine how long the additional resources need to be available.

In addition, the use of real-time data from transit vehicles and the waiting passenger count data from transit stops is one potential approach which could be used to improve the overall performance of the ICMS. The data could be used by the transit agency to proactively assign additional resources so that the capacity of the transit system is maintained. There has been some consideration given to using ridership data to determine if transit vehicles would receive signal priority. The rationale is that the more passengers there are on a vehicle, the more justification there is for giving the vehicle signal priority.

Many transit agencies do not provide the traveler with real-time transit information such as travel times and incident information. The ability to provide this information to the public so that the modes could be compared would encourage mode shifting and improve transit utilization thereby increasing the ICMS performance.

Advanced Parking Management Systems, also known as Intelligent Parking Systems (IPS), are a potential approach to answer the demand for real-time parking information. These systems can provide en-route information to travelers and allow available parking to be found quickly and safely. The systems will become more important as parking facilities at high density areas such as airports, transit stations, and business districts become full due to high demand. These systems use vehicle detectors, ticket splitters, electronic payment, and/or cash registers to detect vehicle entry or departure. This data is then combined with pre-defined information about the parking location, such as total number of parking spaces, number of reserved spaces, etc., to determine the current unused capacity. The resulting parking status is then communicated to the public via signage, Highway Advisory Radio/Traffic Advisory Radio, public media (radio and/or television traffic reports), or the Internet. Some parking management systems also provide the traveler a way to reserve and pre-pay for a parking spot via the Internet.

Transit agencies within the Pioneer Sites have requested real-time data relating to incidents within the corridor. This information will be used to assess potential impacts of the incidents on scheduled routes and paratransit dispatches.

6.4 Summary of Data Gathering Approaches

The data gathering approaches for transit data are fairly well established. Improvements to the approaches have been developed so that more data is automatically collected and available for analysis. The data gathered is used to improve the safety and efficiency of the transit system. In general the data gathered from transit agencies and parking lot management companies is currently available within those venues. Within the ICM corridor, the integration of this data could be used to improve the performance of the ICMS.

7 Transit Data Types and Performance Measures

7.1 *Overview of Transit Performance Measures*

Transit performance measures can be divided into two categories: quantitative and qualitative. The quantitative category elements are typically measured on a route basis. These include:

1. Number of passengers per vehicle mile
2. Number of passengers per revenue hour
3. Speed
4. Travel time
5. Passenger/Platform wait time
6. Schedule adherence
7. Headway regularity
8. Cost per passenger
9. Cost per revenue mile
10. Cost per revenue hour

The qualitative category reflects systemwide performance and includes:

1. Quality of service from the consumer's point of view
2. Effectiveness of routing
3. Effectiveness of scheduling

The consumer's view of the quality of service is dependent upon the convenience of the routes and schedules, the availability of parking, comfort, speed, safety, and reliability of the system.

Other transit performance measures also exist. The additional measures are related to region-specific issues such as source of funding, employment opportunities, mobility service requirements, and regional policies.

7.2 *Pioneer Site Performance Measures*

Many of the pioneer sites expressed a need for the ability to provide travelers with enough information to compare travel times between freeways, arterials, and transit as a means to promote mode shift and improve the performance of the ICMS. In order for a mode shift to occur, there needs to be unused transit and associated parking capacity which is readily available to the traveler so that the destination can be reached in a reasonable length of time. Transit performance measures which were identified to assist with this were:

1. Transit vehicle schedule adherence
2. Transit vehicle speed/travel time
3. Transit vehicle capacity which is sometimes referred to as "Passenger Crowding."
4. Parking space utilization/availability

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 the participating networks. The following surveillance and detection capabilities as defined in Section 3.2 are needed to calculate the improvement:

1. Freeway and tollway monitoring
2. Transit monitoring
3. Arterial monitoring

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

1. Travel time including mean, maximum, buffer, and range
2. Vehicle speed
3. Travel delay time and predictability
4. Incident duration and frequency
5. Fuel consumption savings
6. Pollutant emissions savings

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

7. Transit speed based on transit vehicle AVL data
8. Transit capacity based on APC data
9. Transit frequency
    - Number of passengers per route
    - Number of passengers per service type
10. Transit route performance
    - Travel time
    - Trip mileage
    - Passenger/Platform wait time
    - Dwell time
    - Number of passengers per mile
    - Average passenger load
11. Schedule adherence
12. Parking lot utilization

7.3 Performance Measures for ICMS

Performance measures figure heavily in the design and expansion of transit systems. Most transit 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 and operator salaries. 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/procurement for equivalent capacity works for comparing multiple transportation modes.

