U.S. Department of Transportation
Federal Highway Administration

INTEGRATED CORRIDOR MANAGEMENT, TRANSIT, AND MOBILITY ON DEMAND


NOTICE

QUALITY ASSURANCE STATEMENT

Cover photo: Number 5 bus with bike rack by Fotolia; Ride KC van by Bridj; man in wheel chair by Fotolia; "Big Blue" bus, and people entering light rail car by FHWA; red transit bus by Bridj.

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16. Abstract This primer examines how both public transportation and mobility on demand (MOD) can be incorporated into an integrated corridor management (ICM) approach. It also defines the needs for including public transportation and mod stakeholders in ICM. Additionally, it explores opportunities to effectively integrate transit and other emerging modes of public transportation on institutional, operational, and technical levels. Finally, it also identifies several major challenges to integration, along with potential solutions.The primer also provides real world examples of transit and MOD strategies and services incorporated within the ICM approach.		
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ACRONYMS

AMS	analysis, modeling, and simulation
APTA	American Public Transportation Association
AVL	automated vehicle location (system)
BART	Bay Area Rapid Transit
BRT	bus rapid transit
Caltrans	California Department of Transportation
ConOps	concept of operations
CTA	Chicago Transit Authority
DOT	department of transportation
DART	Dallas Area Rapid Transit
DMS	dynamic message sign
DSS	decision support system
FHWA	Federal Highway Administration
GIS	geographic information systems
HOV	high-occupancy vehicle
ICM	integrated corridor management
ITS	intelligent transportation systems
MMITSS	multi-modal intelligent traffic signal system
MOD	mobility on demand
MPO	metropolitan planning organization
MSAA	Mobility Services for All Americans
MTS	Metropolitan Transit System
MUTCD	Manual on Uniform Traffic Control Devices
SANDAG	San Diego Association of Governments
TMCC	travel management coordination center
TSM&O	transportation systems management and operations
TSP	transit signal priority
USDOT	United States Department of Transporation

INTRODUCTION

In today's urban transportation corridors, each transportation agency within the corridor typically handles operations independently. While the operators may collaborate or interact to some extent to deal with incidents or pre-planned events, each agency conducts most day-to-day operations individually. As congestion and the number of incidents have increased, this method of operations has become less effective in meeting the transportation needs of the businesses and people that rely upon the corridor. The Federal Highway Administration (FHWA) **integrated corridor management (ICM) program plan** defines ICM as "the coordination of individual network operations between adjacent facilities that creates an interconnected system capable of cross-network travel management." A transportation **corridor** is defined as "a combination of discrete, adjacent surface transportation networks (e.g., freeway, arterial, transit networks) that link the same major origins and destinations. It is defined operationally rather than geographically or organizationally."[1] The vision for ICM is that transportation networks will realize significant improvements in the **efficient movement of people** and goods through the integrated, proactive management of existing infrastructure along major corridors. Through an ICM approach, transportation professionals **manage the corridor as a multimodal system** and make operational decisions for the benefit of the corridor as a whole.

Most ICM strategies to date have focused on improving passenger travel, and ICM stakeholders have included public transportation agencies, such as State and local departments of transportation (DOT), metropolitan planning organizations (MPOs), and transit agencies. Although transit stakeholders have been included in current ICM efforts, there is potential to **increase the role of transit in ICM**. For example, public transportation is typically treated as an alternate mode to shift travelers to when congestion occurs on the main freeway in a corridor. Opportunities exist to develop more transit-centric, multimodal responses.

Additionally, the **definition of transit is rapidly evolving**. Evidence of this evolution can be seen in the current transition to the increasingly used term "public transportation," which is considered more inclusive of such new services as bike sharing, car sharing, and various on-demand services. These **mobility on demand (MOD)** options could provide additional travel alternatives for managing demand and increasing mobility along an

Who should read this primer?

The intended audience for this primer includes stakeholders from state and local transportation departments, metropolitan planning organizations (MPO), transit agencies, and other agencies or organizations – public and private sector – that provide mobility services along a corridor. It is intended to encourage these groups to think broadly about the integration of public transportation or mobility services that could be leveraged for integrated corridor management, which would need to be further analyzed for relevance to a specific corridor.

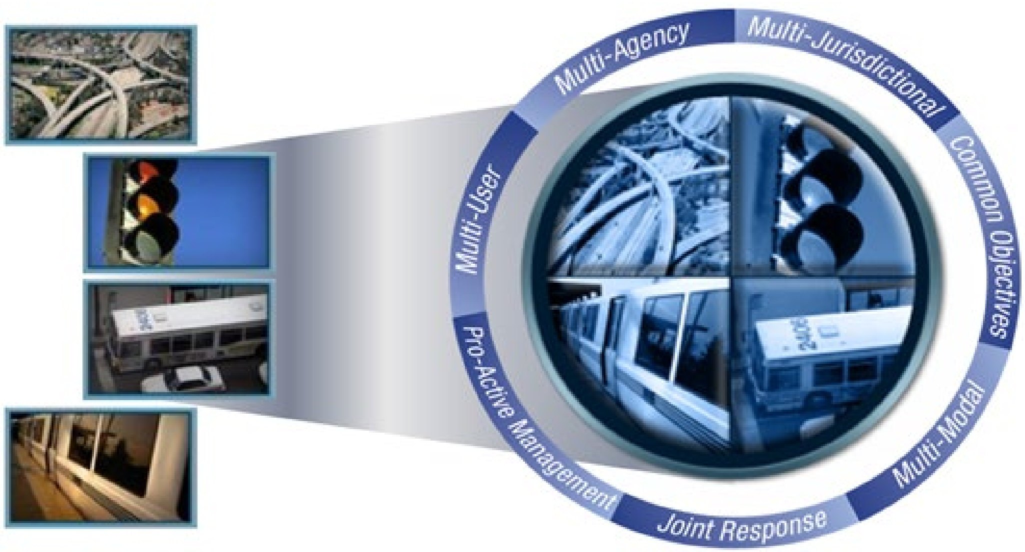
1 U.S. Department of Transportation, Intelligent Transportation System Joint Program Office, *Integrated Corridor Management Concept Development and Foundational Research*, FHWA-JPO-06-034 (Washington, DC: JPO, 2006). Available at: *http://ntl.bts.gov/lib/jpodocs/repts_te/14273.htm*.

ICM corridor. New and additional stakeholders may need to be included in ICM discussions as a result of these shifting transportation patterns.

This primer will:

- Examine how both public transportation and mod can be incorporated into an ICM approach.
- Define the needs for including public transportation and MOD stakeholders in ICM.
- Explore opportunities to effectively integrate transit and other emerging modes of public transportation on institutional, operational, and technical levels.
- Identify several major challenges to integration, along with potential solutions.

The primer also provides real world examples of transit and MOD strategies and services incorporated within the ICM approach. Many of these are from California, and are reflective of the State's position as being home to a number of emerging modes of public and private transportation.



Source: Federal Highway Administration

Figure 1. Illustration. Integrated corridor management involves viewing corridor assets – such as freeways, arterials, and transit – through a common lens.

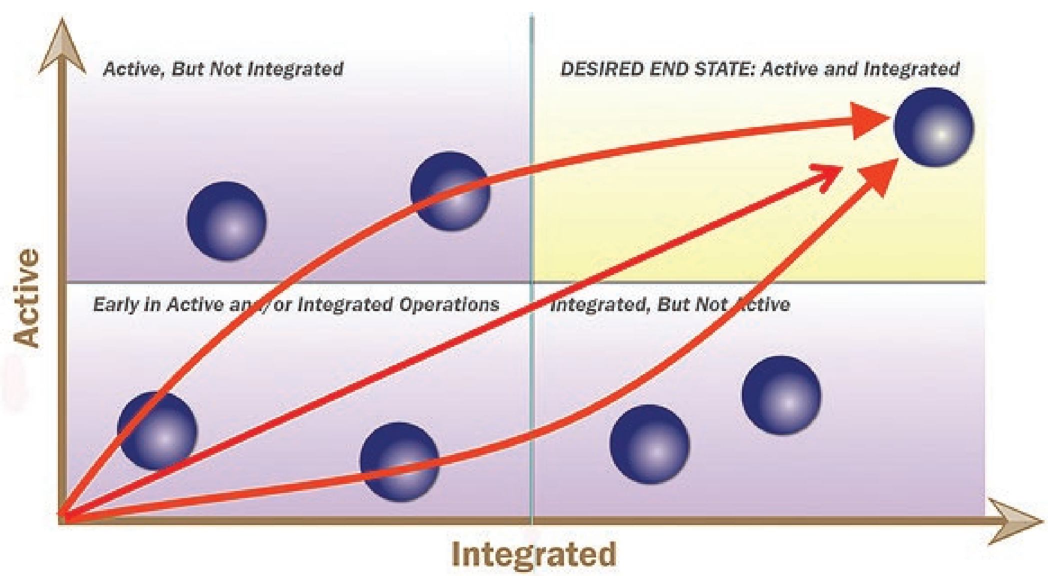
INTEGRATED CORRIDOR MANAGEMENT FUNDAMENTALS

ICM combines two fundamental concepts: active management and integration. Active management involves monitoring and assessing the performance of the system and, at the same time, dynamically implementing actions and providing services in response to fluctuations in demand. In an ICM corridor, all individual facilities and services must be actively managed so that operational approaches can be altered in real-time in response to an event anywhere on the system. An important element of active management entails providing information both to system operators as well as to system users to enable them to make the most informed decisions and choices.

