Regional Transportation Systems Management and Operations Case Studies

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This case study technical report presents three examples of regionally coordinated transportation systems management and operations (TSMO) programs that highlight how the integration of traffic management systems (TMSs) and organizational coordination across participating transportation agencies may lead to increased effectiveness and optimization of the transportation network. In addition, regional TSMO deployment next steps are provided at the end of the document to help agencies consider how to move forward with implementation within their localities. Use case examples are provided to illustrate the various ways in which these systems are being leveraged and how agencies may benefit from similar deployments.</td></tr>
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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		
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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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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List of Abbreviations

ACTC	Alameda County Transportation Commission
ADM	active demand management
AM	arterial management
ARC	Atlanta Regional Commission
ATC	advanced transportation controllers
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ATDM	active transportation and demand management
ATM	active traffic management
ATMS	advanced traffic management system
ATSPM	automated traffic signal performance measures
ATTAIN	Advanced Transportation Technology and Innovation
C2C	center-to-center
Caltrans	California Department of Transportation
CCTA	Contra Costa Transportation Authority
CFX	Central Florida Expressway Authority
CMAQ	Congestion Mitigation and Air Quality Improvement
CMM	capability maturity model
CO	Central Office
CV	connected vehicle
DART	Dallas Area Rapid Transit
DFE	Data Fusion Environment
DMS	dynamic message sign
DOT	department of transportation
DSS	decision support system
ERE	expert rules engine
EVE	evaluation engine
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FY	fiscal year
GDOT	Georgia Department of Transportation
GTFS	General Transit Feed Specification
HCM	*Highway Capacity Manual*
HOT	high-occupancy toll
HOV	high-occupancy vehicle
HTF	Highway Trust Fund
ICM	integrated corridor management
IEN	Information Exchange Network
IMA	intermunicipal agreement
IOO	infrastructure owner–operator
IT	information technology
ITE	Institute of Transportation Engineers

ITS	intelligent transportation system
KPI	key performance indicator
MOEs	measures of effectiveness
MOU	memorandum of understanding
MPO	metropolitan planning organization
NEMA	National Electrical Manufacturers Association
NOCoE	National Operations Center of Excellence
O&M	operations and maintenance
P3	public–private partnership
PM	afternoon
PRE	predictive engine
RCTO	regional concept for transportation operations
R-ICMS	Regional Integrated Corridor Management System
RITIS	Regional Integrated Transportation Information System
RTOP	Regional Traffic Operations Program
RTSMO	regional transportation systems management and operations
SANDAG	San Diego Association of Governments
SLA	service-level agreement
SMART	Strengthening Mobility and Revolutionizing Transportation
SNMP	Simple Network Management Protocol
SOP	standard operating procedure
TCC	Technical Coordinating Committee
TMC	traffic management center
TMDD	Traffic Management Data Dictionary
TMS	traffic management system
TOL	transit-only lanes
TRB	Transportation Research Board
TSMO	transportation systems management and operations
TSP	transit signal priority
TSS	traffic signal system
UC	University of California
USDOT	United States Department of Transportation
VRU	vulnerable road user
WCCTAC	West Contra Costa Transportation Advisory Committee

1 Introduction

This case study technical report presents three examples of regionally coordinated transportation systems management and operations (TSMO) programs that highlight how the integration of traffic management systems (TMSs) and organizational coordination across participating transportation agencies could lead to increased effectiveness and optimization of the transportation network. A conceptual framework, discussed in **Section 1.2**, is developed as part of this work to support a comparative analysis of each TSMO program, the TMS implemented and the organizational characteristics and capabilities that contribute to attainment of the goals and operational objectives of the program. The conceptual framework builds on existing work and allows the findings within the case studies to be visually presented. The case studies provide an entry point to identify and discuss the challenges, benefits, key lessons learned and capability gaps that may be addressed to attain successful integration of TSMO at a regional level.

The implementation of operational strategies to support the safe and efficient movement of people and goods continues to evolve and change with the technologies that agencies leverage to support attainment of their transportation objectives. Agencies are increasingly implementing TMSs to actively manage and operate their networks, share information with other systems, coordinate with service providers and stakeholders, and coordinate with other agencies in managing travel at a regional level. Within their TMSs, agencies are employing arterial management (AM) and traffic signal systems (TSS), active transportation and demand management (ATDM), and integrated corridor management (ICM) to improve their capabilities and increase the efficiency of the full breadth of the transportation network. ATDM, ICM, and TSS operational strategies naturally overlap. This document makes the case that organizational coordination to support regional integration of TMSs could promote seamless travel throughout the transportation network, improving safety, mobility, and reliability for all modes while reducing operational costs. However, organizational coordination and integration of TMSs at a regional scale is challenging. Evidence of this challenge is the lack of compelling documentation on the benefits of regional transportation systems management and operations (RTSMO), despite the substantial investment in these systems nationally over the past two decades. This document leverages a review of regional management and operations programs nationally, selecting three case studies for more in depth exploration of the characteristics of these systems and factors that contribute to their success. A key finding from the national review of integrated TMSs was a focus on either arterial *or* freeway management with few examples of systems that fully integrated arterial and freeway systems. Multimodal integration is exceedingly rare; a number of programs state an intent to integrate in planning documents but have not fully realized integrated multimodal systems.

The desired outcome of this document is to provide a resource for industry practitioners to gain insight into how peer agencies are implementing regional integration, the proven benefits, potential barriers and challenges, and the factors contributing to a successful implementation. In addition, the findings from the literature review and case studies illuminated gaps within the industry, presenting an opportunity to recognize and chart the path toward a fully integrated system.

1.1 Background

The roads in a region include local, collector, arterial and freeway networks that provide static regional connectivity. The management and operation of the transportation network influences the safety, mobility, and reliability of the transportation system. Travelers have a primary interest in safely and efficiently traveling between multiple origins and destinations with little awareness of the complexity of the jurisdictional boundaries and limitations of the TMSs involved in ensuring a reliable and safe traveler experience. The TMSs provide a dynamic component to the transportation system that directly influences the traveler experience through its capability to actively manage infrastructure, optimize capacity, address incidents, manage system performance, and provide information to guide pre- and en route travel decisions. Travelers realize these benefits to an even greater extent during emergencies, events and large-scale incidents when managing agencies have the capability to optimize traffic at a regional scale. Additionally, State and local agencies have the opportunity to share resources and increase effectiveness through the use of RTSMO, reducing operational costs and gaining efficiency (FHWA 2022b).

1.1.1 Regional Integration Foundation

The benefits of regional coordination and system integration are recognized by providing resources and guidance on regional intelligent transportation system (ITS) architectures and systems engineering. Encouragement and support for the implementation of integrated systems was provided through the funding of pilot implementation initiatives such as the United States Department of Transportation (USDOT) ICM initiative and demonstration sites, grant funding opportunities, provision of technical assistance and training, and documenting and sharing lessons learned and notable practices. The following initiatives and programs have provided foundational support to State and local agencies leveraging RTSMO strategies.

- **Regional Concept for Transportation Operations (RCTO).** The RCTO aims to enhance transportation operations and management across a specific region. FHWA drove this initiative, grounded in systems engineering analysis, and collaborated with four selected demonstration sites to promote collaboration and coordination among agencies, stakeholders, and operators. The goal was to improve the efficiency, safety, and reliability of the regional transportation system. The program helps collaborating agencies in reaching a consensus on regional needs, goals, and objectives, resulting in the development of a 3-to-5-year action plan (Bauer, Smith, & Pecheux 2011).
- **Coordinating the Management of Traffic in Corridors.** The ICM initiative aims to improve the efficiency and performance of transportation corridors using ITS strategies and innovative practices. The initiative emphasizes collaboration between agencies and stakeholders to optimize the use of all relevant components of the regional infrastructure network, jointly manage congestion, and more efficiently move people and goods within a corridor. ICM focuses on the coordination of individual network operations, including freeway, arterial, and transit, between adjacent facilities, creating an interconnected system capable of cross-network travel management (FHWA 2020).

- **Actively Managing Traffic.** The ATDM program combines active management initiatives with demand management strategies to improve the efficiency and sustainability of transportation systems. ATDM is a proactive and dynamic approach to managing and influencing travel demand, traffic demand, and traffic flow (shown in **figure 1**). With this approach, the performance of the transportation system is continuously evaluated, and dynamic actions are assessed and implemented in realtime to achieve specific performance objectives, such as maximizing system efficiency, improving safety, reducing congestion, or promoting multimodal travel. The ATDM Program provides industry professionals with tools and methods for performance and cost-benefit analyses as well as training for those interested in deploying the ATDM strategies (FHWA 2022a).

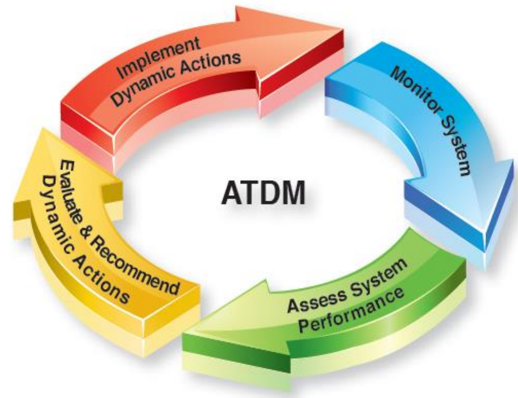


Figure 1. Diagram. The elements of ATDM.
Source: USDOT

- **Arterial Management/Traffic Signal Systems.** The Arterial Management Program aims to optimize the efficiency and effectiveness of arterial roadways throughout the Nation. The goal of the Arterial Management Program is to achieve increased safety, mobility, and efficiency for all travelers through the use of objectives and performance-based approaches to traffic signal management that improve design, operations and maintenance practices. Central to the program is the implementation and enhancement of advanced traffic signal systems that are designed to efficiently regulate vehicular, pedestrian, and bicycle movements at intersections. By incorporating ITS and traffic signal management technologies, traffic signal systems support the Arterial Management program's goal of improving safety, minimizing congestion, and enhancing mobility for all users (FHWA 2022c).

The common thread between these programs is the idea that integration within and across transportation facilities and collaboration between operating agencies can improve the safety and reliability of the transportation system, providing seamless, regional multimodal travel for all users. The case studies highlighted in this document demonstrate the benefits and challenges of regional mobility management.

1.2 Guiding Case Study Framework

The concept of RTSMO is defined as "transportation systems management and operations applied at a regional level" (FHWA 2023a). Agencies have implemented RTSMO through various integrated strategies and applications across the country with demonstrated success. The team reviewed an extensive body of literature related to a variety of RTSMO deployments to understand the state of practice (described in **Section 2**). The full list of RTSMO deployments reviewed is available in **Appendix III**.

The literature and case study review findings demonstrate that regionally integrated systems are complex and multifaceted, each deployment relying more heavily on those mature relationships and system components within their region which varies greatly by deployment and agency. While researching existing deployments and reviewing the case studies for this document, the project team determined that a framework was necessary to provide a consistent way of describing the context and components within which agencies are leveraging RTSMO throughout the industry.

The framework provides a method of clearly communicating the characteristics and key information related to the common regional integration elements that were identified within the literature and case study review. The framework describes the transportation network within the context of the freeway, arterial, and multimodal (primarily focused on transit at this time) network layers. Implementing agencies typically manage and operate their systems within these network layers and can relate to integrating regionally within the layer with adjacent jurisdictions or between network layers (i.e., freeway and arterial integrated systems). Regional integration activities can be characterized by institutional, systems, and operational integration. The team found that agencies are typically stronger within one area and rely much more heavily on that area for success. Thus, describing regional integration within this context allows practitioners to gain a clear understanding about opportunities for growth and how others in the industry are succeeding in areas that they are finding more difficult.

The following sections fully describe the RTSMO conceptual framework.

1.2.1 Regional Transportation Systems Management and Operations Conceptual Framework

Rooted in the Safe Systems Approach and guided by the TSMO Capability Maturity Model (CMM), the RTSMO conceptual framework incorporates the institutional, systems, and operational integration of surface transportation system (freeway, arterial, and multimodal transportation network layers) at a regional scale. **Figure 2** provides a graphical representation of the RTSMO conceptual framework where the regional surface transportation system is represented in the middle of the diagram, surrounded by the operational, institutional, and system areas of a regional program.