Incremental cost of construction/procurement does not work for real-time management or event planning. This difference between construction/procurement planning and operational planning establishes a time-event horizon between construction/procurement 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. Real-time responses do not usually result in changes to existing transportation mode capacities.

Real-time responses to incidents call for messages on existing Dynamic Message Signs and Highway Advisory Radio, as well as information broadcasts to the public through the media, text messaging, and the Internet. The responses may require lanes or entire roadways to be closed. In the case of incidents involving transit, schedules may be disrupted or routes altered or 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:

1 Transit vehicles can be added to and/or diverted from established routes to expand transit capacity between desired locations.
2 Transit vehicles can be given dedicated lanes or rights-of-way.
3 Temporary parking areas can be opened to facilitate additional transit utilization.
4 Event related timing plans can be implemented on arterial signal systems.
5 Intersections can be closed and detour routes established to modify conventional traffic patterns.
6 Lanes or whole roadways can be closed and detour routes established.
7 Lanes or roadways can be blocked and put into contra-flow operation to expand capacity in desired directions.
8 Portable Dynamic Message Signs and 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 the following information:

1. Data about each transit vehicle including capacity and amenities
2. Data about each route, run, stop, schedule, and payment option
3. Data about each parking lot including capacity, location, fees, and associated transit stops
4. Current information associating each operational vehicle with an assigned run, route, and schedule
5. Current information about each in-service transit vehicle – location (30 second reporting desired, 60 second reporting acceptable) and current passenger count (reported after each pull-out preferred, reported at 60 second intervals acceptable)
6. Current information about each parking lot – either current utilization or current un-utilized capacity (60 second reporting desired, 5 minute reporting acceptable)

In order to "reduce or avoid capacity overloading" it is necessary to know the capacity of the system, the current utilization of the system, and the overload point. Without knowing the current utilization of transit vehicles and parking lots, predicting capacity overloading before it happens is not easy. The key to an effective strategy is having timely information that will facilitate a timely response.

All of the pioneer sites have (or can obtain) the data listed above.

Of the eight sites, only San Antonio indicated that information about current parking availability would not be available to the ICMS. Three sites indicated they would estimate occupancy of parking lots and four sites indicated they would calculate the number of available parking spaces. Five of the sites indicated plans for disseminating parking information.

Only Montgomery County indicated that they plan to have current passenger counts for the ICMS. Three of the sites (Dallas, Oakland, and Minnesota) indicated that they plan to have estimated passenger counts (based on historical data).

8 Summary of Transit Data Gaps

8.1 Data Needs

The ICM transit data needs can be summarized as follows:

7 Data about each transit vehicle including capacity and amenities

8 Data about each route, run, stop, schedule, and payment option

9 Data about each parking lot including capacity, location, fees, and associated transit stops

10 Current information associating each operational vehicle with an assigned run, route, and schedule

11 Current information about each in-service transit vehicle – location (30 second reporting desired, 60 second reporting acceptable) and current passenger count (reported after each pull-out preferred, reported at 60 second intervals acceptable)

12 Current information about each parking lot – either current utilization or current un-utilized capacity (60 second reporting desired, 5 minute reporting acceptable)

8.2 Data Gaps

None of the pioneer sites indicated any gaps in acquiring the data for their transit networks. All of the sites reported one or more gaps in observational data (e.g., current passenger counts, current un-utilized parking capacity, or transit vehicle locations).