Integration requires actively managing transportation system assets in a unified way so that actions can be taken to benefit the corridor as a whole, not just a particular section or mode. Integration occurs along three dimensions:

- **Institutional Integration** –Involves coordination and collaboration between the public and private entities, agencies and jurisdictions (i.e., transportation network owners and operators) in support of ICM, including the distribution of specific operational responsibilities and the sharing of control functions in a manner that transcends institutional boundaries.
- **Operational Integration** – Involves the implementation of multi-agency transportation management strategies, often in real-time, that and facilitate management of the total capacity and demand of the corridor and promote information sharing, coordinated operations across the various transportation networks in the corridor, and shared management of assets.
- **Technical Integration** – Provides the means (e.g., communication links between agencies, shared data, system interfaces, and the associated standards) by which information, system operations, and control functions can be effectively shared and distributed among networks and their respective transportation management systems, and by which the impacts of operational decisions can be immediately viewed and evaluated by the affected agencies. Technical integration cannot be accomplished without institutional and operational integration.

Active and integrated corridors can be viewed along a hypothetical continuum, as shown in Figure 2, which is meant to depict a shift towards the desired end state of both active and integrated. For example, some corridors may actively manage some or all of their assets, but not in an integrated way. The ultimate goal of ICM is for corridors (represented by dots) to progress along the continuum to become as active and integrated as possible.



Source: Federal Highway Administration

Figure 2. Illustration. The active and integrated continuum.

THE INTEGRATED CORRIDOR MANAGEMENT RESEARCH INITIATIVE

What could an integrated corridor management (ICM) response plan look like?

A major incident has occurred on the freeway in an ICM corridor. Travelers are advised via dynamic message sign and other traveler information sources (e.g., 511) to take a parallel route or shift to alternative modes, where there is spare capacity. Signal timing on the parallel route is changed to better manage the flow of the detoured traffic, and transit operators prepare for the increased volumes by adding more buses along the impacted route.

The United States Department of Transportation (USDOT) started the ICM Research Initiative in 2006 to explore and develop ICM concepts and approaches and to advance the deployment of ICM systems throughout the country. Initially, eight pioneer sites were selected to develop concepts of operations (ConOps) and system requirements for ICM on a congested corridor in their region. Three of these sites went on to conduct analysis, modeling, and simulation (AMS) of potential ICM response strategies on their corridor. In the final stage, two sites – the US-75 Corridor in Dallas, Texas and the Interstate 15 (I-15) corridor in San Diego, California – were selected to design, deploy, and demonstrate their ICM systems.

The Dallas and San Diego demonstrations "went live" in the spring of 2013. Each demonstration has two phases: design and deployment, and operations and maintenance. Both sites chose to develop a decision support system (DSS) as a technical tool to facilitate the application of institutional agreements and operational approaches that corridor stakeholders agreed to over a rigorous planning and design process.

Though the DSS approach at each site differs slightly, the basic process is similar. The DSS gathers traffic data from an array of intelligent transportation systems (ITS) in the network and uses this information to forecast future conditions on the corridor. If an event (recurring or non-recurring) occurs that is predicted to meet pre-established congestion thresholds, the DSS generates response plans. These plans contain combinations of multimodal strategies to address specific congestion scenarios. Response plans are based on detailed business rules that establish the conditions under which assets can be used, which may vary based on the magnitude of the event, time of day, congestion levels on the network, etc., as well as by policy constraints. The DSS recommends and ranks response plans by running a simulation to determine which plan will most effectively address the congestion. Operating agencies are alerted to either accept or reject the plans; if accepted, the plan will be implemented.

The USDOT is conducting independent "before-after" analyses to evaluate the benefits of ICM on transportation operator situational awareness, response and control, traveler information and overall corridor performance at each site. The experiences and lessons learned from the demonstration sites are being actively shared with the transportation community so that regions interested in ICM can leverage the knowledge gained to better shape a successful deployment for their corridor(s).

Although the demonstration sites provide valuable insights into the necessary components of building an ICM system, they do not represent the only way to implement ICM. There is no "one-size-fits-all" approach to ICM, since the circumstances of a particular corridor will vary based on traffic patterns, agency dynamics, available assets, and a host of other factors.

Source: Dallas Area Rapid Transit.

Figure 3. Photo. Dallas Area Rapid Transit, which operates the light rail and bus transit systems in Dallas, Texas, led the design and implementation of the integrated corridor management system on U.S. 75 in partnership with other regional agencies.

TRANSIT AT THE INTEGRATED CORRIDOR MANAGEMENT DEMONSTRATION SITES

Both ICM demonstration sites currently incorporate transit into their ICM approaches. In Dallas, the Dallas Area Rapid Transit (DART), which operates light rail and bus transit service in Dallas County, led the design and implementation of the ICM project. In San Diego, Metropolitan Transit System (MTS) is a key ICM stakeholder, and bus rapid transit (BRT) on I-15 is incorporated into ICM response plans.

At both sites, transit primarily serves as an alternate mode to shift travelers to in response to significant congestion on the road network (i.e., due to an incident). Transit and roadway agencies mutually benefit from improved situational awareness in this arrangement due to enhanced monitoring capabilities and information sharing across agencies and jurisdictions.

ICM agencies are also able to push the information they share with each other out to travelers. Dallas and San Diego developed integrated smartphone apps so that travelers can make better trip planning decisions along the ICM corridors by using multimodal information, not just roadway travel times. For transit agencies, this means customers have access to real-time information on bus or rail arrival times. This is an added benefit to regular transit riders, and a potential way to attract new riders who would otherwise not consider transit.

AMS results showed that ICM could increase transit utilization by encouraging travelers to shift from driving to transit, especially during incident conditions; however, "parking expansion to accommodate this utilization appears to be a critical enabler of this benefit."[2] Therefore, Dallas and San Diego added parking spaces as part of their ICM approaches. The sites also provide information on parking availability at transit stations so that drivers who experience congestion en-route know whether they can park their car in a nearby lot and take transit.

Although transit stakeholders at the demonstration sites have indicated that a more comprehensive picture of travel along the corridor has been helpful, there is potential to increase the role of transit in ICM at the sites. Currently, only a major event on the network initiates a response that would shift travelers to transit. Neither site incorporates transit-triggered response plans into their approach. For example, if a major rail line shuts down, the ICM system does not recommend alternate strategies to move impacted passengers through the corridor.

2 U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, *Integrated Corridor Management Modeling Results Report: Dallas, Minneapolis, and San Diego*, FHWA-JPO-12-037 (Washington, DC: JPO, 2012), p. A-4. Available at: http://ntl.bts.gov/lib/54000/54300/54346/ICM_Modeling_Results_Report__FHWA-JPO-12-037_.pdf.

As part of its integrated corridor management (ICM) project on I-15, the San Diego Association of Governments (SANDAG) developed a smartphone application called 511 San Diego that makes multimodal, actionable traveler information available to the public, including:

- Maps with current traffic conditions and the latest incident and construction information.
- Real-time dynamic toll rates for the I-15 Express Lanes.
- Predictive travel times, congestion information, and special event information.
- Ability to view current roadside camera images.
- Access to bus routes, fares, and arrival times.

The application also includes an optional text-to-speech feature and look-ahead commands that alert travelers to take alternate routes or modes to avoid congestion along their route.

While the application is currently focused on the I-15 ICM corridor, SANDAG hopes to expand the program to other transportation corridors in the region.

Source: *http://511sd.com*

INTEGRATED CORRIDOR MANAGEMENT AND PUBLIC TRANSIT

PUBLIC TRANSPORTATION STAKEHOLDERS

Institutional integration involves coordination and collaboration between various agencies and stakeholder groups in support of integrated corridor management (ICM), including distributing specific operational responsibilities and sharing control functions in a manner that transcends institutional boundaries. Understanding who public transportation stakeholders are is the first step in identifying the appropriate participants to engage in ICM.

Public transportation includes government-run passenger services for shared use by the general public. An ICM corridor might contain multiple types of transit services and provider agencies, all of which should be included in initial planning discussions. Public transit services that may exist on an ICM corridor include:

- Bus.
- Rail.
  - Rapid transit (i.e., metro, underground, subway, etc.).
  - Light rail, trams, and streetcars.
  - Commuter Rail.
- Ferries.
- Paratransit and shuttle services.