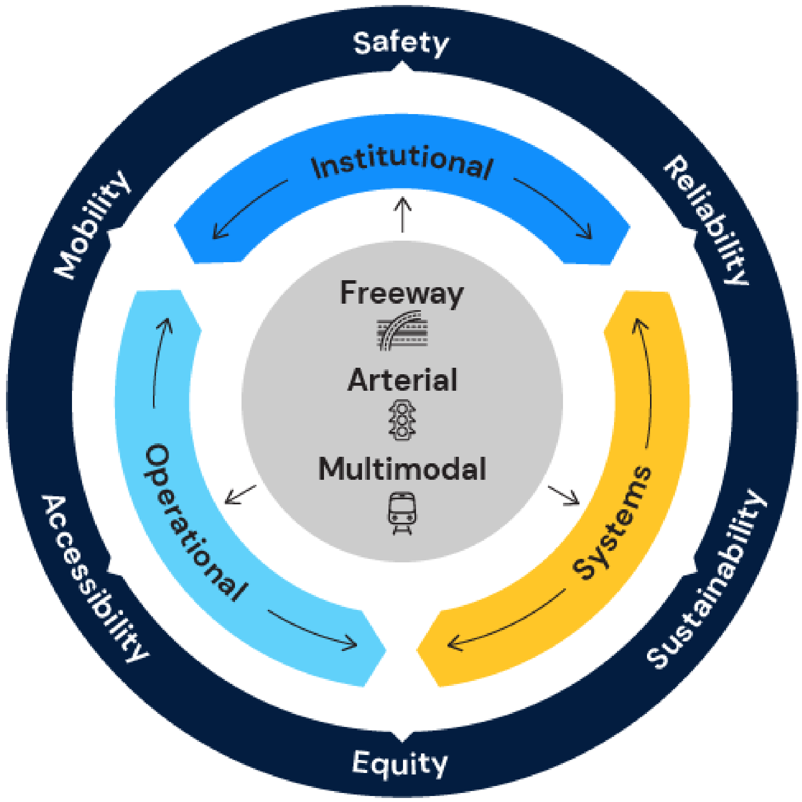


Figure 2. Diagram. The regional transportation systems management and operations case study framework.
Source: FHWA 2023

These three areas of a regional program need to be coordinated and integrated to actualize the system, enabling the attainment of goals including safety, mobility, reliability, sustainability, and accessibility. The conceptual framework is applied to the case studies to provide a visual reference of what areas of a regional program are being coordinated (institutional, operational) and the systems that are being integrated across the networks (freeway, arterial, multimodal).

1.2.1.1 Regional Surface Transportation System: Physical Networks

The comprehensive surface transportation system can be described within the context of the following three physical network layers: freeway, arterial, and multimodal (shown in **Figure 3**). Integration can occur within a particular layer or between network layers. Each surface transportation system network layer is described below within the context of the RTSMO case study framework.

Figure 3. Diagram. The surface transportation system network layers.

Source: FHWA 2023

Freeway. The freeway network layer consists of the physical infrastructure and systems that provide the supply and capacity management capabilities of the freeway system. The Highway Capacity Manual defines a freeway as a divided highway with full control of access and two or more lanes for the exclusive use of traffic in each direction providing uninterrupted flow (FHWA 2017). Freeways are classified as roadways with directional lanes that are separated by a physical barrier with limited access points at on- and off-ramp locations or at-grade intersections (FHWA 2017). Freeway operations have a primary focus on improving safety and reducing congestion. FHWA's **Freeway Management Program** promotes integrated and well-coordinated freeway systems with proactive freeway management and provides State agencies with support to enhance the safety, efficiency, and dependability of travel across the Nation's freeway network. State agencies provide traveler information and manage incidents to encourage smooth and uninterrupted movement along freeways within a region. Integration with stakeholders through the use of lane management strategies such as high-occupancy vehicle, high-occupancy toll, or express lanes further enhances freeway operations and improves regional mobility. Freeway network performance and reliability can be even further enhanced through integration with arterial networks and multimodal networks, resulting in a more efficient transportation network. Integration is possible through effective shared systems, data, and information as well as communication, coordination, and resource sharing, especially during congested conditions or large events.

Arterial. The arterial network consists of the physical infrastructure and systems that provide the supply and manage the capacity of arterial roadways and the nodes that connect them. The arterial network includes multiple types of roadway classifications: arterial roads, collector roads, and local roads. Each of these roadway classifications making up the arterial network has different characteristics and plays a different role in connecting the roadway network, and the level of mobility and accessibility provided to vehicles, pedestrian and bicycles, and other mobility devices to access land use. Principal arterials are high-capacity roads that are designed to facilitate the efficient movement of large volumes of traffic with access points at signalized intersections, connecting travel between central business districts and residential areas. Minor arterials connect and augment the principal arterials and provide more frequent access points. Collector roads serve as connectors with nodes linking local roads to arterial roads at signalized intersections, with frequent access points but limited access to direct driveways. Local roads are primarily for access to residences, businesses, and other properties and make up the largest percentage of roadways (FHWA 2017). State and local agencies manage arterial networks, facilitating local and regional mobility and providing access to traveler destinations. As previously discussed, travel within this network layer varies significantly given the variety in roadway characteristics. Arterials tend to be managed by local agencies with limited coordination between jurisdictions. Agencies can achieve a seamless and interconnected arterial network by integrating within and across jurisdictional boundaries to promote coordinated traffic signal systems operation. Significant cost savings and efficiencies may be realized by integrating and consolidating traffic signal operations and management systems. In general, coordinated traffic signal operations have been proven to improve traffic flow, minimize delay, enhance safety, and increase reliability. The arterial network can be integrated with the freeway network and multimodal network by leveraging active management strategies such as ICM to further enhance and optimize the transportation network.

Multimodal. The multimodal network layer includes the physical infrastructure and systems to support public transit, cycling, walking, rolling, and ridesharing. Examples of infrastructure in this layer include light-rail lines, dedicated bus lanes, dedicated bike lanes, multiuse paths, and sidewalks. Although the multimodal network consists of different modes and infrastructure, for the purpose of this document and based on the findings of the case studies provided in later sections, discussion of the multimodal network will focus on public transit.

Managing agencies are typically local transit agencies or local public works departments, which tend to operate differently from State and local departments of transportation (DOTs). Integration with collaborating multimodal agencies and various modes of transportation involves developing interconnected infrastructure, shared information systems, and coordinated operations and schedules. Multimodal networks can be further enhanced through integration with the freeway and arterial network layers to improve the complete trip travel experience in many ways, such as providing real-time information to travelers on transit schedules, notifying bus operators of riders' needs, and improving on-time performance. This integration enhances accessibility, convenience, and efficiency within the layer of multimodal networks and services, while also promoting sustainable and efficient transportation.

Although there is significant effort to optimize each layer of the transportation system, the maturity of that integration across the regional transportation network varies by deployment agency and type.

1.2.1.2 Program Areas and Levels of Integration

The potential integration between each network layer presents an opportunity for improvement to achieve system-level benefits. By better understanding the opportunities for integration, there can be greater realization of these system-level benefits. The RTSMO conceptual framework describes coordination and integration across the following areas of a regional program.

Institutional. Coordination and collaboration form the foundation for successfully integrating regional systems. Formal institutional arrangements and partnerships emphasize continuous collaboration to fulfill the responsibilities throughout the deployment lifecycle, ensuring that all stakeholders actively support the effort and take ownership of the program and operations. Institutional integration corresponds to the culture, organization and workforce, and collaboration dimensions of the CMM for TSMO, which can be used to guide the assessment and maturation of an agency (FHWA 2016).

Types of institutional arrangements and partnerships that were found to be successful within the RTSMO deployments reviewed include:

- Institutional, shared-use, interagency agreements
- Regional agencies as a facilitator

- Regional coalitions

Systems. Systems integration involves connecting and making disparate systems work together—this includes both physical and logical systems (Kuciemba, Jacobson, Mizuta & Nguyen 2023). Systems integration involves significant technical expertise and experience with each hardware and software component. One approach USDOT and industry leaders have adopted to reduce the complexities associated with systems integration is to encourage and maintain a strong focus on standards-based systems, systems engineering, and ITS architecture. This approach ensures that proprietary components do not limit agencies' ability to integrate as new technologies and systems continue to emerge.

Systems integration corresponds to the systems and technology CMM dimensions. Industry practitioners are currently leveraging integrated transportation management systems, such as:

- Transportation management center (TMC) systems
- Network communication and security
- Shared field hardware and software systems

Operational. Operational coordination of freeway, arterial, and multimodal networks regionally is complex and involves modifications to agency methods and procedures for success. Operational integration should start with developing shared operational objectives that consider the shared goals and context of the freeway and arterial networks and the dynamics of the multimodal layer. Modifying these methods and procedures can affect traveler safety positively. To ensure this, all parties need to understand the goals, objectives, timeline of events and how their approach may need modifications to support integration.

Industry professionals can mature their operational integration by leveraging resources available through the ATDM Program. In addition, by assessing and understanding their status, agencies can consider operational integration within the context of the business processes and performance management dimensions of the CMM TMSO framework. The following are examples of integrated operational strategies that agencies are currently implementing to support RTSMO:

- Integrating traffic signal timings across jurisdictional boundaries
- Sharing information and data to enhance collaborating agency efficiency
- Coordinating demand management strategies regionally
- Coordinating and integrating with public transportation agencies to enhance reliability and the travel experience

1.3 Document Overview

This report highlights three government programs chosen for case studies that document their methods and lessons learned about working together, using resources, and considering both technical and nontechnical aspects. Interviews were conducted with representatives from each of the selected case study programs to better understand the qualitative and quantitative deployment benefits, challenges, and lessons learned. The remainder of this document consists of the following sections and content:

- Section 2. State-of-the-Practice Summary

- Section 3. Regional Transportation Systems Management and Operations (RTSMO) Case Studies
- Section 4. Case Study 1: Interstate 80 Integrated Corridor Mobility Program
- Section 5. Case Study 2: District 5 Regional Integrated Corridor Management Program
- Section 6. Case Study 3: SigOps Program
- Section 7. Summary of Findings
- Section 8. RTSMO Deployment Next Steps
- Appendix I. References
- Appendix II. Bibliography
- Appendix III. Database of Deployments

1.4 Key Terms

Industry professionals tend to broadly use terms to describe RTSMO and integrated strategies of varying degrees. For the purposes of this technical report, the following key terms and definitions are used throughout:

- ATDM: ATDM is the capability of an agency to improve trip reliability, safety, and throughput of the surface transportation system by dynamically managing and controlling travel and traffic demand, and available capacity, based on prevailing and anticipated conditions, using one or a combination of real-time operational strategies (FHWA 2022a).
- ATM: Active traffic management (ATM) is the ability to dynamically manage recurrent and nonrecurrent congestion based on prevailing and predicted traffic conditions (FHWA 2023a).
- ADM: Active demand management (ADM) uses information and technology to dynamically manage demand, which could include redistributing travel to less congested times of day or routes or reducing overall vehicle trips by influencing a mode choice (FHWA 2023b).
- ICM: ICM is the coordination of individual network operations, including freeway, arterial, and transit, between adjacent facilities that creates an interconnected system capable of cross-network travel management (FHWA 2020).
- TSMO: TSMO is an integrated set of strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system (FHWA 2023c).

2 State-of-the-Practice Summary

The state-of-the-practice review provides an overview of existing integrated traffic signal, TMSs, and service providers throughout the country. The team reviewed an extensive body of literature to understand the state of the practice, which included published material from the USDOT, National Operations Center of Excellence (NOCoE), Institute of Transportation Engineers (ITE), Transportation Research Board (TRB), FHWA ATDM Program, along with readily available information in the form of fact sheets, presentations, and project websites. The team used information and knowledge from the larger project team to supplement the gaps in the literature where necessary.