The root causes of transit surveillance and detection data gaps can be described in three broad categories:

1. Data that is not available in a timely manner
2. Data that is not currently collected
3. Data that is not available due to institutional (data ownership) or technical reasons (systems cannot support automated data exchange)

The following information gaps have been identified:

1 Current passenger count data may not be available fleet-wide or on a timely basis.

- Ridership data (whether manually or electronically gathered) may not be available until after the vehicle has completed its daily runs.
- APC may only be implemented on selected in-service vehicles.
- Some rail transit systems count passengers entering the platform area for departure, but do not associate this data with the time or vehicle the passengers board.
- Some rail transit systems do not count how many arriving passengers leave the platform or do not associate this data with the time or vehicle providing the service.

2. Current vehicle location data may not be available fleet-wide or on a timely basis.
   - AVL may only be implemented on selected in-service vehicles.
   - Location and schedule adherence information reported by vehicle operators may not be entered into transit data systems as it is received, or archived for future use.
   - Bandwidth or other communication limitations may restrict how frequently vehicle location data is reported.
   - Rail transit systems may only report vehicle locations as the vehicles pass specific points in the network.
3. Parking facility utilization data may not be available on a timely basis.
   - Parking facilities may be owned or operated by organizations that do not report utilization data.
   - Parking facilities may not be equipped to record or report utilization data.
4. Institutional issues affect the availability of the gathered data as that data may be owned by another business entity.
5. Transit data systems may not support automated transferring and sharing of data with other systems.
6. Transit data systems may not support the automated receipt of data from other systems which affects the dissemination of incident information to the transit vehicles.

8.3 Other Limiting Factors

Even if the above technical and institutional issues are resolved and all of the required data is available in a timely manner, there are still major concerns about how effectively transit networks can respond to unanticipated changes in the corridor transportation situation. Short-term responses (four hours or less) are difficult because of the time and labor required to add or re-allocate vehicles within the network.

Adding short-term capacity is not easy. While each transit network has spare vehicles, the number of spare vehicles usually represents a small percentage of the total network capacity, and these “spare vehicles” often include vehicles that are in, or awaiting, shop maintenance or repairs. Operators are not always available on short notice for additional vehicles. While additional vehicles can be added to rail transit runs without adding operators, the total number of vehicles in such a consist is limited by the length of the shortest platform at the stops along the run. Trains powered by electric propulsion may be limited in length due to power traction issues. Union rules for train operators may also limit the train car length.

Longer term changes (days to weeks) are somewhat easier to accommodate since arrangements can be made for additional operators and vehicles can be pre-positioned. Responses can still be constrained by limitations associated with vehicle availability (how much additional capacity is available), route availability (especially on rail routes that are shared with other carriers), and parking availability.

8.4 Conclusion

It is possible, though expensive, to obtain all of the required surveillance and detection data required using currently available technology. Mobile data communications with transit vehicles appears to be a key limiting factor in acquiring desired transit vehicle location and passenger count data. The cost of implementing systems to track parking lot utilization appears to be the limiting factor in acquiring the desired parking utilization data.

Transit agencies are reluctant to invest in the necessary technology to collect current passenger data from transit vehicles. Many agencies indicate that their ability to respond to short-term situations is so limited that there is no value to having up-to-the-minute data versus daily data dumps.

There is more interest in acquiring vehicle location and lot utilization data in real-time since this information is seen as useful for encouraging travelers to switch to transit as a preferred mode of travel.

APPENDIX A – Acronyms

AMS	Analysis, Modeling, and Simulation
APC	Automatic Passenger Counter
AVL	Automatic Vehicle Location
CCTV	Closed-circuit Television
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
DMS	Dynamic Message Sign
DOT	Department of Transportation
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
IPS	Intelligent Parking Systems
ITS	Intelligent Transportation Systems
KTT	Knowledge and Technology Transfer
MDT	Mobile Data Terminal
NCHRP	National Cooperative Highway Research Program
RITA	Research and Innovative Technology Administration
RWIS	Road Weather Information System
U.S. DOT	United States Department of Transportation
VDS	Vehicle Detection Sensor

1)

APPENDIX B – Bibliography

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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 usable 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 timeframes 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, e-mail, 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 [29].