When engaging transit stakeholders in an ICM project, it is important to recruit executive level support, as this will trickle down to the management and engineering levels. There should also be a day-to-day contact from each transit agency for technical issues and coordination meetings

PUBLIC TRANSPORTATION TRENDS

Public transportation use in the United States is growing. According to a study by the American Public Transportation Association (APTA), public transportation use in 2013 was the highest it has been in 57 years. From 1995 to 2013, "public transportation ridership grew 37.2 percent, almost double the amount of population growth."[3] This trend is likely to continue as attitudes about transportation are shifting. Young Americans (16 to 34-year-olds) are driving less; according to the National Household Travel Survey, the annual number of vehicle miles traveled by young people decreased 23 percent from 2001 to 2009. During the same timeframe, the number of passenger-miles traveled on public transportation by this age group increased 40 percent per capita.[4] This generation is also factoring proximity to public transit into their housing decisions, driving urbanization and driving the

3 American Public Transportation Association, "Public Transportation Use is Growing – Here Are the Facts" web page. Available at: http://www.apta.com/mediacenter/ptbenefits/Pages/Public-Transportation-Use-is-Growing-.aspx.

4 B. Davis, T. Dutzik, and P. Baxandall, *Transportation and the New Generation: Why Young People Are Driving Less and What It Means for Transportation Policy*, (The Frontier Group, April 2012). Available at: http://www.frontiergroup.org/reports/fg/transportation-and-new-generation.

demand for other situational mobility choices such as bike share, ride share. Together, these factors point to the continued growth in demand for and use of public transportation.

Meeting this demand may prove challenging for public transit agencies due to a lack of financial resources. Fare revenue typically does not cover agencies' operating costs, which rely significantly on government subsidies. This means that many agencies struggle to maintain their existing systems, much less invest in new technologies and upgrades.

The emphasis on public transit in Federal legislation reinforces its importance in the Nation's transportation system. As such, regions pursuing initiatives such as ICM should increasingly look for innovative ways to incorporate transit or other mobility services and models into their approaches.

BENEFITS OF INTEGRATION

The integration of public transportation and other mobility services into ICM planning and implementation offers a number of potential benefits to operators and users of the transport system:

- **More comprehensive knowledge of corridor operations** – A critical element in the management of transportation facilities is real-time information regarding current conditions and operations. To this end, monitoring capabilities are a vital component of ICM projects. ICM-transit integration can lead to the enhanced data and information sharing between agencies, which provides for a more comprehensive and complete picture of conditions.
- **More efficient transit operations** – More knowledge of both roadway and transit service conditions can allow transit operators to better manage their resources. This can include short-term adjustments in response to incidents or longer-term adjustments designed to minimize the impacts of recurring conditions. Whether through enhanced knowledge about current conditions or the implementation of transit priority treatments, ICM-transit integration can lead to more efficient utilization of available transit resources.
- **Better informed travelers** – By collecting more comprehensive data on current conditions (i.e., broader coverage, include full range of travel options) and disseminating this information in a coordinated manner, travelers can make more informed decisions about when and how they travel. This can lead to more efficient utilization of the transportation system.
- **Increased transit ridership** – More efficient service, reduced delays, better incident response, and more information about travel options can make transit more attractive to potential users. Increased ridership leads to secondary benefits, such as increased transit service revenue, reduced congestion, lower fuel consumption, and reduced emissions.
- **More efficient roadway operations** – With more information gained through integration with transit services, roadway managers will have better knowledge of prevailing conditions and can respond accordingly. Additionally, with the potential for increased transit ridership and other travel that does not involve single-occupancy vehicles, vehicular demands may decrease, reducing congestion levels and delays on the roadway network.

- **More efficient implementation of infrastructure and improvements** – Coordinated planning between agencies can help identify opportunities where multiple improvements can be incorporated into the same design and construction, and where key infrastructure, such as a communication network, can be implemented to serve multiple purposes and agencies. This can help eliminate redundancies, minimize disruptions for construction (e.g., avoids individual agencies constructing improvements separately on the same facility), and provide cost savings.

- **Funding for transit improvements** – A number of treatments that provide direct transit travel time benefits can be implemented as part of an ICM project. By participating in a coordinated initiative like ICM, transit agencies may be able to make stronger arguments for various improvements. For example, they may be able to justify an automated vehicle location (AVL) system for buses in order to feed data into an ICM system. Additionally, they could work with local signal operators to request more advanced detection and signal systems on arterials.

The benefits noted above can support transit agencies' goals and objectives (see table below). In order to gain buy-in and support from public transit agencies, ICM project leaders should be prepared to effectively articulate how ICM could help achieve these transit-specific goals (i.e., what's in it for them?).

Table 1. Public transit goals and objectives.

Reliability	In order to maintain a loyal customer base, transit providers need to ensure reliable service. Passengers need to trust that their trip will be predictable or on-time.
System Efficiency	Transit agencies want to use their resources as efficiently as possible by minimizing non-revenue miles and evolving to user needs.
Safety	As with all other transportation agencies, safety and security of the system is a major priority for public transit providers.
Affordability	Transit providers need to ensure that their services are priced affordably for their customer base.
Accessibility	What types of transit services are available and where stations are located have a major impact on how frequently transit is used. Services must also be accessible for travelers with disabilities.

STRATEGIES FOR INTEGRATED CORRIDOR MANAGEMENT INTEGRATION

There are numerous strategies that agencies implementing ICM can consider to further integrate public transit into corridor operations. These strategies can both improve transit operations and enhance overall corridor performance and user experience by optimizing throughput. While not all of these strategies will be appropriate for every corridor implementing ICM, they offer a range of strategies which agencies can consider before narrowing down to those approaches that work best based on resources available and corridor travel patterns.

Transit Priority Treatments

One strategy to incorporate transit into ICM is transit priority or preferential treatments, which can enhance the efficiency of transit operations, reduce delays and congestion, and improve overall mobility and user satisfaction. Transit signal priority (TSP) and dedicated transit vehicle facilities are the most common preferential treatments for transit in an ICM environment.

Transit Signal Priority

TSP strategies adjust signal timing at intersections to better accommodate transit vehicles. Typically, a bus approaching a traffic signal will request priority. This request is often transmitted directly from an approaching bus to a traffic signal, but may also be originated by a centralized transit priority management system. When a request is received, the traffic signal controller applies logical rules to decide whether or not to provide priority to the bus. These rules typically include consideration of whether the bus is behind schedule, the length of time since the last priority was awarded to a bus, the state of the traffic signals along the route, and the time of day. In most cases, the form of priority given is to extend an existing green phase to serve the bus or to shorten other phases to start the next green phase for the bus earlier.

In simple TSP systems, each signal controller operates independently. It detects the bus directly and does not receive priority requests from any external source. It makes a decision about providing priority without reference to any external system or consideration of the state of any other signal controller. In more complex systems, a central priority management system may determine when to request priority at various intersections and employ more complex rules that include feedback from the traffic signal system. This type of system could potentially be integrated into larger ICM system.

Connected Transit Signal Priority

An extension of more traditional transit signal priority (TSP), the Multi-Modal Intelligent Traffic Signal Systems (MMITSS) is a bundle of applications that allows for the real-time monitoring and adjustment of traffic signals to maximize traffic flows or to accommodate specific user groups. The TSP MMITSS application grants signal priority to buses based on a number of factors. Using an on-board device, buses can communicate their passenger count data, service type, scheduled and actual arrival time, and heading information to roadside equipment. While MMITSS is not yet widely deployed, connected TSP could grow in popularity as market penetration of connected vehicle technologies grows. (residential or single business delivery).

Dedicated Transit Vehicle Facilities

A second common form of transit priority treatments include dedicated transit vehicle facilities, such as exclusive busways and high-occupancy vehicle (HOV) lanes. Because of their scale, such facilities would generally be implemented as stand-alone projects; however, a number of other smaller-scale treatments and strategies could be implemented as part of an ICM project.

Source: Federal Highway Administration.

Figure 4. Photo. Example of a transit/high-occupancy vehicle priority on-ramp in California.

For example, on arterials where transit vehicles generally operate within a shared lane environment, queue jump lanes may be used at isolated delay points. The queue jump lane may take the form of a separate lane developed for buses only, or may involve allowing buses to use a right-turn lane as a through lane. A separate lane is essential where there are heavy right turns that move on special phases. If an existing right-turn lane is used, the queue jump operation may be limited to peak periods only. In either case, the queue jump lane should be of sufficient length to allow the buses to bypass the general traffic queue at the intersection most of the time. On a roadway with existing shoulders, a queue jump or bypass lane treatment can be developed assuming shoulder width (10 feet minimum) and pavement design can accommodate bus traffic.