2.1 Typical Goals and Objectives

The reviewed programs primarily aimed to increase mobility using various integrated systems and operational strategies. Typical goals and objectives of the programs reviewed include:

- **Goals:**
  - **Improve safety.** This goal is critical for all agencies. Improved safety within the context of integrated deployments is related to reducing crashes due to reduced congestion and smoother traffic progression.
  - **Mitigate impact of incidents.** Mitigate the impact of incidents and improve incident management by providing means for communicating consistent and accurate information regarding incidents and events between transportation networks and public safety agencies. This approach ensures an integrated and coordinated response among stakeholders.
  - **Improve transit mobility.** Increase transit mobility by enhancing the efficiency of transit, increasing coverage, and providing real-time information to travelers. Initiatives such as bus-on-shoulder programs, transit-only lanes, and transit signal priority (TSP) have been proven to increase transit travel time reliability and ridership.
  - **Support economic development.** Foster economic development through initiatives that optimize existing infrastructure, enable seamless transport of goods and people, and improve connectivity and accessibility, contributing to the growth of the region.
- **Objectives:**
  - **Improve efficiency.** Maximize the efficient use of corridor capacity, reducing delays on other saturated networks, facilitating intermodal transfers, as well as route and mode shifts, and improving preplanning for events and incidents.
  - **Support institutional coordination.** Provide better information and coordination of multiagency jurisdictions and develop an institutional platform for managing and operating multiple transportation systems across disciplines and jurisdictions.
  - **Improve travel time reliability.** Reduce delays throughout the corridor to improve travel predictability and reliability.
  - **Improve capability of existing systems.** Enhance the capability of existing systems to better manage and operate traffic and share information between systems.

2.2 Typical Programs and Strategies

FHWA's *Freeway Management and Operations Handbook* defines a program as a coordinated, interrelated set of strategies, procedures, and activities. The variation in programs and their supporting strategies depends on the goals and objectives of the deployment and the characteristics of the deployment area. **Table 1** shows programs typically found within integrated deployments, such as ICM, ATM, and ADM along with the strategies commonly associated with them.

Table 1. Typical programs and strategies.

Program	Common Strategies
Integrated Corridor Management (ICM)	• Prearranged standard operating procedures (SOP) • Proactive interagency engagement • Decision support systems (DSS) • Real-time traveler information • Dynamic wayfinding • Modified signal control • Modified ramp metering • Increased transit capacity
Active Traffic Management (ATM)	• Variable speed limits • Adaptive signal control • Dynamic junction control • Adaptive lane use • Adaptive ramp metering • Part-time shoulder use • Queue warning • Transit signal priority • Dynamic merge control • Dynamic lane reversal
Active Demand Management (ADM)	• Dynamic pricing • Managed lanes • High-occupancy vehicles • High-occupancy tolls • Dynamic ridesharing • On-demand transit • Dynamic routing • Predictive traveler information

2.3 Institutional, Systems, Operational Integration

The following sections summarize the state of the practice of program institutional, systems, and operational integration from the literature review findings.

2.3.1 Institutional Integration

Institutional integration refers to the process of agencies establishing formal or informal arrangements and partnerships to achieve successful integration of RTSMO. Successful institutional integration offers benefits such as enhanced collaboration, shared resources, and a common understanding of roles and responsibilities.

Currently, successfully leveraged methods of institutional integration related to arrangements and partnerships include:

- **Institutional, shared-use, interagency agreements –** Agencies often establish formal agreements to define terms for shared resources, service-level expectations, and roles and responsibilities of stakeholders. This method promotes a common understanding of the concept and instills confidence in those operating shared assets. These formal agreements vary by deployment and agency but may include a memorandum of understanding (MOU), service-level agreements (SLAs), maintenance agreements, or others.
- **Regional agencies serving as facilitators –** Regional agencies can play a role in ensuring coordination and cooperation in regional transportation planning. They can efficiently support multiagency integrated deployments through pre-existing relationships and standing coordination committees. Integrated deployments have leveraged regional agencies to facilitate collaboration and institutional partnerships within a given metro area. Metropolitan planning organizations (MPOs) often have standing committees with TSMO-focused initiatives that may include RTSMO deployments. MPOs are often well-positioned to lead and fund planning efforts.
- **Public-private partnerships (P3) –** P3s offer nontraditional partnerships where public agencies collaborate with private entities to deploy integrated solutions. These partnerships are commonly used in tolling facilities and can integrate enhanced management strategies with adjacent arterials or demand management efforts.

Successful methods of institutional integration related to funding and leadership include:

- **Federal Discretionary Grant Program Funds –** Federal funding opportunities are available through various discretionary grant programs such as the ICM initiative, Advanced Transportation Technology and Innovation Program (formally Advanced Transportation and Congestion Management Technologies Deployment), and the Strengthening Mobility and Revolutionizing Transportation (SMART) Program.
- **State and Regionally Programmed Funds –** State and regional agencies such as State DOTs, MPOs, or government collaborations, have broader jurisdictions and are responsible for managing Federal formula program funding streams such as the Highway Trust Fund Surface Transportation Block Grant Program, and Congestion Mitigation and Air Quality Improvement program.
- **State Leadership –** State agencies, particularly State departments of transportation (DOTs), often take the lead in integrated deployments. They have the expertise and

responsibility to manage freeway facilities that span multiple jurisdictions, making them well-suited for collaborative efforts in integrating arterial and freeway systems. Additionally, State DOTs are familiar with overseeing large-scale capital projects and have the necessary resources for such endeavors. State-funded deployments typically prioritize freeway management because it falls within the jurisdiction and control of State agencies. For example, when integrated deployments include toll facilities, close coordination and sharing of responsibilities between State DOTs and toll authorities are critical. Effective collaboration between the two entities ensures smooth integration between both arterial and freeway systems, facilitating efficient traffic flow and toll collection operations.

- **Regional Leadership –** Regional agencies, including MPOs, government collaborations, and regional transit agencies, play a notable role in leading and facilitating successful integrated deployments. With their wider jurisdiction, these agencies are well-positioned to coordinate and oversee multiagency collaborations. They are often responsible for programming and planning within their respective areas, while collaborating agencies take ownership and operation of facilities. In many cases, regional agencies initiate projects and provide leadership during the concept development phase, subsequently transferring the responsibility to owners and operators for design and deployment.
- **Local Agency Leadership –** The shift to alternative funding mechanisms and shared arrangements enables smaller agencies to secure and manage larger projects in the realm of local agency-led integrated deployments. This approach has proven successful when local champions of a particular deployment are invested in and fully supportive of the project.

2.3.2 Systems Integration

Systems integration refers to the process of connecting and sharing information between different systems, components, and devices. Integration allows disparate systems to share information and coordinate their operation and control of traffic. Successful integration enables a system to perform with improved coordination, data sharing, and operational efficiency. Systems integration can be the most challenging technical aspect of any TSMO deployment. Connecting and making disparate systems work together involves significant expertise and experience with each hardware and software component. Furthermore, with the advent of emerging technologies and advanced operational tools, there are a significant number of potential systems to be integrated. This provides an even greater opportunity to leverage integrated systems to support enhanced arterial and freeway management but also increases the complexity of the technical considerations. As mentioned previously, USDOT and industry leaders encourage development based on national standards such that systems are able to better integrate and provide deployers flexibility.

Typical components considered for systems integration include:

- **Traffic Management Systems (TMS) –** As described by FHWA's Review of Traffic Management Systems – Current Practice, a TMS is a system that comprises a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. TMSs are focused on improving the efficiency, safety, and predictability of travel on the surface transportation network.

These systems are critical to an integrated arterial, freeway management deployment, and a lead agency primarily manages and operates them. Next-generation TMSs are dynamically evolving in capability and technology, providing a more modern and advanced approach to traffic management.

- **System Configuration –** The physical configuration of managing systems greatly influences the level of complexity of integration. Each collaborating agency commonly has an independent system with unique hardware and managing software. System configurations are either distributed or central. Integration tends to be significantly easier and much more scalable if managed through a central system without the need for lookup tables or directed connections.
- **Network Communication –** Network communication provides the foundation by which any technology deployment is built. The provision of higher capacity communications through agency-owned fiber is often a key element within an integrated deployment as support for additional infrastructure elements and for communication gap closures. Some collaborating agencies have existing secured connectivity or center-to-center connections that are used to share video or access data. These connections can be leveraged to integrate further systems or expand capacity to support integrated deployments.

  However, in the absence of existing connections, collaborating agencies sometimes struggle to integrate or provide connections between networks. Establishing a secure connection between networks involves significant coordination and shared understanding of security policies and requirements that should be approached individually—not in a "plug-and-play" fashion. Network integration involves coordination and support from collaborating agency information technology (IT) departments and a familiarity with security standards of ITS devices (e.g., National Electrical Manufactures Association TS 8) as well as networking devices (e.g., IEEE 802.11).

2.3.3 Operations Integration

Agencies may need to establish dedicated processes for managing and maintaining their assets to provide safe, reliable travel for RTSMO operations.

Integrating the operations of traffic signal systems and freeway management strategies like ATDM and ICM is complex and agencies may need to modify their methods and systems to achieve success.

Modifying these methods and systems could impact traveler safety. To encourage a positive impact, all parties should understand the goals, objectives, timeline of events, and how their system may need modification to support integration. It is crucial to gain the trust and support of system operators, those who are directly responsible for the safe and efficient operations of their networks. The current state of the operational methods for RTSMO integration within the context of the transportation network include:

- **Integrating Freeway and Arterial Management –** Freeway and arterial traffic signal management operators have different priorities, which can sometimes conflict. While arterial operators focus on optimizing network traffic flow and maximizing vulnerable road user safety, freeway operators are primarily focused on freeway progression that may negatively impact the adjacent arterial network when ramp metering is implemented, and route diversions are suggested. Current integrated deployments have implemented various methods to support successful integration of arterial and freeway traffic signals. Interagency agreements such as MOUs or SLAs may be executed to allow access to collaborating agencies' traffic signals for the purpose of responding to incidents after hours or of significant impact.

- **Integrating Public Transportation –** The integration of strategies and tactics to support more efficient transit or encourage mode shift with RTSMO is currently in use; however, there is an opportunity to more fully engage transit-centric strategies to benefit travelers. There is a growing interest in incorporating these strategies such as the use of TSP on diversion routes to support more efficient transit service. In several locations, integration of freeway facilities with managed lanes and park-and-ride facilities that include transit options have effectively proven the benefits of public transportation. By leveraging transit incentives and information sharing, these strategies can further support more efficient operations and encourage mode shift.
- **Integrating Demand Management –** There have been limited integrated operational deployments in which ADM has been fully leveraged to support enhanced mobility through demand management. Although strategies that integrate active response to influence demand (i.e., dynamic fare pricing to encourage mode shift to transit or dynamic incentives for high-occupancy travel) are commonly used and many systems have integration with their TMCs to some degree, few deployments have leveraged operational integration to its full potential. The I–15 ICM deployment in San Diego and the U.S. 75 ICM deployment in Dallas are two notable examples of integrated operational deployments that have leveraged demand management and proven the benefits of integrated corridor management.

2.4 Summary of Findings

Efforts to improve traffic management have the potential to provide significant safety, mobility, reliability, and sustainability benefits. Several multiagency initiatives, including San Diego, Dallas, Atlanta, and Phoenix, have deployed integrated strategies that explore opportunities to improve their traffic management capabilities. However, in doing so, they have encountered challenges such as technological limitations of legacy arterial systems, the inability to fully leverage ADM, and difficulties in analyzing the relative operational tradeoffs between strategies focused on shifting demand versus increasing capacity.

In addition to technical issues related to systems integration, achieving consensus on policies, practices, standards, staffing, cultures, and operational priorities among collaborating agencies, adjacent jurisdictions, or even within departments can be difficult. This has led to deployments that, although well intentioned, have primarily focused on enhanced mobility strategies for arterial *or* freeway management. This approach results in a system that acknowledges the benefits of integration without addressing all aspects needed to deploy a fully integrated, harmonious system. Many of those integrated deployments active today are of this nature and have been seen to have a difficult time remaining sustainable. Challenges to sustain the integrated deployment include maintaining the required agency leadership support, funding, partnership agreements, as well as hardware and software system consistency.

3 Regional Transportation Systems Management and Operations (RTSMO) Case Studies

The following case studies expand upon and explore the initial findings of the literature review. The case studies provide industry practitioners with practical information, encouraging and supporting their efforts to plan and improve traffic management within their region, jurisdiction, or a corridor.

3.1 Case Study Exploration Process

The project team provides information related to each deployment's approach, lessons learned, resources, and technical and nontechnical considerations for improving how agencies manage traffic within specific transportation corridors. The case studies also include a discussion of deployment benefits, challenges, and practices for other practitioners to learn from, demonstrating the business case for integrating the systems agencies and different service providers use to manage traffic within these corridors.