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 Guidance [32] p 13 Generic ConOps [31] 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 [31] p 19, 35
SD-003	**Surveillance and detection in an ICMS should support integrated operational approaches by the agencies.**	ICM Approaches and Strategy [20] p 4 ICMS Requirements [19] p 14
SD-004	**Surveillance and detection in an ICMS should support real-time, automated data sharing between agencies.**	Implementation Guidance [32] 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 [31] p 16 Implementation Guidance [32] p 23
SD-006	**Surveillance and detection in an ICMS may support real-time route shifts.**	Generic ConOps [31] p 16 Implementation Guidance [32] p 3, 23 ICM Technical Systems Integration Focus Group ICMS Requirements [19] p 14
SD-007	**Surveillance and detection in an ICMS may support real-time mode shifts.**	Generic ConOps [31] p 16 Implementation Guidance [32] p 3, 23 ICMS Requirements [19] p 14
Needs related to ICM strategies		
SD-008	**Surveillance and detection in an ICMS may support real-time travel demand management.**	Implementation Guidance [32] 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 [31] p 16, 19 Implementation Guidance [32] p 23
SD-010	**Surveillance and detection in an ICMS may support**	Implementation Guidance

	network-wide, real-time traffic monitoring.	[32] p 3
SD-011	**Surveillance and detection in an ICMS may support the real-time monitoring of recurring and non-recurring congestion.**	Implementation Guidance [32] p 3 ICM Transit Focus Group Meeting ICMS Requirements [19] 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 [31] p 16, 19, 40, 43,55 Implementation Guidance [32] p 3 ICM Transit Focus Group Meeting; ICMS Requirements [19] p 14
SD-013	**Surveillance and detection in an ICMS should support efficient bus and rail transit operations.**	Generic ConOps [31] p 16, 19 Implementation Guidance [32] p 23 ICM Transit Focus Group Meeting ICM Approaches and Strategy [20] 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 Guidance [32] p 23 Generic ConOps [31] p 19 ICM Approaches and Strategy [1] p 7
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 [31] p 19, 40 Implementation Guidance [32] p 3, 23 ICM Transit Focus Group Meeting ICMS Requirements [19] p 14
SD-016	**Surveillance and detection in an ICMS may support transit hub connection protection.**	Generic ConOps [31] p 16 Implementation Guidance [32] p 23
SD-017	**Surveillance and detection in an ICMS may support transit priority and emergency vehicle pre-emption at traffic signals.**	Generic ConOps [31] p 16, 19 Implementation Guidance [32] p 23 ICMS Requirements [19] 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 Guidance [32] p 3, 23 ICMS Requirements [19] 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 Guidance [32] p 23 ICMS Requirements [19] p 14
SD-020	**Surveillance and detection in an ICMS may support the implementation of variable speed limits.**	Implementation Guidance [32] p 23
SD-021	**Surveillance and detection in an ICMS may support the implementation of variable truck restrictions.**	Implementation Guidance [32] p 23 ICMS Requirements [19] p 14
SD-022	**Surveillance and detection in an ICMS may support real-time special event management.**	Generic ConOps [31] p 37
SD-023	**Surveillance and detection in an ICMS may support the coordinated operation of ramp meters and arterial signal systems.**	Implementation Guidance [32] p 23
SD-024	**Surveillance and detection in an ICMS may support the coordinated operation of arterial signal systems and at-grade rail crossings.**	Implementation Guidance [32] 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 [19] 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 Guidance [32] 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 [20] p 7 Implementation Guidance [32] p 17 Generic ConOps [31] p 55 ICMS Requirements [19] p 14, 18 ICM Technical Systems Integration Focus Group ICM Approaches and Strategy [45] p 7
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 [20] p 7 Implementation Guidance [32] p 23 Generic ConOps [31] 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 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 [31] p 16, 19, 72 Implementation Guidance [32] p 16, 25 Analysis Modeling & Simulation Focus Group ICM AMS Methodology [1] p 3-4

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