If there is no receiving lane on the downstream side of the intersection, a separate, short bus signal phase (3 to 4 seconds) would need to be provided that gives the bus an early green to move into the through lane ahead of general traffic. Typically, green time for the parallel general traffic movement is reduced to accommodate the special bus signal phase. To detect buses in the queue jump lane, an in-pavement loop sensor in the queue jump lane on the near side of the intersection (just short of the stop bar or crosswalk) or video detection can be used. In cases where there is a downstream receiving lane, the bus would not have a separate signal phase but would continue through the intersection into a far-side stop before pulling back into general traffic.

On freeways, an example of a smaller-scale transit priority treatment is a transit/HOV priority lane on a metered on-ramp. These priority lanes can be unmetered, but more typically are metered to provide preferential treatment to transit vehicles/HOVs (e.g. serve vehicles in the priority lane first or more frequently). In the latter case, this priority treatment needs to be incorporated into the ramp metering algorithm.

The California Department of Transportation (Caltrans) has adopted a policy of including transit/high-occupancy vehicle (HOV) priority lanes on all metered on-ramps, where feasible. Although the priority lanes are also metered, the control algorithms used typically provide preferential treatment of the transit/HOV lane. Depending on the location, this may include serving the transit/HOV lane first if vehicles arrive at the same time or serving the priority lane more frequently (i.e., at a higher metering rate).

Bus queue jump lanes are relatively uncommon in the United States. While on-ramp transit/HOV priority lanes are common in some areas of the country such as California, they have not been widely implemented in most areas. Within the context of ICM and transit integration, it may be possible to define the applicable priority rules, construct the dedicated facilities, and implement the necessary technology (e.g. transit vehicle detection or location systems, signal or meter hardware and software upgrades, etc.) as part of an ICM project.

As part of the East Bay bus rapid transit (BRT) and I-880 integrated corridor management (ICM) projects, AC Transit, the City of Oakland, and Caltrans are implementing a joint fiber optic communication network along International Boulevard. This network will be used by AC Transit to provide connections to ticket vending machines and bus arrival/departure signage at BRT stations. For the City of Oakland, the network will provide connections to signals along the corridor, as well as to traffic monitoring devices. For Caltrans, the fiber network will help support incident management functions as part of the I-880 ICM project. This includes implementing "flush plans," controlling electronic "wayfinding" message signs that will direct diverted vehicles back to the freeway, and monitoring conditions along the arterial.

Shared Communication Infrastructure

The transmission of data and information between facilities, in-field equipment, and vehicles is vital to effective monitoring and management of every transportation system. For roadways, this may include the flow of data from detectors and other surveillance equipment to a central operating center, and the flow of operating commands from the operations center to electronic signs and controllers. On the transit side, there is the flow of location and operating status information from vehicles to an operations center, and the flow of schedule status information to electronic signs at stops and stations. While many agencies are shifting to wireless systems, communication networks often still involve significant wireline infrastructure involving conduit, pullboxes, cables and end equipment. Often times, individual agencies implement their own networks or infrastructure, creating redundancies, overlaps, and cost inefficiencies.

Because most ICM and system management projects involve implementation of a supporting communication network, the integration of transit into an ICM project provides the opportunity to incorporate transit agency needs into the communication network and infrastructure. Coordinated implementation can help reduce overall costs, support compatibility between equipment, and minimize disruption caused by infrastructure construction. It also facilitates information sharing and coordination (see "Interagency Information Sharing and Coordination" below).

Information Sharing and Communication

In addition to supporting individual agency decision-making, information sharing can facilitate coordination between different modal agencies, between transit agencies, and between agencies and travelers. Having common and comprehensive information about current transportation system conditions can also lead to consistent and compatible operating decisions across the various system managers.

Roadway-Transit Information Sharing and Communication

A critical element in the management of transportation facilities and services is knowledge of current conditions and operations. To this end, roadway managers often deploy monitoring devices such as roadway detectors and video cameras to track traffic flows and speeds. Similarly, transit operators use AVL systems and other means to monitor the movement and status of their vehicles. However, this information is often not shared between roadway managers and transit operators.

The integration of transit into an ICM system requires the implementation of protocols and systems to share pertinent information and data. As noted above, this can be greatly facilitated by the implementation of shared communication infrastructure. The ICM project development process can also provide a forum for developing or enhancing interagency communication and coordination. In the case of a severe or major incident, interagency coordination in a region may already occur through an emergency operations center; however, this is limited in application. Under an ICM approach, information is shared more routinely. This provides roadway and transit managers with a more complete understanding of system conditions, which supports more informed and coordinated operations and management decisions.

For example, transit system data can not only provide roadway managers with additional information about traffic conditions (see "Use of Transit Vehicles as Probes" below), but can also alert them to transit-related incidents that impact traffic operations, such as a bus breakdown that blocks a travel lane or a rail line breakdown that causes a shift in demand from transit to auto travel. This information may then be used to adjust roadway management and control strategies accordingly. From the transit operators' perspective, roadway or traffic data could be used to re-route service around congested areas or make other service adjustments in response to major roadway traffic incidents that may impact (increase) transit service demand in a corridor.

Transit-Transit Information Sharing and Communication

In addition to improving communication between transit and roadway agencies, ICM provides an opportunity to enhance coordination between public transportation operators, transit agencies, and metropolitan planning organizations (MPO) in regions with multiple providers. This could include sharing information about system status and delays to improve transfer timing, or possibly sharing data, virtual operations, assets or dispatch centers.

Coordinated services allow travelers a seamless transfer between modes and providers. One potential strategy to better integrate transit services is through joint fare payment systems, which can be rolled into a broader ICM project. In regions with multiple transit providers, this would allow users to easily shift between transit services without having to purchase and keep track of individual fare cards. For example, in Chicago, Chicago Transit Authority (CTA) owns Ventra, which is "one card and one system that does everything."[5] Users can pay fare for CTA or Pace – the two major transit providers in Chicago – using a Ventra card, tickets, a contactless credit or debit card issued by their bank, or a smartphone. A Ventra smartphone app is also under development, which will incorporate information for transit trip planning.

5 Chicago Transit Authority, "About Ventra," accessed 9 Feb 2015. Available at: http://www.transitchicago.com/ventra/.

Another potential model for transit agency coordination is the U.S. Department of Transportation's Mobility Services for All Americans (MSAA) initiative. This program aims "to improve transportation services and simplify access to employment, healthcare, education and other community activities"[6] by improving coordination between transportation providers for older adults, people with disabilities, and the economically disadvantaged. This is achieved through development of a virtual or physical travel management coordination center (TMCC) that networks all parties together and uses proven ITS technologies to provide:[7]

- Fleet scheduling, dispatching, and routing systems;
- Integrated fare payment and management systems;
- Better traveler information and trip planning systems, particularly for customers with accessibility challenges; and
- Advanced geographic information systems (GIS) and demand-response systems to provide door-to-door service.

Using the TMCC, agencies are able to schedule trips more efficiently and better match capacity to trip requests. In an ICM corridor, this approach could be considered on a daily basis or to address traveler needs when there is an incident on a particular transit route or line.

Transit-Traveler Information Sharing and Communication

In today's connected world, travelers have many sources for traffic and transit information, such as various public agency internet and phone systems (e.g. 511); roadside dynamic message signs (DMS); arrival/departure signage at transit stops and stations; television and radio reports; third-party services (e.g., websites and smartphone apps such as Inrix and Waze); and newer in-vehicle navigation systems. For traffic conditions, information typically includes congestion levels, travel times, and incidents. On the transit side, information includes schedules, next arrival, and service disruptions.

These information sources have a number of common shortcomings. First, they are often mode-specific and most often focused on traffic conditions. Second, transit information is typically static or schedule-based, not real-time. When real-time transit information is provided, oftentimes it is only to report a significant incident or delay.

ICM-transit integration can provide the opportunity to incorporate real-time or predictive transit information into traffic information and to better disseminate this information in a coordinated manner. This equips travelers with the ability to make informed decisions about travel options, leading to more efficient utilization of corridor assets.

Source: A. Mortazavi et al., Travel Times on Changeable Message Signs Volume II – Evaluation of Transit Signs, UCB-ITS-CWP-2009-2 (CCIT, 2009)

Figure 5. Photo. Comparative freeway and transit travel times on a dynamic message sign in California.

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6 USDOT, Intelligent Transportation Systems Joint Program Office, "Success Stories: Mobility Services for All Americans (MSAA)" web page. Available at: http://www.its.dot.gov/msaa/.

7 USDOT, Intelligent Transportation Systems Joint Program Office, "Success Stories: Mobility Services for All Americans (MSAA)" web page. Available at: http://www.its.dot.gov/msaa/.

Transit Incentives

Diverting single occupant vehicle drivers to transit or other modes can be an effective way of relieving congestion during traffic incidents on the roadway. However, convincing drivers to shift to transit can be challenging unless they are familiar with and comfortable switching between modes. To encourage mode shift, agencies can provide incentives to try transit, such as discounts for low-income riders and frequent user rewards. These incentives could potentially be offered during the early stages of an ICM deployment so that travelers become more aware of the transit options available to them.