3.1.1 Literature Review

The project team conducted a literature review to research and review existing integrated plans, systems, and deployments around the country and documented common characteristics, successful approaches, and noted challenges within the program areas of ATM, ADM, and ICM. The team reviewed published material from USDOT, NOCoE, ITE, and TRB as well as the FHWA ATDM Program. Additionally, the team reviewed readily available information in the form of fact sheets, presentations, and project websites to expand the understanding of the current state of practice.

3.1.2 Selection Process

During the process of researching and reviewing relevant literature pertaining to the deployment of integrated systems, the team created a database of more than 40 ADTM and ICM deployments from around the Nation, which can be found in **Appendix III**. The database provides information including each deployment's lead agency, geographic extent, goals and objectives, strategies and tactics, funding, etc.

The team selected the three deployments shown in **table 2** for further exploration because all three had been deployed and operational for a substantial amount of time. They share deployment benefits, challenges, lessons learned, and best practices with industry professionals. Furthermore, these deployments provide an example of how an integrated deployment may evolve over time to provide further reaching benefits within a larger regional area.

Table 2. Deployments selected for further study.

Deployment	Lead Agency	Brief Description
I–80 Integrated Corridor Mobility (I–80 ICM) Project	California Department of Transportation (Caltrans)	The I–80 ICM Project uses ITS technologies to enhance the effectiveness of the existing network through freeway management, diversion routing to parallel arterials, and transit system management.

Deployment	Lead Agency	Brief Description
Florida District 5 (D5) Regional Integrated Corridor Management (R-ICMS) Program	Florida Department of Transportation (DOT)	The Florida DOT D5 R-ICMS Program uses advanced arterial traffic signal timing, ramp metering, TSP, emergency vehicle preemption, traveler information (including 511 and a third-party GPS application), and emergency shoulder use.
SigOps Program	Georgia DOT	The SigOps Program leverages technology, advanced operational methodologies, and collaboration to monitor and optimize traffic flow throughout the State.

3.1.3 Case Study Interviews

The project team conducted virtual interviews with representatives from each of the selected deployments to gain a better understanding of the deployments from practitioners directly involved in developing and implementing them. The interviews, lasting 60 to 90 minutes, helped the team collect available information, such as understanding shared stakeholder objectives, institutional and governance frameworks, financial mechanisms and frameworks used, quantitative and qualitative benefits, institutional and organizational agreements (including data-sharing agreements), approach to stakeholder engagement and buy-in, technology constraints, geographic constraints, approach to day-to-day operations and operator feedback, performance measures, performance reporting, and operational impacts/influence outside of the deployment area. The team shared the completed case studies with the interviewees for review and feedback and gathered additional information where necessary.

3.2 Regional Transportation Systems Management and Operations (RTSMO) Case Study Context

The RTSMO concept can be described within the context of transportation network layers and the interfaces, or integration elements, within and between those layers. **Figure 4** provides a graphical representation of RTSMO. Institutional, operational, and systems integration are represented within each layer as blue, teal, and yellow circles, respectively. Vertical gray lines between layers represent the integration interfaces between network layers. The presence of all integration elements and interfaces represents a fully integrated management system.

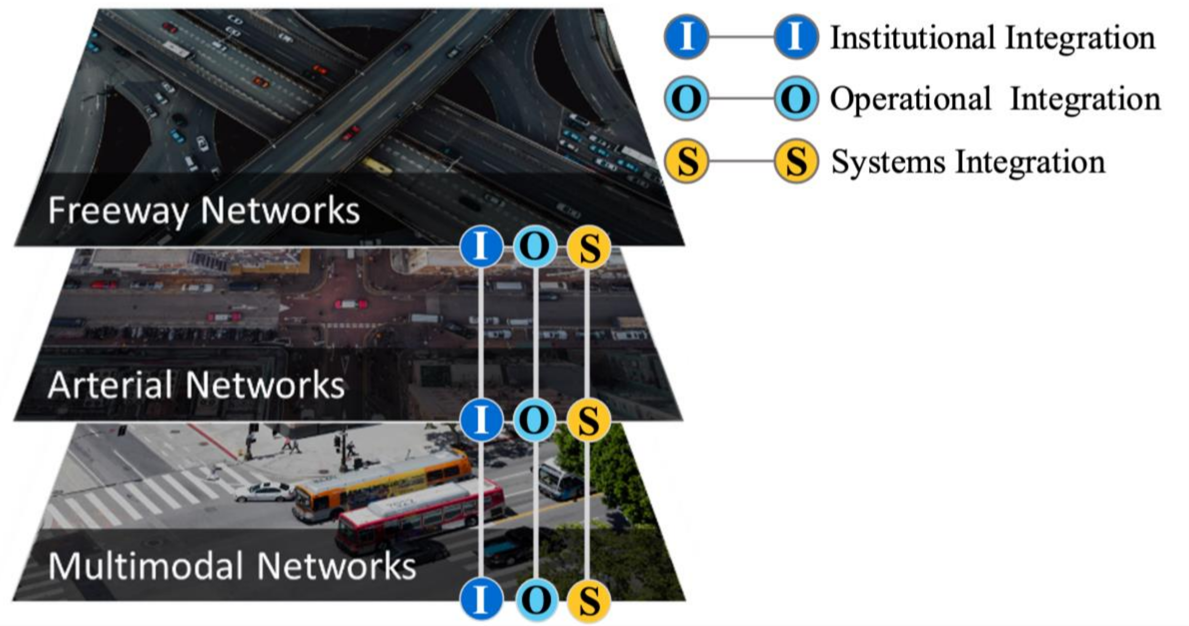


Figure 4. Diagram. The surface transportation system network layer integration.
Source: FHWA 2023

Each of the following case studies uses this diagram to graphically represent the existing elements of the deployment. It should be noted that the case studies are not expected to have all aspects of integration. Integration varies by deployment goals, priorities, and constraints.

4 Case Study 1: Interstate 80 Integrated Corridor Mobility Program

The I–80 SMART Corridor Project (I–80 Integrated Corridor Mobility) was initiated with the goal of improving safety, reducing travel times, maximizing the flow of the existing transportation network for all modes, and incorporating measures to reduce air pollution and greenhouse gases. The deployment uses ITS technologies to enhance the effectiveness of the existing network through freeway management, diversion routing to parallel arterials, and transit system management. The project also operates an incident management plan involving incident signal timing plans and the use of trailblazer signs that provide traveler information along San Pablo Avenue.

4.1 Deployment Background

The segment of I–80 between the Carquinez Bridge and the San Francisco-Oakland Bay Bridge, shown in **Figure 5** is one of the most congested corridors in the San Francisco Bay Area. Traffic demands on the freeway far exceed the roadway capacity, causing severe congestion, unreliable travel times, and traffic diversion to the local arterials. The primary goal of the I–80 ICM Project is to enhance the effectiveness of the existing transportation network, including the freeway, ramps, parallel arterials, crossing arterials, and transit service in Alameda and Contra Costa Counties.

Stakeholders include California Department of Transportation (Caltrans), Alameda County Transportation Commission, Contra Costa Transportation Authority, West Contra Costa Transportation Advisory Committee, Contra Costa County, AC Transit, WestCAT, and the Cities of Oakland, Emeryville, Albany, Berkeley, El Cerrito, Richmond, San Pablo, Pinole, and Hercules.

Figure 5. Map. I–80 SMART Corridor.

Source: [ITS International: I–80 SMART Corridor Sets the ITS Standard for California's Bay Area]

4.2 Deployment Overview

The I–80 ICM Project, deployed in 2017, aimed to create an integrated system that leverages advanced technology and real-time data to enhance traffic operations, improve safety, and provide efficient travel options for drivers along the I–80 corridor. Through the collection of real-time data, the project provides timely information to drivers through dynamic message signs (DMSs) and other traveler information services, divert travelers to parallel arterials, and dynamically adjust traffic signal timings to reflect traffic conditions.

4.2.1 Program Goals

To achieve the project's purpose of enhancing the effectiveness of the existing transportation network, the I–80 ICM Project team established the following goals:

- Increase corridor throughput
- Improve travel time reliability
- Improve safety

These goals are achieved through better use of existing freeway capacity and coordinated diversion operations with the surrounding arterial system to better balance demand between the facilities. To improve throughput, reliability, and safety, the project team focused primarily on managing traffic during major incidents. The system guided active routing and diversions to efficiently use local arterials during major freeway incidents. This approach necessitated close institutional and operational coordination between different network operators and jurisdictions.

4.2.2 Program Areas

The project uses ICM strategies, which consider freeway, arterial, transit, and parking systems within the corridor together as a system, rather than separately as individually managed assets. ATM strategies, which use more dynamic and automated traffic operations approaches to better match fluctuating demand and varying conditions, were also applied to further advance operations throughout the network. Additionally, the project implemented ADM strategies to influence traveler behavior and better manage travel and traffic demand in response to changing operational conditions on the corridor.

4.2.3 Strategies

The I–80 ICM solution comprises strategies from the three complimentary program areas:

- **ICM Strategies:** Prearranged standard operating procedures (SOP), proactive interagency engagement, real-time traveler information, dynamic wayfinding, and modified signal control (FHWA 2023d)
- **ATM Strategies:** Variable speed limits, adaptive ramp metering, TSP, and incident management (FHWA 2023a)
- **ADM Strategies:** Dynamic routing and predictive traveler information (FHWA 2023b)

4.3 Deployment Integration

Figure 6 represents the transportation network layer integration elements that are present within the I–80 ICM Project, which primarily focuses on integration between freeway and arterial operation, specifically in response to major incidents.

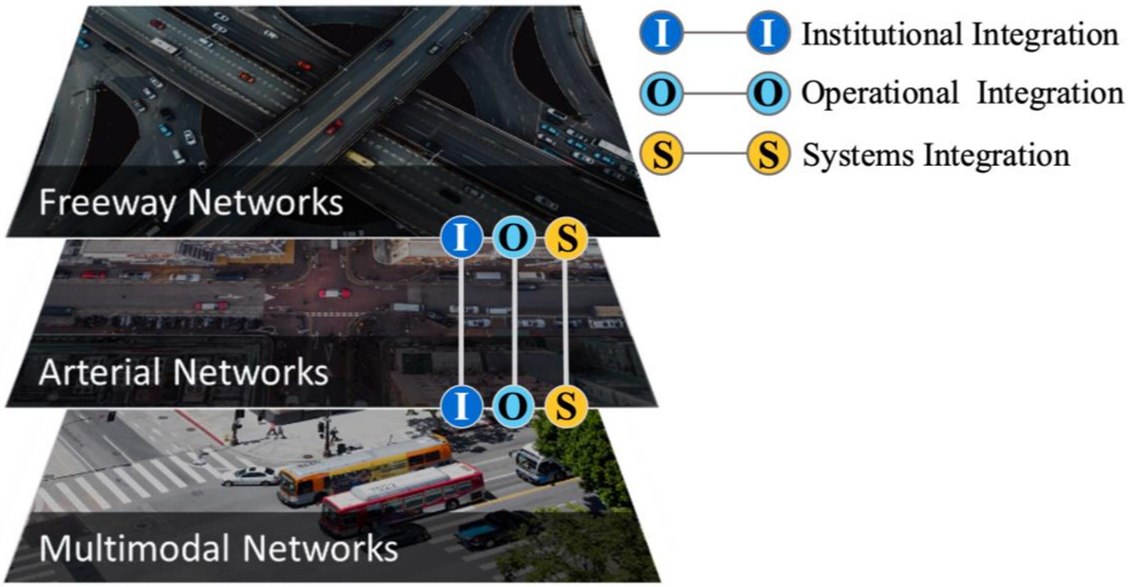


Figure 6. Diagram. The I–80 Integrated Corridor Management Project transportation network layer integration.

Source: FHWA 2023

4.3.1 Institutional Integration

From an institutional perspective, the I–80 ICM Project effort fostered increased collaboration and communication between Caltrans and the other corridor agency stakeholders. The corridor agency stakeholders developed an MOU to establish the project's goals, policies, and procedures as well as the overall commitment and responsibilities regarding ownership, operations, and maintenance of the various systems and equipment installed as part of the project. The MOU also established the governance structures and hierarchy for the project, including the Policy Advisory Committee, Corridor Steering Committee, and the I–80 Technical Coordinating Committee (TCC) (California DOT 2012).

The TCC was the venue in which corridor stakeholders' technical staff fostered communication and common ground, working collaboratively across institutions to exchange information and assist in resolving issues. These activities led to the development of operational protocols to best serve ramp metering, incident management, signal operations, and transit service.

The project team faced a major challenge in overcoming initial public concern and opposition to the concept of selective freeway diversions onto local routes. The project team continued public outreach and clarified messaging to help the public understand that the concept aimed to guide preexisting, naturally diverted incident traffic back to the freeway as soon as possible. Once this understanding was achieved, public support increased. During the project, especially during the planning phase, it became evident that regional agencies were often more adept than Caltrans at community outreach (refer to **Deployment Lessons Learned** for further discussion).

The MOU also outlined project costs and funding sources for the project development and construction phases and established ongoing operational funding responsibilities among the corridor stakeholders. Funding for the project development phase came from a mix of Federal, State, and regional sources, totaling $13,155,000. The California Proposition 1B Transportation Bond Program, totaling $76,700,000, entirely funded the construction phase.

Various functional groupings influenced allocation of funding and responsibilities for the operations and maintenance phase generally assigned to the infrastructure owner–operator. These groupings included:

- Freeway equipment used for an ICM strategy
- Freeway equipment not used for an ICM strategy
- Arterial equipment used for an ICM strategy
- Arterial equipment not used for an ICM strategy

4.3.2 Systems Integration

The project deployed network communications and several system components to enable communication and remote commands between centers and their respective field infrastructure. A data network connected various components of the project to support automated response recommendations. The local and regional operating agencies shared traffic and transit data along I–80, San Pablo Avenue, and other key local arterials to inform operational decisions.

Several project stakeholders continued to operate on their legacy platforms and systems and did not upgrade to the latest software, which caused significant system integration challenges during project deployment and operations. The lack of systems integration limited the ability to implement certain strategies, such as flush plans, consistently throughout the corridor and made scaling technically challenging. It also limited the system's flexibility to change plans when necessary.

4.3.3 Operational Integration

During normal operating conditions, each local agency assumed primary control and was responsible for operating all the project devices within its jurisdiction. However, Caltrans had the authority to step in and implement incident management actions during a major freeway incident. Under its incident management authority, Caltrans could implement preapproved timing plans on local arterials in certain conditions, following previously developed multiagency ICM operating plans. They could also implement preapproved Caltrans signal and ramp flush plans. Additionally, Caltrans could activate automated trailblazers on/off signs to notify drivers on San Pablo Avenue (the parallel arterial) where to reenter the freeway downstream of the incident location. The project did *not* actively divert freeway traffic onto local arterials in the event of an incident on the freeway. In this way, the ICM system's diversion response capability acted "passively" rather than "actively" in the freeway-to-arterial portion of the diversion.

4.4 Deployment Benefits

As the first major ICM project deployed in the region, the I–80 ICM Project provided a valuable understanding of project benefits. It also established a baseline for performance and comparison against which to identify viable corridors for future projects. Some of the benefits realized from the I–80 ICM Project may be summarized as follows:

- **Safety:**
  - The project reduced total collisions on the freeway by 3 percent in the westbound direction, where gantries and incident response efforts were focused (year 2017 versus 2016). This decrease compares with an overall increase in collisions regionally over this same time.

- > Rear-end collisions decreased around freeway locations with new infrastructure.

- ► **Mobility:**
  - > Travel times and speeds were maintained even as VMT in the region increased (VMT increased by 8.5 percent between 2014 and 2017).
  - > Throughput improved at several freeway bottleneck locations attributable to adaptive ramp metering.
  - > PM peak travel times along the mainline decreased, attributable to ramp metering. (At times when ramp metering was unavailable due to communications failures, peak period travel times along these segments increased by 50 percent).

4.5 Deployment Lessons Learned

The project team identified several institutional, operational, and systems lessons learned that can be applied to future ICM deployments in the region and by industry professionals throughout the country.

Institutional Lessons. The I–80 ICM Project team noted that a regional agency may be better positioned to be the lead agency during certain project phases rather than the State DOT. A regional agency may have more community outreach capabilities, knowledge, and experience with local stakeholders. An agency that regularly interacts with regional travelers might make for a better “public face” of the project. Another consideration is that a regional agency that is not a primary operator of a facility on the corridor could better facilitate discussions and agreements between modal operators on operating plans, especially where tradeoffs and concerns about balancing demand throughout network facilities may arise. Additionally, experience and strong relationships with collaborating agencies could benefit the interagency coordination aspects of the project.

The I–80 ICM Project team also recognized that design-bid-build is not the optimal procurement approach for ICM as it is a heavily technology-oriented effort, consisting of new and emerging technology applications. As such, it is not well suited to design-bid-build procurement, which supports more traditional capacity-expansion-type projects.

The project team identified the value of change management because ICM projects can be years-long efforts and often rely on agency champions to secure key institutional and operational agreements, which makes the success of the effort susceptible to staff changes.

Moreover, additional upfront coordination is needed to better integrate transit and mode shift strategies into the ICM operations. There may be institutional concerns around co-posting of corridor transit travel times. Project teams should appreciate the complexities involved with rerouting buses around incidents by recognizing the systems, operational, and institutional challenges.

Operational Lessons. Public acceptance of and compliance with various ICM strategic elements will vary. The I–80 ICM Project team found that they had to modify operations and provide targeted public outreach and education in response.

The public accepted the I–80 ICM Project synchronized signals. However, the public initially received ramp metering negatively, but accepted as the operations matured. Additionally, the public did not comply well with variable advisory speeds. Lane control appeared to have better compliance in certain instances. Limited value was noticed from the deployment of arterial message signs (trailblazers) as they did not prove to be successful in conveying detour guidance to drivers when the network was extremely over-saturated.

Systems Lessons. Reliable network communications are critical for ICM applications and may need to be included within the design and deployment. The I–80 ICM Project did not have reliable network communication to arterial field devices, which resulted in degraded system performance. A redundant network might have added value to the project.

The I–80 ICM Project team learned that a single integrated platform for all regional stakeholders is preferrable in comparison with a distributed ICM architecture design. Integration complexity is reduced for a single platform and is easier to maintain. Additionally, there is improved ease of use for operators with a unified user interface rather than having to monitor multiple separate applications.

A robust data management planning effort is a core piece of an ICM deployment. Dealing with separate agency platforms and limited data governance resulted in a lack of data consistency, challenges in sharing data across agencies, and limited corridor-wide performance monitoring. Strong data governance planning is also valuable to the sustainability of an ICM deployment such that extra allowances and expectations for hardware and software changes can be considered proactively.

Lastly, disparate software systems constrained the I–80 ICM Project. Software development was needed to integrate these systems, which proved costly and added project delay. Recognizing and planning for these efforts or potentially mitigating this risk through design could be advantageous in other deployments.

5 Case Study 2: District 5 Regional Integrated Corridor Management Program

The Florida Department of Transportation (FDOT) District 5 Regional Integrated Corridor Management System (R-ICMS) originated in response to the significant impact expected due to the I–4 Ultimate construction project. The system was developed as a tool to help mitigate the impacts of increased volumes on parallel arterials during construction. The R-ICMS deployment is designed to operate beyond typical ICM incident management operations and has evolved to support day-to-day operations throughout the region. However, the term ICM is generally still used to describe the RTSMO program that is in use today.

5.1 Deployment Overview

The Central Florida TSM&O Consortium leads the R-ICMS Program, which includes stakeholders such as State, county, and city agencies. They jointly identified their needs, developed system requirements, and participated in the selection of the required vendors. The FDOT D5 Regional TMC houses the R-ICMS.

The R-ICMS is focused on the Interstate 4 (I–4) Corridor, which is a major east–west corridor traveling northeast–southwest in the central Florida region in the vicinity of Orlando. The I–4 Corridor and influence area encompasses a primary freeway, a commuter rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and significant ITS infrastructure.

The R-ICMS uses SunGuide® software, which collects data on the freeway and arterial system to actively manage the multimodal system and make operational decisions for the benefit of system mobility through coordination with local agencies. Within minutes, the R-ICMS can analyze an incident, predict traffic behavior up to 30 minutes into the future, and provide the most efficient alternate route plan to divert traffic around a major incident. It provides the district and local agency stakeholders with the ability to treat transportation as a single system, increase the operational efficiency of the whole transportation network, and maximize the effect of transportation investments (FDOT 2016a).

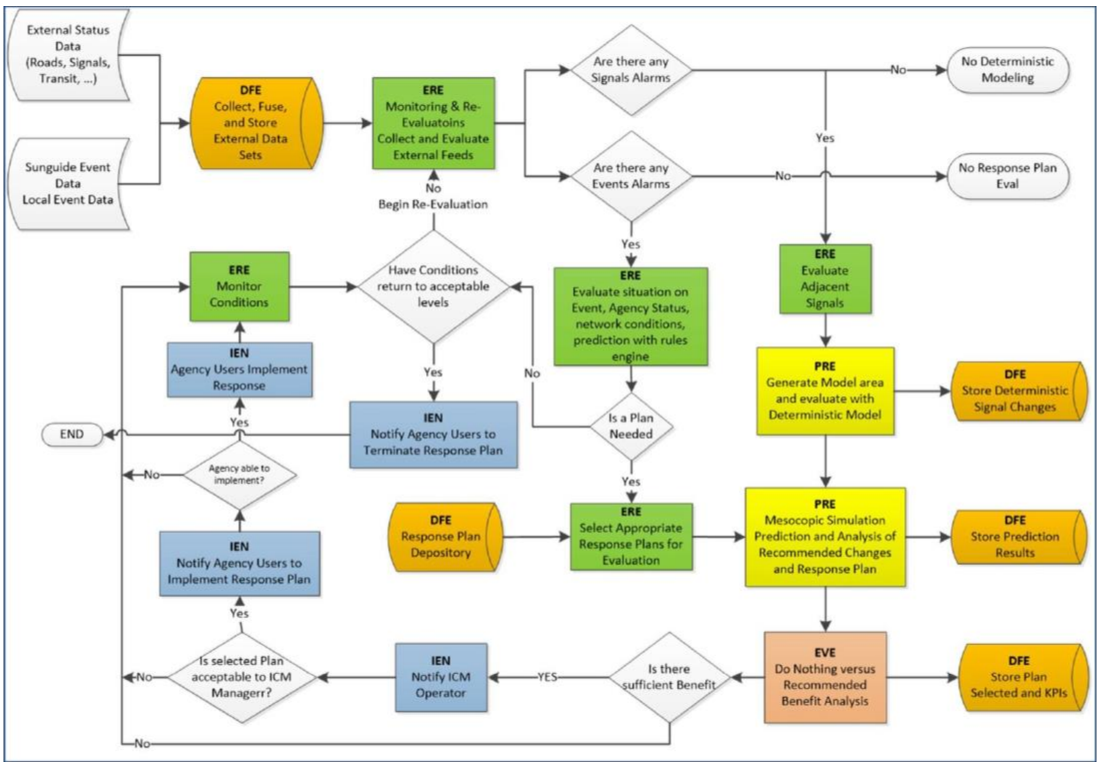
The R-ICMS consists of a decision support system (DSS) that reviews the system and evaluates current and predicted conditions to make smart decisions in managing both recurring and nonrecurring congestion conditions. DSS comprises the following three components (Aimsun 2023):

- **Expert Rules Engine (ERE) – ERE** checks for updates in status of the system, such as incidents and abnormal increase in queue length, evaluates the needed response from the Data Fusion Environment (DFE), and sends the request of analysis to the predictive engine (PRE).
- **PRE** – PRE centered on the mesoscopic simulation, Aimsun®, provides a rolling 30-minute horizon view of the traffic conditions on the roadway network, including 10-, 20-, and 30-minute forecasts.
- **Evaluation Engine (EVE) –** EVE evaluates the score of the response plans versus a do-nothing scenario. EVE additionally evaluates the measures of effectiveness and provides recommendations that are sent via the Information Exchange Network (IEN) to the ICM operator and sends approved recommendations to the agencies. The

approved response plan is then implemented and continuously monitored by the ERE. If needed, the process restarts from the ERE component.

These components select the response plan for evaluation, predict the outcomes of the suggested scenarios, score the results, coordinate with operators and agencies through the IEN, and invoke the approved response plan actions through the SunGuide® software system. The DSS monitors the situation after deployment to modify or deactivate the response plan as needed.

The R-ICMS interacts with the **DFE,** which collects, formats, and stores external data sources and event data sources. Additionally, the R-ICMS notifies the agencies and operations of the ERE and EVE decisions through the **IEN**. **Figure 7** illustrates the relationship between the systems.