It could also be part of an ICM approach to reduce or eliminate transit fares during major incidents based upon predefined conditions of traffic delays (i.e., during incidents of a certain level of severity). In combination with temporary park-and-ride lots or transit "bridges" to access primary line-haul transit (see box on p. 29), this can be a very cost-effective strategy for diverting travelers. Use of an automated fare payment system facilitates easy reduction or refunding of transit fares and transfer of funds among partner agencies.

Los Angeles Metro Transit Rewards Program

Los Angeles Metro implemented a transit rewards program on the I-10 and I-110 express lanes in which customers earn toll credits for frequent transit use. Using their registered "TAP" card (an integrated transit fare payment card), transit riders can earn a $5 toll credit by taking 32 one-way trips during peak hours along the I-110 Harbor Transitway or the I-10 El Monte Busway. As of September 2014, 6,896 accounts had enrolled in the rewards program, earning 26,195 in toll credits.

Source: Metro "ExpressLanes" web page. Available at: *https://www.metroexpresslanes.net en/about/transit.shtml.* See also, E. Higueros, Transportation Planning Manager, Los Angeles Metropolitan Transportation Authority, Metro, "Transit Rewards-Granting Express Lane Credit to Transit Riders" (presentation). Available at: *http://www.itscalifornia.org/session-presentations*.

Use of Transit Vehicles as Probes

Real-time information on current conditions and operations is a critical element in transportation management. To this end, ICM projects typically include the implementation of monitoring devices such as roadway detectors and video cameras where they are not already installed. The integration of transit into an ICM system can provide additional monitoring capabilities.

In cases where transit vehicles are equipped with an AVL system, speed and travel time information can be shared with roadway managers. This may be most appropriate for long-haul or express services where the transit vehicles have few or no stops, and thus their travel speeds or times are generally reflective of other vehicles on the roadway. However, even data from local transit services may be useful where post-processing procedures recognize and account for scheduled stops when computing travel times. In either case, monitoring programs may be set up to identify when travel speeds or times fall outside acceptable parameters or excessive delay occurs at non-stop locations.

Another possibility for gathering real-time data is video feeds from cameras installed on transit vehicles. While such cameras are typically used to monitor activities within transit vehicles, there is a growing trend of installing front-facing cameras to view conditions ahead. This "driver's view" has the advantage of covering the entire route and can supplement roadway video monitoring systems.

A third opportunity is to use the transit vehicle driver as another "set of eyes" in the field. Drivers could report on incidents through their dispatchers or directly to the applicable roadway managers. Again, this would be a supplement to other video monitoring systems, with the possible advantage that drivers could provide additional details from the field. This concept would be facilitated by the increased level of agency coordination and communication arising from the joint implementation of an ICM project. Recognizing that most transit agencies may be hesitant to add to the responsibilities of their drivers, this may only be applied to the reporting of significant incidents.

A fourth opportunity involves using bus sensors, particularly the telematics, to survey the physical condition of the road and system behaviors. For example, a record of the vertical accelerometer can be used to identify the location of potholes. A record of braking force can be used to map common bottlenecks and the propagation of their congestion as well as be used as a criteria in a pavement management plan (a heavy vehicle stopping every day at the same place will probably lead to premature pavement buckling.)

Challenges to Integration

Although strategies for integrating transit into corridor operations show great potential, there are still challenges associated with this process. While none of the challenges described below are insurmountable, ICM teams should take them into consideration to be sure that they are addressed during the planning and development stages of the ICM project.

Resistance to Roadway-Transit Coordination

Most transit agencies operate independently of highway departments and other modes. Federal funding sources are also typically separated into modal "silos" (Urban Mass Transit Act/Federal Transit Administration and Federal Highway Administration, respectively). In more recent years, the USDOT has adopted a "One DOT" policy as a multimodal approach; however, it takes time for industry to react, and organizational inertia drives transportation agencies to continue to operate in their familiar way of doing business.

In many cases, there is a history of less than amicable relationships between highway and transit interests, which can lead to a mutual lack of trust. With ICM, transit providers may perceive that they are being asked to hand over control of transit services to roadway agencies. They may fear that the roadway operators will overreact and commandeer transit assets in response to relatively minor incidents on the network.

In addition, some agencies may fear jeopardizing their transit operations by participating in ICM. Diverting drivers from the freeway to transit as part of an ICM response could be viewed as disruptive to regular transit riders. Why should they suffer delays and overcrowding on "their" buses or trains? As loyal transit riders, they may be feel they are being penalized when the roadway experiences an incident. Also, fixed guideway transit systems (rail and bus) can benefit from traffic delays on the primary freeway in a corridor; with exclusive rights-of-way, transit can deliver more reliable travel times, whereas highway travel times can vary greatly. Recent research has shown that travel time reliability is of greater importance to commuters than travel speeds. Some transit operators may worry that their reputation for reliability will be jeopardized if they change their operations to benefit overall corridor performance.

I-95 Express Bus Service in South Florida

Prior to implementation of the I-95 Express Lanes Project, bus commuters traveling between Fort Lauderdale and Miami had to make a transfer at the Golden Glades Park and Ride and switch buses between Miami-Dade Transit and Broward County Transit near the county line. These two providers now provide an integrated, "one-seat" trip between the two downtown areas, using the express lanes.

Source: Florida Department of Transportation, District 6, Intelligent Transportation Systems, "Press Room – Express Lanes Photo Gallery" web page *http://www.sunguide.info/sunguide/index.php/gallery/express_lanes)*

Figure 6. Photo. A 95 Express bus on the I-95 express lanes in Southern Florida.

Florida Department of Transportation, "95 Express" web page. Available at: *http://www.95express.com/*.

It is understandable that transit agencies may question "what's in it for them" when considering ICM, but careful communication in a forum that allows transit agencies to express their concerns may help mitigate this response. The challenge lies in effectively conveying the benefits of ICM to the traveling public as a whole.

Lack of Resources

Fare box revenue covers only a portion of total costs for most transit agencies. Many agencies struggle to provide basic services and may not have resources to take advantage of new systems and other changes in operations. Even if an ICM program were to provide capital costs, transit agencies may not have staff resources to actively monitor additional information or to maintain any new equipment. In addition, transit services may not have spare capacity at peak periods when ICM scenarios commonly would kick in, and they may not have the budget to make a major capital investment to add capacity. In these situations, ICM implementers will need to think carefully about under which circumstances they are able to use transit, as well as potential strategies to increase transit capacity without adding significant new infrastructure.

Operational Restrictions

Transit providers may also feel that they have little or no flexibility in adjusting service to accommodate ICM applications. During peak periods, transit agency assets (bus and rail capacity, park and ride lots, drivers) may be in full use already, especially in congested urban areas. Rail lines in many metro areas are packed at peak commuting periods, as are buses during special events and incidents when ICM scenarios are most likely. In addition, providers may not have the ability to re-route their buses, as they are required to hit every stop. Negative impacts on bus operations may affect lower-income residents along the corridor in favor of more affluent travelers from the suburbs (particularly for auto-centric metropolitan areas in the Southern and Western United States), which could trigger environmental justice concerns.

Competition among Transit Providers

Transit agencies may not be interested in coordinating services, because multiple providers within a corridor may see themselves as serving “different markets.” They may be focused on their operations only, serving their tax district with the services that they are dedicated to provide. On the same corridor, one agency may provide a pass-through, commuter-based service, while another agency may serve a more local community. For example, Bay Area Rapid Transit (BART) and San Francisco Muni operate heavy rail, light rail, trolley, and bus service all along essentially the same corridor within San Francisco city limits, but they serve different commuter and local needs. Agencies may also view each other as competitors, and to may be territorial with regard to their geographic “turf.” There can be very strict adherence to crossing county lines or other boundaries that inhibit full corridor efficiency.

Despite the fact that agencies may see themselves as having different interests, their customers – passengers – often transfer between multiple public transportation services (i.e., take one bus route for part of their trip, then transfer to another bus or to rail). Therefore, it is important for agencies to realize that they share the end goal of supporting common customer needs, and the best way to do that is to provide as coordinated services as possible in order to facilitate seamless travel along the corridor. In Florida, Dade and Broward Counties have recently come together to provide “one-seat” service along I-95, whereas in the past, commuters would need to transfer buses in the middle of the corridor.

Conflicting Objectives

Another obstacle to implementing a number of the transit-specific ICM strategies is a potential conflict with the objectives of roadway managers and the needs of other transportation system users. For example, while implementing TSP can reduce delays for transit vehicles and passengers, as well as other vehicles traveling in the same direction, it can result in added delay to vehicles making conflicting movements. This may oppose the roadway system manager’s objective to minimize vehicular delay and maximize vehicular throughput, rather than person delay and throughput.

Likewise, implementing a transit priority facility, such as a queue jump lane at an intersection or a transit or HOV priority lane on an on-ramp, may mean taking right-of-way that could be used for other purposes, such as a general-purpose traffic lane, parking, or a bicycle lane. A common argument against shoulder use by transit vehicles is that this space is needed for vehicles to pull over in case of a breakdown or incident.