DFE = Data Fusion Environment; ERE = expert rules engine; EVE = evaluation engine; IEN = Information Exchange Network; KPI = key performance indicator; PRE = predictive engine.

Figure 7. Flowchart. The Regional Integrated Corridor Management System (R-ICMS) response plan process flow.

Source: Scope of Services for Central Florida R-ICMS

5.1.1 Program Goals and Objectives

The R-ICMS Program aims to improve efficiency, reliability, and incident management within the heavily populated and tourist area of Central Florida. The program defines its goals in the *FDOT District 5 Concept of Operations: Decision Support System and Advanced Transportation Management System Software* as follows:

- Increasing corridor throughput
- Improving travel time reliability

- Improving incident management
- Enabling intermodal travel decisions
- Improving information sharing
- Improving infrastructure coverage

Stakeholders ranked these goals by priority and developed objectives in support of each goal (FDOT 2016b).

5.1.2 Program Areas

The R-ICMS Program uses ICM strategies more broadly to accommodate the region's extreme growth. It does so by improving efficiency, reliability, and incident management through maximizing existing resources and coordination with local agencies. The program facilitates an interconnected system through coordination between freeway operations with arterial operations ensuring seamless flow throughout the network.

5.1.3 Strategies

In support of the R-ICMS Program's goals (NOCoE 2019a), the following strategies have been implemented:

- **Incident and Emergency Management –** This strategy showcased its value after Hurricane Irma in 2017 when 6.8 million Floridians were evacuated. The implemented Emergency Shoulder Use Plan allowed people to safely evacuate while enabling emergency responders to travel in the opposite direction without causing severe incidents or major traffic disruptions. FDOT now has response plans explicitly designed for incident response and supporting emergencies such as extreme weather events (NOCoE 2019a).
- **Traveler Information –** This strategy provides travelers throughout the program's influence area with accurate and timely information. The R-ICMS Program communicates with the public through different mediums including the program's website (**www.cflsmartroads.com**), Florida's 511 website, DMSs, and other navigation apps that closely coordinate with FDOT.

Additional strategies, such as advanced arterial traffic signal timing, ramp metering, TSP, and emergency vehicle preemption are used to further support the R-ICMS Program's goals. The influence area also includes different functional classes and transportation modes, including transit bus service, park-and-ride lots, major regional arterial streets, toll roads, and bike lanes facilitating an interconnected, multimodal system.

5.2 Deployment Integration

Figure 8 represents the transportation network layer integration elements within the R-ICMS Program. The program has achieved mature integration within the arterial layer, demonstrating significant regional arterial traffic signal systems and operational integration. The program has also achieved mature integration within the freeway network layer by implementing ramp metering and successfully executing the Emergency Shoulder Use Plan. Furthermore, the program has advanced its integration within the multimodal layer through the use of TSP and the provision of infrastructure that fosters a more interconnected, multimodal system.

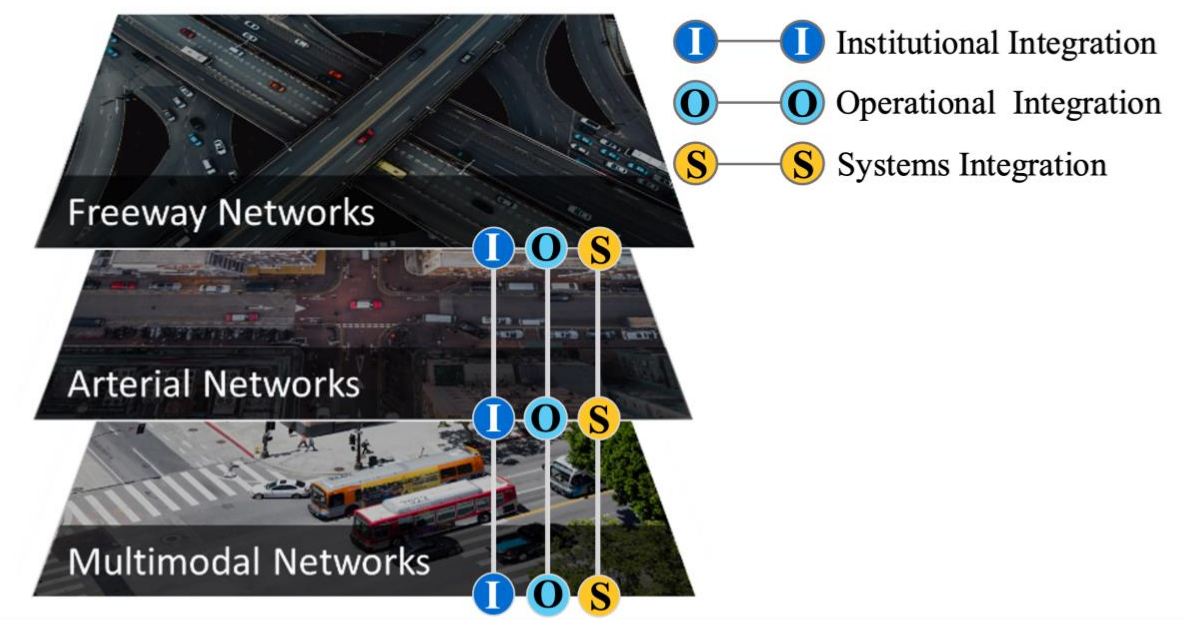


Figure 8. Diagram. The Regional Integrated Corridor Management System (R-ICMS) transportation network layer integration.

Source: FHWA 2023

5.2.1 Institutional Integration

R-ICMS has established an engaging collaboration among the involved parties in the program, including State, county and local agencies that also contribute to funding sources in addition to the FHWA grants. All members participate in defining the requirements, scope, and selection of consultants. The Central Florida TSM&O Consortium, led by D5, has periodic meetings to discuss all TSM&O-related issues, share resources, and collectively develop solutions.

All stakeholders have access to the R-ICMS and can choose to "turn off" the system for their respective jurisdictions or opt out of the system at any time. Furthermore, intermunicipal agreements were formalized after the system had been operational for approximately 3.5 years to ensure that system performance had been satisfactory enough to warrant formal agreements. This approach has allowed participating agencies to fully understand and buy into the program.

Funding for the project has been provided by Federal (grants), State, and MPO sources. The Federal Government initially allocated approximately $20 million, and subsequently, the FDOT Central Office (CO) has incorporated operations and maintenance into its annual budget.

5.2.2 Systems Integration

The R-ICMS has integrated many different hardware and software systems including:

- Traffic signal systems consisting of two deployments of Econolite, three deployments of Cubic®, and two deployments of Siemens® and Q-Free Intelight
- General Transit Feed Specification with three different agency near-real-time feeds
- Automated traffic signal performance measures (ATSPM) integration encompassing Cubic, Econolite, and Intelight
- Detection cameras including Cubic Gridsmart® and Miovision®

- Third-party data including HERE and WAZE

According to the SOP, the City of Orlando and several counties publish weekly reports about communication issues, vehicle detector failures, pedestrian detector failure, and coordination errors. Additionally, a monthly report provides data on TSP/preemptions as well as focused information for each corridor summarizing the travel time and origin/destination results. The time ranges are morning (A.M.) and afternoon (P.M.) peaks during weekdays (FDOT 2018).

Cybersecurity often poses a major challenge in system integration. Establishing a proper cybersecurity standard can involve extensive cooperation and constant monitoring. If a cybersecurity issue is detected, the IT team should be immediately consulted to resolve the issues. Consequently, FDOT usually initiates updates in cybersecurity, necessitating cooperation and coordination from the vendors. When FDOT initiates updates in the system, meetings with State, county, and MPO officials are held as part of the TSM&O Consortium that manages these requests.

5.2.3 Operational Integration

Operator feedback from each agency at biweekly meetings provides FDOT with information about the operation of the system, and FDOT uses this information to decide whether any system or operational modifications are needed. The R-ICMS program communicates with the public through its website by providing reports about the system and its overall performance. FDOT publishes monthly or quarterly reports on its website, including key performance indicators which are particularly useful for the MPOs.

The vital role of the R-ICMS became more pronounced after the COVID-19 pandemic, as traffic began rebounding. Despite increased demands on the transportation system, R-ICMS Program efforts have shown success in improving or maintaining some key performance measures. They include metrics on both the freeway and arterials (FDOT 2022 and FDOT 2023e):

- Travel time index for interstate and arterials
- Average roadway clearance time
- Speed differential between the I–4 express lanes and the general-use lanes
- Travel time reliability indicating the percentage of time; I–4 Express keeps traffic moving at 45 mph or greater

According to the quarterly performance measures report of the second quarter of fiscal year (FY) 2023 (FDOT 2023b), the total number of diversion routes implemented increased from 446 in 2021 to 673 in 2022, which can be assumed to indicate a greater return of R-ICMS system investment.

The Central Florida Expressway Authority (CFX) stated in the SOP for the R-ICMS Program operation that event types that usually lead to the system activation include crashes, congestion, debris on the road, disabled and abandoned vehicles, police activity, and emergency vehicles (FDOT 2018).

5.3 Deployment Benefits

The R-ICMS Program publishes a range of performance measures on a monthly and quarterly basis. As mentioned earlier, these measures include freeway, arterial, and transit-specific metrics. They are centered on travel time reliability, number of incidents responded to or assisted by the road rangers, incident clearance times, delay savings, and ITS equipment uptimes. Based on a review of their most recent reports and a case study report that NOCoE published (NOCoE 2019b), some of the benefits can be summarized as follows:

- **Mobility:**
  - Dynamic shoulder running reduced travel time by up to 25 percent with no adverse impact on safety.
  - TSP improved bus travel times with minimal impact on side streets, and adaptive signal control reduced overall delay by 4 to 40 percent.
  - Ramp metering, in development on I–4, is expected to reduce crashes by 15 to 40 percent.
- **Other:**
  - Benefit-to-cost ratio ranged from 5 to 10:1.
  - Traffic signal control improved air quality by 3 to 22 percent.
  - Variable speed displays reduced CO2 by 10 to 20 percent.
  - Total savings of more than $42 million due to reduction of secondary crashes, achieving the less-than-60-minutes goal for the second quarter of FY 2023.
  - Comparing the monthly reports of March and April in 2022 and 2023 indicates an increase in the number of lane closure events either due to an incident or construction. This effect highlights the increasing necessity and importance of the R-ICMS Program in managing these closures.
  - The average roadway clearance time is 62 minutes, which, given the increases in traffic volumes and events, can be considered a positive outcome.

5.4 Deployment Lessons Learned

The lessons learned throughout the implementation and operation of the program are summarized below:

Institutional Lessons. Collaboration was an essential factor in the development of institutional integration. Traffic engineers with IT experience simplified collaboration with the IT departments across agencies/organizations. This collaboration was notable for integration. Establishing working relationships among stakeholders encouraged resource sharing (personnel) that was integral for troubleshooting and issue resolution. Onsite vendor support was used, allowing vendors to work part-time onsite to support integration for their respective products. Additionally, implementing a change management process for vendors became essential with many diverse systems in operation. Recognizing and being aware of political concerns that may impact the development of the system also may be helpful.

Systems Lessons. The R-ICMS Program started with simple elements and gradually added complexity, contributing to its success. Developing standards-based interfaces, such as the Traffic Management Data Dictionary, and engaging vendors to develop the required interfaces was a focus due to the complexity of integrated systems. Additionally, cybersecurity updates including migration to more secure Simple Network Management Protocol (SNMP), such as SNMPv2 or v3, was a focus that supported system security and required cooperation from vendors.

Operational Lessons. The traffic simulation models (PRE) were enhanced using supplemental data sources, such as intersection turning movement data from ATSPM modules. Additionally, activation of the Emergency Shoulder Use Plan, as learned from Hurricane Irma in 2017, demonstrated the importance of incident management during disasters when hundreds of thousands of Floridians evacuated ahead of the storm (NOCoE 2019a).

6 Case Study 3: SigOps Program

The Georgia Department of Transportation (GDOT) leads the SigOps Program, leveraging technology, advanced operational methodologies, and collaboration to monitor and optimize traffic flow throughout the State. Although this example is not a traditional *regional* integrated deployment, GDOT shares it as a case study because of how the program has evolved from a regional corridor-based focus to a more widespread integrated system to support the efficient operations along arterials and freeways.

6.1 Deployment Background

The Atlanta metro area has a history of using advanced traffic signal management methods to support efficient travel, having invested significantly in the infrastructure and systems deployed to manage the 1996 Summer Olympics. These systems matured and evolved over time but maintained the regional footprint:

Communications Infrastructure. Communication was provided to a majority of traffic signals throughout the region. Communication mediums evolved but generally consisted of fiber optic cable and wireless communications at initial deployment.

Common Architecture. A consistent approach to hardware and software architecture was established throughout the region. GDOT has deployed standard controller types (advanced transportation controllers (ATC)) and consistent managing software. These hardware and software systems have been upgraded and migrated, but the majority of the traffic signals throughout the region have maintained consistency, making regional management and integration of advanced solutions more efficient.

Regional Partnerships. Regional stakeholders have a history of working together and have benefited from regional integrated methods. The region's established culture of collaboration has been shared more broadly throughout the State. In addition, legislation enabling collaborative procurement structures has been enacted, further supporting the use of regional partnerships.

These systems and partnerships established for the Olympics continued to mature and were the foundation for GDOT's Regional Traffic Operations Program (RTOP) in 2010. At inception, the RTOP had a primary focus on increasing throughput on key arterials throughout the Atlanta metro region. The RTOP accomplished its goal of increasing throughput on key

In 2017, a highly traveled bridge along Interstate 85 (I–85) within the Atlanta metro area collapsed due to a catastrophic fire. This incident led to a significant disruption to the freeway and surrounding arterial traffic, as travelers had to find alternative routes. The Georgia Department of Transportation (GDOT) leveraged Regional Traffic Operations Program engineers' existing knowledge of the area and expertise to immediately implement new timings and provide additional monitoring and fine-tuning throughout the area to minimize the impact. The program proved to be immensely valuable as it was able to swiftly respond to the challenging circumstances and provide continued enhanced management of the arterials and freeway within the area. GDOT was recognized for its ability to quickly respond and optimize regional traffic.

arterials by leveraging institutional, systems, and operational integration. As the program evolved, capabilities matured, and corridors became saturated, reliability also became a primary focus leading to the adjustment of the program's goals and objectives, as discussed in **section 6.2.1**. This evolution resulted in the currently active SigOps Program. Additionally, the program's coverage significantly expanded with the transition from the RTOP to the SigOps Program, which included the entire statewide transportation network rather than major corridors only.

Although the program primarily focused on arterials, there were opportunities to increase coordination with freeway operations, particularly during large incidents such as the 2017 I–85 bridge collapse (NOCoE 2018) (highlighted in the yellow box above), or significant special events that impact traffic regionally. These types of events provided the opportunity to clearly demonstrate the value of RTSMO and gained additional encouragement and support to evolve the program to provide benefits throughout the State.

6.2 Deployment Overview

GDOT established the SigOps Program in 2019 to *proactively manage and maintain traffic signals statewide by leveraging existing and emerging technology*. The program achieves this objective by leveraging existing and emerging technologies that enable active management of more than 8,000 signalized intersections around the State. The SigOps Program is structured into six zones throughout the State, and distinct consultant contracts manage these zones, as shown in **figure 9.**

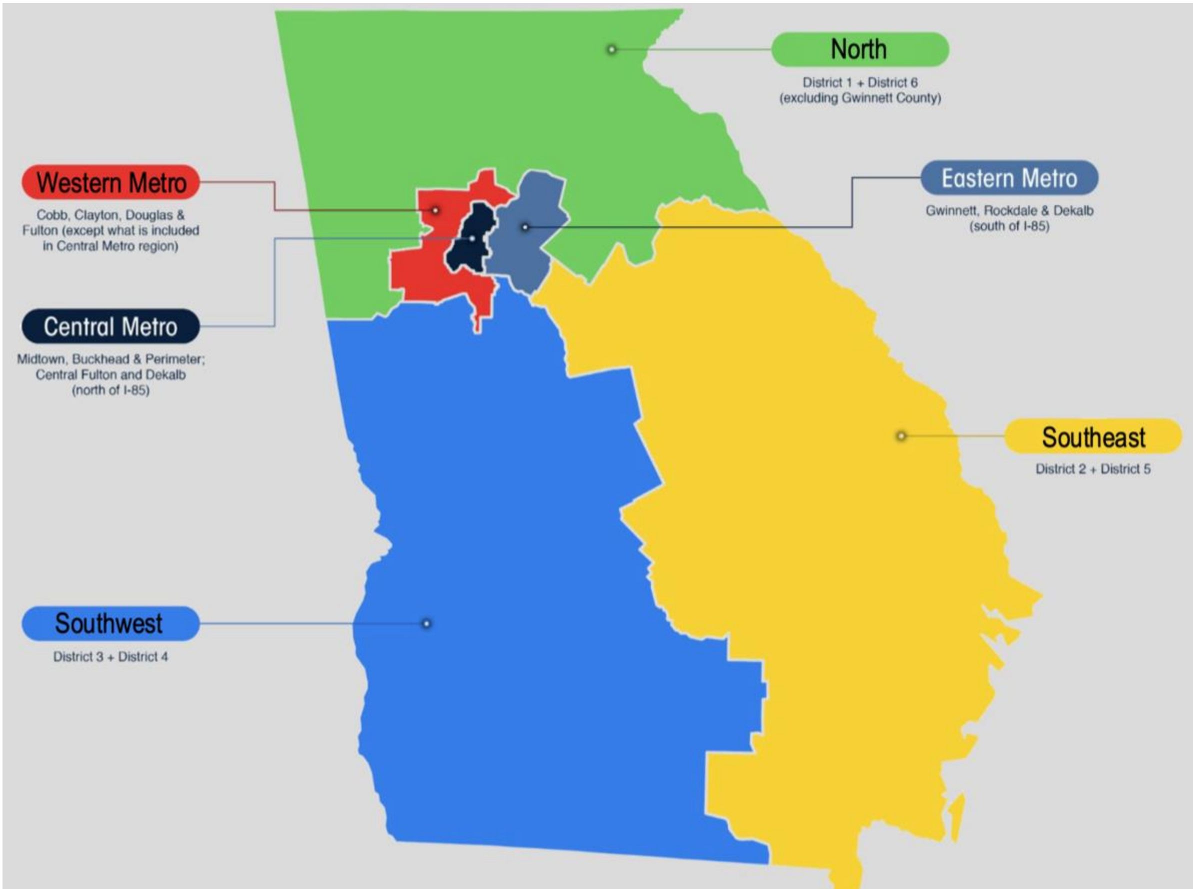


Figure 9. Map. SigOps Region.
Source: [Traffic Signals: Optimization, Outage Reporting - GDOT (ga.gov)]

Currently, the statewide SigOps Program uses:

- Connected traffic signals—8,000-plus
- High-resolution controller data—7,000-plus
- Cameras—1,000-plus
- Performance measures—ATSPM for all 8,000-plus traffic signals (GDOT n.d.a), Regional Integrated Transportation Information System (RITIS), SigOps Metrics (GDOT n.d.b).

6.2.1 Program Vision and Goals

GDOT defines its vision in the *Statewide Traffic Operations and Response Management Program: Concept of Operations* as providing consistent, safe, reliable, and secure travel through improved traffic operations. To achieve this vision, GDOT focuses on the following goals related to safety, reliability, efficiency, and customer service (GDOT 2019):

- Provide a safe, efficient, and well-maintained statewide traffic signal system.
- Facilitate informed data-driven decision making through technology.
- Efficiently manage and allocate financial and contract resources.
- Provide a flexible, accountable, scalable, and transparent traffic signal program.

- ► Promote collaboration and cooperation between statewide, regional, and local stakeholders.
- ► Provide a high level of customer satisfaction for traffic signal operations and maintenance.

6.2.2 Program Areas

GDOT's SigOps Program is an ATM deployment that focuses on monitoring and optimizing traffic flow to provide a more efficient and safer commute for the public. Although the program's primary motivation is to improve operations on Georgia's arterial network, ATM is also used for freeway coordination during large planned and unplanned events expected to impact traffic flow throughout the region.

6.2.3 Strategies

The SigOps Program achieves its vision of minimizing congestion and reducing delays through improved traffic operations by implementing the following strategies.

- ► **Signal optimization** involves real-time adjustment of signal timings as traffic patterns change throughout the day, resulting in improved travel times and reduced delay and fuel consumption. Signal optimization is achieved through the synchronization of traffic signals on primary corridors, allowing vehicles to progress through multiple signalized intersections without stopping. The SigOps Program uses signal timing approaches based on location, special circumstances, or both. Time-of-day schedules are used to program traffic signals on coordinated corridors that experience consistent and predictable traffic conditions. Using the time-of-day method, timings are pulled into the system based on the time of day (e.g., AM peak hours, midday peak hours, and PM peak hours). Traffic responsive operations in which timings dynamically adjust based on real-time traffic conditions are used at locations that experience irregular or less predictable traffic conditions. The program additionally has preset timing plans that can be manually implemented in the case of planned events or unplanned incidents.
- ► **Signal Operations and Maintenance** of Georgia's arterial traffic signals are overseen by SigOps consultant contracts that divide the State into the six zones as shown in **Figure 9.** A team of traffic engineers and technicians who lead all active signal monitoring and operations, signal timing, ITS device deployments, signal maintenance (including preventative, routine, and repair), and surveillance at key locations manage each zone, resulting in balanced traffic flow throughout the region.
- ► **Performance measures** are used to drive operational decisions throughout the State as well as to evaluate the performance of the program. GDOT uses ATSPM software to measure real-time and historical performance of each signalized intersection under the SigOps Program. The collected information is used to further optimize the network and improve mobility throughout the region by reporting volumes, travel times, speed, and malfunctions. GDOT developed the SigOps Metrics site, which leverages the ATSPM data and reports on the operational health of the arterial transportation network. Key metrics include queue spillback rate, split failure, travel time index, planning time index, daily volume (traffic and pedestrian actuations), and device and communication uptime. The SigOps Metrics site also reports corridor volumes per day and per peak hour, as well as equipment measures and activity measures reported by traffic engineers (GDOT n.d.c). The RITIS is used to track system performance and analyze trends of the entire transportation network.

6.3 Deployment Integration

Figure 10 represents the transportation network layer integration elements within the GDOT SigOps Program. The primary focus of GDOT's SigOps Program is day-to-day arterial traffic signal management. The program demonstrates significant integration throughout the arterial transportation network layer. Furthermore, GDOT is capable of integrating with the freeway network layer to support efficient transportation operations during large planned and unplanned events and demonstrates limited integration with the multimodal transportation network layer.

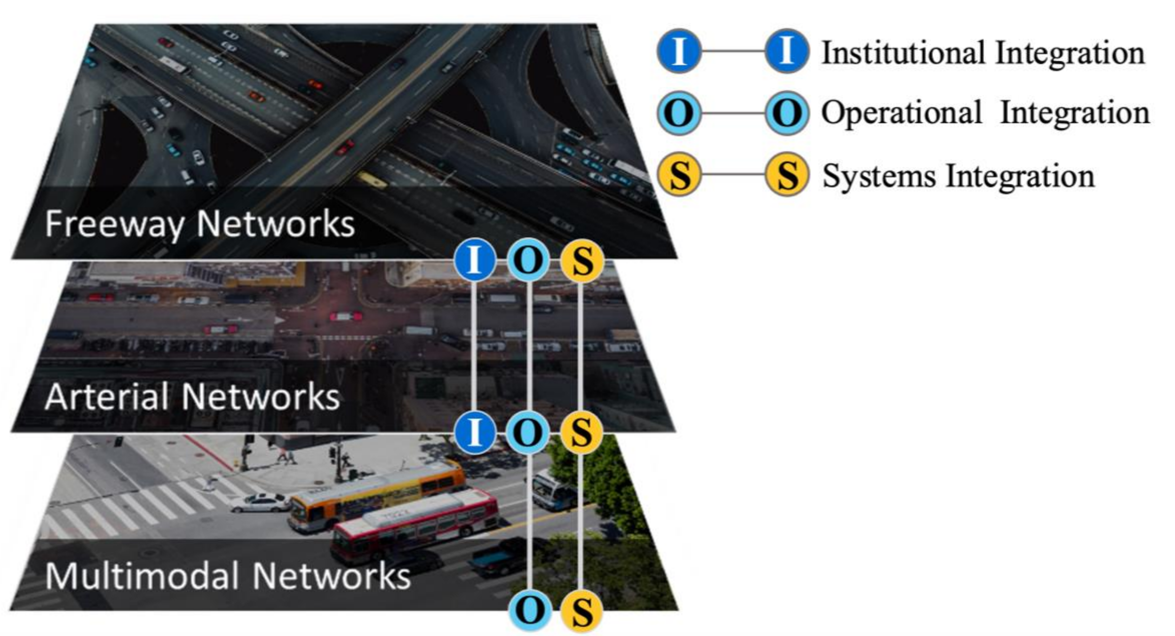


Figure 10. Diagram. The Georgia Department of Transportation SigOps transportation network layer integration.
Source: FHWA 2023

6.3.1 Institutional Integration

GDOT actively leverages interdepartmental institutional integration within the agency to support integration of the freeway and arterial networks. This integration is informally accomplished through shared resources (TMC), regular meetings, and relationships. Additionally, this integration is achieved through shared State goals, objectives, and governing structures.