Overcoming the challenge of conflicting objectives begins with acknowledging the different interests and needs of corridor agencies, while recognizing the importance of a balanced, multimodal transportation system. This should be followed by analysis to determine the actual benefits and impacts of transit-based strategies. For example, in the case of TSP, analysis may show that priority requests are so infrequent that the impact to conflicting movements is limited and even offset by the reduced delay for concurrent movements. Lastly, measures to address any impacts should be explored. For example, when allowing shoulder use by buses, monitoring systems can be implemented to detect when the shoulder is occupied by another vehicle and alert the bus driver to use the adjacent travel lane.

Shared Use/Access Restrictions

While integrated strategies can lead to cost-savings and operational benefits, they can raise institutional issues regarding access to and maintenance of equipment. Most TSP-related functionality is located within traffic signal controllers, which are typically managed by local departments of transportation. If a TSP operation fails or needs fine-tuning, agencies will need to coordinate to fix the issue. The roadway agency may not want to allow the transit agency to access the controller, and the transit agency may not trust that the roadway agency will fix the issue in a timely fashion, especially if the signal is otherwise operating fine. Similarly, in the case of a shared communication network, agencies will need to determine who is responsible for maintenance an establish protocols to ensure that disruptions are repaired promptly, without impacts to any mode's operations. These and related issues need to be addressed in the planning stages of an ICM project. This includes clearly defining roles and responsibilities, as well as performance requirements and contingency plans where appropriate.

Equipment Limitations

ICM implementers will also need to account for practical equipment limitations when considering strategies. For example, although one strategy to encourage mode shift may be to display transit travel times on DMS, the Manual on Uniform Traffic Control Devices (MUTCD) limits the number of signs and the quantity of information that can displayed for safety and traffic operations reasons. In addition, agencies may need to update their equipment to apply certain strategies; for example, TSP requires more sophisticated signal controllers, which an agency may not have the resources to purchase and install. As part of the ICM planning process, implementers should be aware of these constraints and discuss opportunities for funding technology upgrades.

Counterproductive Traveler Information

Providing real-time traveler information is central to an ICM approach, but in some cases, this can be counterproductive to transit ridership. Many riders choose to take transit for reliability. Transit services that have exclusive (or priority) right-of-way are less prone to disruptions due to unpredictable events such as incidents than are freeway commutes. However, transit riders may overestimate their time savings or make their mode choice based upon the worst-case incident that they have experienced on the freeway. With real-time travel times provided for transit and roadway options, transit riders may realize that driving is typically a quicker option than transit and switch modes. Given this, some transit providers may prefer to only provide transit-specific information, such as "next bus," park and ride availability, directions to stations, and route maps, rather than comparative travel times across modes.

INTEGRATED CORRIDOR MANAGEMENT AND MOBILITY ON DEMAND

WHAT IS MOBILITY ON DEMAND?

Mobility on demand (MOD) encompasses USDOT's long-term vision for a multimodal, integrated, and connected transportation system in which mobility is a commodity and service. This could include, but is not limited to interoperable bike sharing, car sharing, and demand-response systems. The backbone of MOD is interoperable data and ubiquitous payment methods that provide seamless use of mobility services for the user. MOD is enabled by information provided and presented in a mobile data environment. Under a MOD paradigm, travelers will have increased options for when and how they reach their destination. The guiding principles of the MOD vision are that it is:

- **Traveler-Centric/Consumer-Driven** – MOD is defined by performance in terms providing quality and carefree personal mobility choice for individuals.
- **Data Connected/Platform Independent** – There is no particular MOD technology; rather, the vision of an intermodal, connected system will drive the development of enabling technologies.
- **Mode Agnostic/Multimodal** – MOD embraces all modes and resources to support personal mobility choice. It is not limited to traditional public transit.

Conceptual Notions of Mobility on Demand

- Promotes choice in personal mobility.
- Promotes Intelligent Transportation Systems.
- Advances connected vehicles.
- Advances vehicle automation.
- Leverages emerging technologies.
- Leverages data exchange.
- Encourages multimodal connectivity.
- Encourages system interoperability.

There are four primary reasons why the MOD concept is critical to the future of the transportation system.[8]

- **Aging Americans require mobility choice** – The number of older Americans is rapidly increasing; there will be 30 million additional people age 60 or older in 2020 than there were in 2005.[9] While many older Americans are still driving today, those individuals will at some point be unable to provide their own transportation due to either physical or mental disabilities or possibly because they may no longer be able to afford to own and maintain their own vehicles. MOD affords older Americans the opportunity to age in place and live independently for longer periods of time than they can currently.

8 Federal Highway Administration. http://innovativemobility.org/wp-content/uploads/2015/02/Robert-Sheehan-Mobility-on-Demand.pdf.

9 N. Farber, D. Shinkle, J. Lynott, W. Fox-Grage, and R. Harrell, *Aging in Place: A State Survey of Livability Policies and Practices* (National Conference of State Legislatures and the AARP Public Policy Institute: December 2011). Available at: http://www.ncsl.org/documents/transportation/aging-in-place-2011.pdf.

- **Millennial Americans want mobility choice** – Studies and surveys of Millennials show that they are choosing to take public transit for both convenience and cost savings. For 66 percent of Millennials, the availability of public transit factored into deciding where to live. The success of companies such as Uber and RideScout show that there is a market demand for door-to-door services at varying price points.[10]

- **All Americans need mobility choice** – Americans who rely on paratransit services, including the elderly, those with disabilities, and low income individuals, need improved personal mobility options. They currently are generally required to request trips at least 24 hours in advance, through systems that can be confusing to individuals. They also may experience lengthy rides that can be over an hour long to go a few miles from home. When the vision of MOD is realized, these individuals will be afforded levels of personal mobility that are comparable with those of individuals driving their own vehicles.

- **Low-income Americans need reliable, low-cost transportation** – For Americans in the lowest 20 percent of income earners, transportation costs account for approximately 32 percent of their after tax income. Limited access to affordable housing near employment centers, or affordable transportation options to and from employment centers, contributes to the high burden of transportation costs for working class families. This represents both a major financial hurdle for low-income families and a serious barrier to economic and social opportunity.[11]

In addition to demographic trends driving the need for MOD, many emerging technologies serve and enable mobility, such as a "big data," Smart Cities and the "Internet of Things," connected and automated vehicles, social media, and Smartphone technology and payment applications. Current social and economic trends also encourage MOD, such as declining car ownership, the growth in the shared economy model and peer-to-peer transactions, increase urbanization and changing demographics, and an increased social preference for alternative transportation.

Source: FHWA.

Figure 7. Photo. A vehicle owned by Car2Go, a car sharing company, in Denver, Colorado.

EXAMPLES OF MOBILITY ON DEMAND

Taxi operations represent traditional MOD services; riders request a door-to-door trip and receive it in a relatively short timeframe. Some of the most rapidly

10 American Public Transportation Association, *Millennials and Mobility: Understanding the Millennial Mindset*, n.d. Available at: http://www.apta.com/resources/reportsandpublications/Documents/APTA-Millennials-and-Mobility.pdf. See also, H. Malcolm, USA Today, "Millennials prefer cities with good public transit," April 24, 2014. Available at: http://www.usatoday.com/story/money/personalfinance/2014/04/24/millennials-prefer-public-transportation/8097555/.

11 USDOT, Beyond Traffic 2045 – Trends and Choices (Draft), n.d. Available at: http://www.transportation.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf.

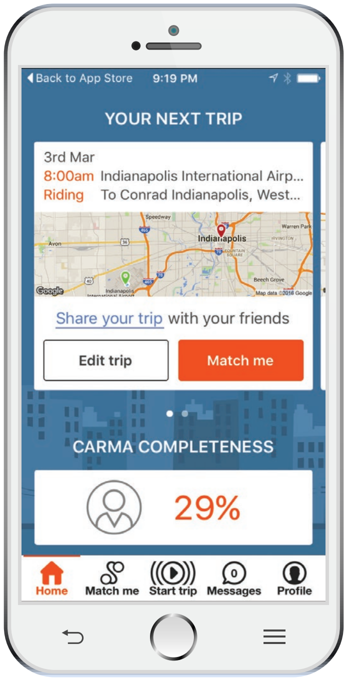
growing MOD services available today are transportation network companies (TNC) such as Uber and Lyft that build upon the taxi model, but leverage mobile data and cashless payment systems. These providers allow users to request rides through a smartphone application. Riders can track the location of the requested vehicle as it arrives, and payment is automatically integrated into the application. These companies have also introduced ridesplitting services (e.g. Lyft Line, UberPOOL) that allow users to split payment with other riders through the application, providing an environment for and encouraging shared-use mobility.

Car sharing is another form of MOD. These are typically member-based services where users can reserve local vehicles online or through a smartphone application for a time-based fee. These vehicles may be part of a fleet owned and maintained by the car sharing company (e.g., Zipcar, car2go), or they could be owned by other subscribers (e.g., RelayRides). For example, a user may choose to rent their car out for local use while they are at work during the day. Car sharing offers users flexibility in car ownership. It may be an attractive option particularly in urban areas, where users only need to make occasional use of a car. It could also appeal to users who need to use a particular type of vehicle (e.g., an SUV) for a short-term trip.

Transportation network and car sharing services allow travelers to get door to door without having to own a car. They are not restricted to fixed routes and pick-up and drop-off points as are public transit services. A dynamic transit service operating in Boston and Washington, DC optimizes pick-ups, drop-offs, and routing based on demand. The system, called Bridj, enables smart phone users to select the trip that meets their needs, purchase their trip, and walk to their tailored pick-up location. All rides are shared.

These dynamic network and sharing models may be further revolutionized by automated and connected vehicle technologies. In the future, users may be able to order driverless vehicles to get to their destination, which could expand use of these services and potentially lower the cost.

While taxis, Uber, Lyft, and car sharing companies are for-profit services, other forms of MOD are peer-to-peer based. These includes carpooling arrangements, which can be run by public agencies (i.e., ride-matching and commuter connections programs), or made informally between travelers. In these arrangements, drivers may not be paid a fee beyond splitting the cost of gas with the rider. Rather, the driver benefits by being able to use HOV lanes or express lanes for a lower or no cost than they would as a single driver. This trend in peer-to-peer transactions also has a broad impact on ownership and thus business models, encouraging shared assets, situational use and mobility based on need. Smart phone applications that help travelers make these kinds of transactions have also emerged (e.g., Carma).



Source: CARMA Technology Corporation, "Carma" web page. Available at: https://carmacarpool.com/)

Figure 8. Screenshot. The Carma carpool smartphone application enables drivers and riders to match based on their trips.

Lastly, some employers support MOD through bus, vanpool, or shuttle services, which can be offered at a fee or for free to employees. These services typically operate on a fixed route similar to transit, but can be beneficial to users who commute to large employment centers that are not located within walking distance of a transit station.

What does Mobility on Demand address?

- Additional coverage
- First and/or last mile travel
- Flexible scheduling of travel
- Flexible route and nodes
- Availability of vehicles and bikes

As the list of mobility options for travelers rapidly expands, some private sector companies are developing tools that integrate information into a common platform. For example, RideScout™ is an application that shows users their travel options across multiple modes – driving, transit, walking, biking, taxi, ridesharing, etc. It compares travel times and options for all of these prices so that user can make an informed decision on how to make their trip.

But the private sector is far from the only interested party. For example, the Federal Highway Administration (FHWA) is currently working on a project designed to illustrate the current practices and opportunities for two key aspects of active demand management: behavior-economic strategies deployed through smartphone applications and enhanced shared-use mobility travel options. This work is designed to provide information that both operations and planning communities can utilize to advance demand management strategies that can make significant impacts on transportation systems management and operations (TSM&O).

MOD options will continue to expand as technologies advance. As end users continue to seek alternative forms of transportation, public and private sector organizations will continue to advance innovative ways for travelers to travel from point A to point B.

BENEFITS OF INTEGRATION

There are many benefits to incorporating MOD concepts into corridor operations. The purpose of ICM is to make the best use of assets across a corridor travel shed, and MOD supports this goal by providing a broader range of travel options. Other benefits include the following:

- **Increased opportunities for mode shift** – Travelers who may be hesitant to shift between driving and transit may be willing to shift to MOD options because they provide door-to-door service, flexibility and an opportunity for situational mobility. MOD services also provide first/last mile connections to transit enabling access where it may not have been present before, extending the catchment area of existing public transportation services. For example, if there is a major incident on the freeway and travelers are advised to consider transit for their commute, some drivers may feel if they need to drive to the transit station anyway, they might as well drive all the way to their destination. With MOD, they could potentially find alternative means by which to arrive at the transit station and be more flexible about shifting modes.

- **Decreased vehicle volume and parking requirements** – Another benefit of incorporating MOD concepts within ICM is that it could potentially decrease the number of vehicles on the road, which in turn leads to a decrease in parking requirements. With expanded options, travelers may become increasingly less likely to own and commute with vehicles. Those that continue to drive may become more open to ridesharing opportunities so that they can take advantage of faster commute times on HOV or express lanes. It should be noted, however, that the impact of these emerging services with respect to factors such as vehicle miles traveled and number of trips is uncertain.
- **Raised awareness of MOD options** – ICM could benefit MOD providers by raising awareness about the availability of MOD services. If MOD is integrated into ICM traveler information, travelers may learn about MOD options that they did not know about before.
- **More real-time information to MOD providers** – MOD services could benefit from real-time information on corridor travel times. Drivers of MOD services could re-route based on information provided by an ICM system, or could travel to pick-up points where it is likely that travelers would be looking for a ride.

Temporary Parking Lots

In order to accommodate mode shift to transit during a major incident on the roadway, integrated corridor management (ICM) operators may want make agreements with local organizations and businesses that they will make their parking lots available temporarily, especially if existing park-and-ride lots are at capacity. Drivers could leave their vehicles at these lots and be taken to a transit station via a shuttle, mobility on demand service, bus, or other provider.

For example, the ICM Concept of Operations for I-394 west of Minneapolis calls for temporary parking at nearby mall or church lots and shuttle buses to the main transit line during events.

Source: Minnesota DOT, Minnesota I-394 Integrated Corridor Management (ICM) Concept of Operations, n.d. Available at: www.dot.state.mn.us/guidestar/2006_2010/icm/mn-icm-stage-1-conops-mar-20081.pdf

STRATEGIES FOR INTEGRATION

Distributing demand across the transportation network in order to make the best possible use of all assets is a fundamental element of the ICM approach. This requires facilitating route or mode shift from overcrowded facilities or services to those with spare capacity. The focus of ICM to date has primarily been on shifting drivers off of the freeway during an incident or heavy recurring congestion. Not as much emphasis has been placed on finding alternatives for moving transit riders through the corridor during a major transit incident, such as a rail line breakdown.

One of the most significant opportunities presented by MOD is the possibility of developing “transit-centric” ICM responses in which MOD options are made available to non-driving travelers so that they can still make their trip when their primary transit route is not available. Possible MOD strategies to realize this opportunity are discussed in more detail below, along with other MOD-related strategies that contribute to an ICM vision and benefits MOD providers and users.

Mobility On Demand Services as Public Transit Bridges or Supplemental Transportation

During major roadway incidents, shifting travelers to public transportation can be an effective means of relieving traffic. However, this requires giving drivers a way to access other forms of transportation, and in many cases parking lots at transit stations may not have available space. Parking may be available at a park-and-ride lot or a temporary lot some distance from a transit station, but travelers still need to get from the lot to the station, and buses may not have spare capacity to accommodate these travelers. Additionally, some drivers who are willing to take transit instead of drive may not be comfortable leaving their vehicle in a public parking lot, but they would be willing to leave it at home or the office parking lot.

MOD services can play a valuable role in these scenarios by functioning as a “bridge” between parking locations and transit facilities. For example, the ICM scenario planning for I-394 in Minnesota calls for “shuttle” services between temporary park-and-ride lots and existing transit stations. An agency could also contract with taxis or other MOD services to deploy a predetermined number of vehicles to serve this bridge function under certain scenarios.

MOD can also supplement the line-haul capacity of transit. This can be beneficial because congestion often occurs during peak periods or special events when transit assets are already in full use. For example, bike sharing provides a limited opportunity for special event pre-planning. Denver’s B-cycle plans for additional storage of bikes at Rockies and Broncos games, and they advertise this event planning to their members. Similarly, car sharing companies may have vehicles already parked at transit park and ride facilities. This could provide a limited number of vehicles to serve a line-haul function in the event of a rail transit ICM scenario. There may also be opportunities for agencies to partner with private bus fleet owners for special events and incidents.

Ridematching Services

Smartphone-based, dynamic ridesharing applications have revolutionized the traditional ridematching services. Casual carpools (arranged at fixed locations at the time a trip is needed) have been popular in some locations for many years. Dynamic ridesharing can also be an effective strategy to support HOV lane use, especially during light incidents that are not deemed severe enough to warrant waiving HOV restrictions or tolls on adjacent managed lanes. Dynamic ridesharing could be particularly effective for evening peak period transit ICM incidents when commuters that rode transit in the morning are seeking an alternative route or mode to get home. In these cases, one viable option could be to share a ride in an HOV or express lane.

Source: FHWA.

Figure 9. Photo. A bike sharing station in Denver, Colorado operated by Denver B-cycle.

An agency could provide designated carpool formation locations (temporary or permanent) to prepare for ICM scenarios. Strategic placement relative to freeway exits, major transit connections, and managed lane/toll access points is critical. Direct connector ramps to serve these locations, as well as carpool queue jumps on ramp meters, can further expedite recovery in a freeway ICM scenario.

En-route messaging can also supplement the ridematching applications by alerting drivers of ridematching options without having to access a smartphone while driving. An agency could further promote this transportation option during ICM events by providing financial incentives, such as reimbursing a riders' payment to the driver in exchange for carpooling. This could also have longer-term positive impacts as drivers and passengers become aware of this service.

Targeted Travel Information for Mobility On Demand Service Providers

In addition to corridor operations benefiting from MOD services, MOD operators could benefit from ICM by receiving tailored information about traffic conditions in their service area. This information may include more detailed traffic data for less-major roadways and incident alerts. Because MOD vehicles do not operate on fixed routes, they have greater flexibility to adjust routes in response to information they receive about prevailing conditions. They could also use this information to determine where high demand pickup locations might be. Information could be provided to a central dispatch center or directly to drivers via a smartphone application or an in-vehicle navigation device.

A key consideration for this strategy is whether it can add value beyond the information available through existing public and private services. In addition to public 511 services, MOD providers may already have access to traffic information through a number of private services (e.g., INRIX, Waze, Google, etc.).

Use of Mobility On Demand Vehicles as Data Probes

Similar to the opportunity for ICM-public transit integration described above, the integration of MOD into an ICM system can provide additional monitoring capabilities. In cases where MOD vehicles are equipped with an AVL system (or through other tracking devices), speed and travel time information could be shared with roadway managers to help them monitor system operations. The value of such arrangements, however, may be mixed. Because MOD trips do not follow specific routes, the amount of data or sample size for a particular route may be limited. Also, these trips may avoid the major (and likely congested) roadways of greatest interest to roadway managers. On the other hand, this may provide information on routes that have little or no other monitoring capability. There is also the issue of possible "data overload" and whether roadway managers can make effective use of this additional input.

It should also be recognized that the use of private vehicles as probes is already being done, to some degree, by private sector entities. Services such as INRIX contract with various fleet operators to access their AVL data to help generate the real-time traffic and congestion maps for their mobile app. Additionally, several private sector firms compile data from various mobile devices (cell phone, blue tooth, navigation systems) to support transportation planning functions. While this typically involves the use of historical data, the time will most likely come when the data is compiled on a more real-time basis. This would provide for a greater dataset beyond just MOD vehicles.

Comprehensive Traveler Mobility Information

As MOD services grow, it is important to recognize their contribution to the overall mobility of the public. Information about MOD services should be shared along with that about traffic conditions, parking availability, and public transit. Combining this information in one place, such as a 511 website, can provide travelers with a more comprehensive understanding of their travel options. The MOD service information provided may include estimated trip time, cost, and how to schedule a ride (e.g., via a direct link to ride request site). However, since MOD services are usually for-profit and compete against one another, care must be taken to be all-inclusive and not show any favoritism toward a particular service.

CHALLENGES TO INTEGRATION

Although strategies for MOD services into corridor operations show potential, there are many challenges associated with this process. While none of the challenges described below are insurmountable, ICM teams should take them into consideration to be sure that they are addressed during the planning and development stages of the ICM project.

Engaging Travelers

For several MOD strategies, the stakeholders who drive the strategy are individual travelers. For example, with peer-to-peer carpooling, drivers provide "supply" in the form of single-occupancy vehicles with room for passengers. This poses several challenges. Contractual arrangements for ICM are not practical with independent travelers, and it is logistically difficult and costly to position these MOD vehicles to match high-demand locations during congested conditions. Additionally, while these services take cars off the road, the carpools that are formed are still subjected to incident traffic delay, especially where HOV lanes are not available.

Public-Private Sector Service Coordination

Many MOD services are run by private sector businesses. One of the challenges to involving the private sector in a public sector initiative, such as ICM, is defining the benefits of participation for drivers, operators, and riders. Creating effective messaging for MOD operators and communicating with a disparate group of travelers are ongoing challenges that will continue as MOD strategies evolve. Drivers for many MOD services are independent operators who set their own schedules, and their compensation is based primarily on distance traveled for the ride provided. They will likely not be interested in line-haul trips during ICM scenarios since they know it will be congested. Furthermore, dead-heading could be significant in incident scenarios, and drivers would not have the opportunity to pick up additional customers. Significant additional incentive would be required to entice drivers to participate.

It may also prove difficult to contract with MOD services providers in order to support corridor operations. For example, it would be difficult for a public agency to contract with MOD services drivers, such as taxi companies, because drivers may be concerned about too much uncertainty and wait time just to deliver short trips, and compensation would need to be significant.

Car sharing and bike sharing would also have very limited and localized applicability in incident scenarios. It could be too labor intensive to dynamically reposition car sharing vehicles to serve high-demand locations, especially since prices for many car sharing companies are based on roundtrip from a specific parking space. It is also highly unlikely that fixed-location bike racks would be positioned near freeway exits. Though bike sharing companies could potentially supply a few loads of bikes to temporary parking lots for cross-corridor bridge trips to transit, they may have a very limited number of trucks to move the bikes to high-demand locations.

Data Sharing

The efficient and effective integration of MOD services within ICM requires clear understanding of these emerging services and their impacts. This understanding is necessary to model and plan for these services, and is achieved through data sharing. However, because most MOD service providers are private entities, there may be apprehensions about and obstacles to this sharing of data. Overcoming this challenge will require public-private partnerships or agreements that clearly define the data that can be shared while addressing business and individual privacy concerns.

Competition with Public Transit

Some agencies may resist ICM approaches that encourage travelers to use MOD services because these services are viewed as competition for public transit. For example, transit operators may worry that MOD services that enable easier carpooling will attract transit riders. In addition, many MOD services enable travelers to make transportation decisions from any location along their route, without having to queue at specific locations. Transit providers may worry that travelers prefer the flexibility of MOD to fixed route transit.

One potential approach to this concern is to convey that MOD strategies will not necessarily take riders from transit, but they may convince SOV drivers to consider alternate modes of transportation. MOD services creates additional choices and flexible alternatives to SOV drivers. MOD services could actually benefit transit ridership, because it is less likely that transit assets will become overcrowded during roadway incidents if demand can be dispersed across more travel options.

In addition, it can be argued that if coordination is executed correctly and new MOD services are employed in the first and last mile access environment to public transportation, MOD may actually drive ridership.

Impact of Technological Change on Mobility On Demand Services

MOD is a growing area that will mostly likely be influenced and shaped by connected and automated vehicle technologies. For example, new services may develop around fleets of driverless vehicles. Market penetration of connected and automated vehicles is not yet high enough to understand what the exact impacts will be on personal mobility. Incorporating a concept as dynamic and unknown as MOD may be difficult; however, setting a framework for partnership with MOD providers now can smooth the transition in the future.

CONCLUSION

Integrated corridor management (ICM) is a practical and logical evolutionary step in transportation operations. As congestion continues to grow, and agencies' ability to expand the roadway network is limited by both space and resources, ICM provides operators with a tool to maximize the capacity of existing roadway infrastructure through active management of all assets along a corridor.

ICM is about moving transportation system users along and around a corridor as efficiently as possible, and public transportation plays a critical role in accomplishing that objective. Trends show that travelers increasingly look to public transit to make all or part of their trips. From their perspective, it does not matter who operates transit, but that they can anticipate a reliable ride. ICM can help agencies meet customer expectations through multimodal strategies that seek to maximize person throughput and enhance personal mobility not just vehicular throughput.

Although current ICM efforts do incorporate transit, sites could take into consideration strategies that are more transit-oriented strategies rather than strategies that consider transit solely as an alternative mode to which travelers should be shifted during congested periods. This primer has explored some of these strategies, such as transit priority treatments, transit incentives, and information sharing and communication between transit and roadway agencies, among transit agencies, and between transit agencies and travelers. These approaches could reap direct benefits for transit agencies and encourage them to participate in an ICM effort.

Perhaps the ICM approach with the greatest potential benefit for transit is the development of transit-centric response plans, in which operational strategies are implemented in response to incidents that disrupt transit service. The rise of mobility on demand (MOD) services such as car and bike sharing, dynamic carpooling, transportation network companies, and others can assist with these response plans by providing increasing options for travelers when they cannot use public transit, or need another option. These services can also help move travelers through the corridor on a day-to-day basis, providing a new type of situational mobility for travelers who choose not to own or regularly commute using a personal vehicle.

While this primer has presented examples of transit- and MOD-related strategies that ICM sites could consider, it does not represent a "one size fits all" model; what works for one region may not work for another. In addition, ICM implementers should be aware of and prepared to address the institutional, operational, and technical barriers associated with these strategies.

Despite these hurdles, the benefits of integrating ICM, public transportation, and MOD services promises a payoff that minimizes the impact of the challenges. As more regions begin to explore an ICM concept for their region, they should think of how to engage these critical stakeholder groups. Ultimately, further collaboration and integration can help further the shared goal of roadway and transit agencies, as well as MOD companies, to provide customers with an efficient and reliable travel experience.

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