More formal methods and mechanisms actively support institutional integration within the arterial network layer among the State and local agencies. The SigOps Program drives this integration, which varies with collaborating agencies but generally takes the form of an MOU. These MOUs define the roles, responsibilities, and financial obligations of each agency concerning arterial traffic management, maintenance, and operations.

The SigOps Program also actively leverages extensive data resources managed through the Joint Agency Data Governance Program. GDOT and the Atlanta Regional Commission manage this program to standardize data analytics, promote shared access, efficiency, and a culture of data-driven decisions. Collaborators can access data through data-sharing agreements that the Joint Agency Program manages.

In addition, standing monthly and ad hoc SigOps Program meetings achieve collaborating agency institutional integration. These meetings support more successful systems and operational integration by facilitating a regular consideration of needs, successes, challenges, and opportunities for improvement.

The State-allocated formula Federal-Aid Highway Program funds provide financial assistance for the SigOps Program. Funds are divided among the six zones shown in **figure 9**. Five-year consultant contracts manage each zone, defining a specific budget amount. The Central Metro, Western Metro, and Eastern Metro zones are each allocated $25 million, whereas the North, Southwest, and Southeast zones are each allocated $20 million. The SigOps Program also allocates $15 million to the SigOps System Support and Maintenance contract and $10 million to the SigOps Communications contract, both actively supporting statewide efforts to increase data-driven decisions, active operations, and optimized performance. Statewide, the SigOps Program receives $160 million over the 5-year contract term, equating to approximately $32 million spent annually.

6.3.2 Systems Integration

The SigOps Program systems integration generally leverages a common architecture (communication and systems) that the GDOT established as a statewide best practice during the early stages of advanced management deployments with the 1996 Olympics. Although these systems have migrated and evolved over time, the common architecture and general expectations of that architecture have allowed GDOT to efficiently integrate various systems and stakeholders over the years.

GDOT's communication network infrastructure is composed of fiber optic cable with the use of wireless radio or cellular communications in less densely managed areas. A number of local agencies throughout the State integrate with GDOT's network either through sharing fiber (supported through institutional integration and shared-use agreements) or through center-to-center connections. This approach facilitates the opportunity for both parties to integrate systems, share access, and, in some cases, provide redundant communication in the case of a failure.

Furthermore, Georgia's State Legislature passed the Transportation Funding Act of 2015 (House Bill 170) (Georgia Department of Revenue 2015), which established a method for local agencies to share qualified equipment contracts with the State. Although local agencies are not required to leverage these contracts, the method has proven to promote quality, consistency, and efficiency as well as cost savings throughout the State. This improvement has led to systems built on similar hardware deployments that are easier to integrate. For example, many of the connected vehicle TSP deployments throughout the State leverage interoperable devices and architecture.

GDOT has also provided local agencies with access to data and software systems:

- **Data.** Public agencies leverage access to datasets and data platforms (by executing data use agreements). Commonly shared data include speed, travel time, congestion, delay cost, trip, commercial vehicle, volume, multimodal, and demographics analytics; roadway attributes; data storage; and platform enhancements.
- **Software.** Public agencies have free access to traffic signal controller and management software MAXTIME/MAXVIEW as well as the State's central advanced traffic management system software platform.

By providing common systems access to local stakeholders throughout the State, GDOT has developed an environment in which systems integration is more efficient and prevalent, leading to the ability to integrate more regularly at an operational level.

6.3.3 Operational Integration

The operational integration of the SigOps Program varies depending on operating conditions and managing agency. Primary integration is present between the freeway and arterial transportation networks with limited arterial, multimodal integration in the locations with TSP deployments.

Day-to-Day Operations. GDOT coordinates freeway and arterial operations through the statewide TMC, where operators have access to real-time data, traffic cameras, and central managing software for freeway ramp meters, DMSs, traveler information systems, and arterial traffic signals. While the freeway network layer is managed by the TMC operators, the SigOps Program arterial operators oversee operations within a designated zone. There are varying levels of operational agreements with collaborating agencies throughout the State, but there is generally limited integration of freeway and arterial operations during the day-to-day activities. Continuous integration of arterial and transit (multimodal) operations occurs in locations that deploy TSP.

Large Event Operations. During large events or incidents, freeway and arterial operations become more actively integrated, with operators coordinating and leveraging shared systems for monitoring and management. The SigOps Program relies primarily on integrated operational policies and procedures (informal and formal) and emergency operations SOPs to support freeway and arterial operations during large planned or unplanned events. Examples of strategies used to support the integration between freeway and arterial operations include coordination with ramp meter operations, DMSs along freeways informing travelers where to exit, and CCTV coverage of hotspots. Although GDOT does not currently implement any automated response systems, critical arterial corridors have pretimed alternative timing plans that can be implemented remotely to accommodate emergency or planned event operations.

6.4 Deployment Benefits

The SigOps Program has enhanced GDOT's capabilities in regional traffic management and operations by adopting uniformity in signal management through the standardization of traffic signal operations, remote and local access to traffic controllers, and the collection of high-resolution data. The program can regionally manage and integrate advanced solutions more efficiently due to consistency in controller and software systems. The migration from legacy hardware and software to ATC controllers operating on MaxTime firmware allowed for the standardization of traffic signal settings. The standardized system enabled the program to collect high-resolution data from the controllers, which are integral to both operations and performance measurement.

ATSPM allows for the collection and review of high-resolution data and reports to optimize both day-to-day as well as project-specific operations. On a day-to-day basis, once the public reports an issue or the system reports an alarm, operators can remotely assess and troubleshoot the issue before dispatching staff to the field to resume operations in a timely manner. This approach saves time and money for both the agency and the traveling public. In regard to project-specific operations, ATSPM has significantly improved GDOT's signal retiming processes through the collection of high-resolution data, such as turning movement counts, over a period of several days directly from the traffic controllers rather than manually collecting traffic counts. Additionally, ATSPM helps continuously track and analyze the performance of the entire system and contributes to efficient resource use to maintain the system's health.

6.5 Deployment Lessons Learned

Since the launch of SigOps 13 years ago, there have been many lessons learned that shaped the program into what it is today. Building and fostering relationships with stakeholders, agencies, and communities early on to gain buy-in, transparency, and successful outcomes may be helpful Effective communication allows all collaborating agencies to have a common understanding of the goals and objectives and maintains the momentum of the program by keeping all parties up to date. GDOT has standing meetings with SigOps stakeholders and provides them with reassurance by respecting that they each have their own goals and objectives. The SigOps Program also incentivizes local jurisdictions to participate in the program through the funding of equipment. Additionally, asset management is notable as it provides improved operational efficiency and encourages the technology deployed throughout the network is being used to its full potential. From the administrative perspective, balancing several contracts is challenging, and tradeoffs on the structure of contracts are expected. Developing line-item pricing helps increase consistency and simplicity in the billing process. Ensuring that the administrators of the contracts have the technical skills and experience to effectively monitor and manage the contract may also be beneficial.

7 Summary of Findings

The surface transportation system network can be described within the context of three network layers—freeway, arterial, and multimodal—with the opportunity for integration both within each layer and between each interface (described and shown in **Figure 4**). While there is significant effort to optimize each layer of the transportation system, the maturity of interfaces across transportation network layers varies. Each interface presents an opportunity for realizing system-level benefits. System-level benefits of RTSMO include reduced congestion, increased reliability, increased safety, enhanced multimodal connectivity, balanced demand, and reduced operational costs.

7.1 Gaps and Opportunity for Maturation in Regional Integration

This case study technical report is representative of not only the three case studies reviewed, but also a comprehensive literature review completed prior to this effort. Review of the literature as well as the interviews conducted for the case studies have shed light on existing gaps and opportunities for maturation in regional integration. These gaps and opportunities were specifically identified during the interviews in which the deployments reflected on the opportunities to further realize benefits related to regional integration. Although complete integration is not expected across all transportation network layers for all programs, there are a variety of strategies that industry practitioners could implement to meet their regional goals and needs through the support of fuller integration. Specifically, the following gaps and opportunities for maturation were identified.

Multimodal Network Layer Interfaces. Although many programs have intentions to integrate with the multimodal network, few have succeeded in practice. Addressing the gap in integration between multimodal and freeway integration can be achieved by deploying managed lanes on freeways to be utilized by transit vehicles. Supporting multimodal integration with arterials can be accomplished with the use of transit signal priority (TSP). This approach can enhance transit operations by reducing the delay experienced by transit vehicles at traffic signals and providing more reliable services throughout the transportation network. In addition, multimodal services are more likely to be effective when accessibility and connectivity are considered. Integrating park-and-ride facilities at freeway interchanges provides commuters with a convenient transition between their private vehicles and transit services or carpooling. This integration promotes mode shift and travel demand integration by providing easy access to public transportation options. Furthermore, implementing complete streets improvements that promote infrastructure such as sidewalks and bike lanes can further enhance the accessibility and connectivity of arterials and promote sustainable transportation options.

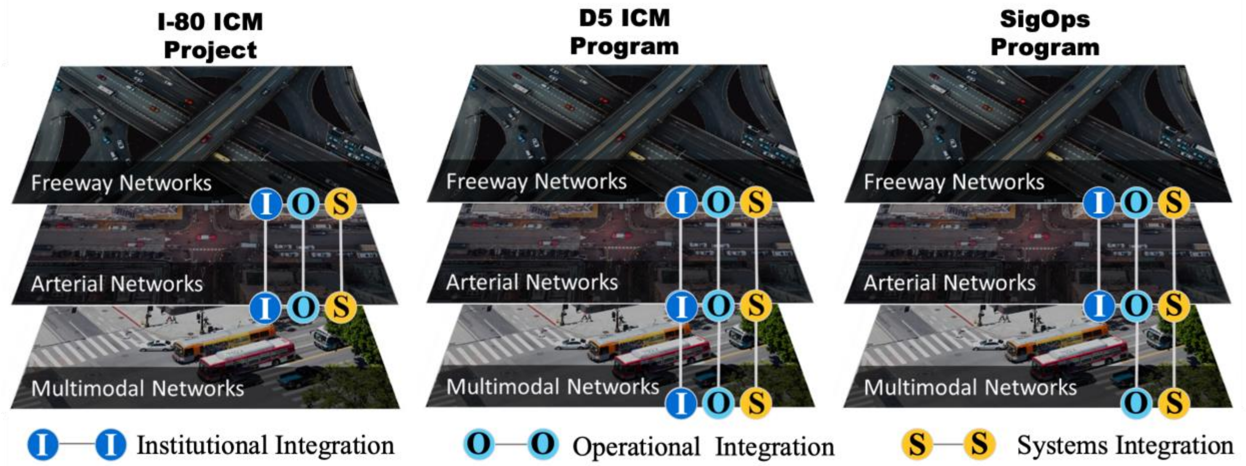
Travel Demand Management Considerations. There is a significant gap with the integration between travel demand management and the three layers of the surface transportation network, which has the potential to provide additional system-level benefits. Future research may be helpful to better understand traveler behavior to improve the potential to influence travel demand. Currently, real-time information is shared to influence travel demand by providing travelers with updates on transit schedules, parking availability, and alternative modes, enabling them to make informed decisions. However, this approach has been shown to have limited impact because travelers tend to make mode choice decisions further in advance of their trip.

Leveraging infrastructure and probe-based sources of traffic data, with the application of predictive analytics may enhance the capability of operating agencies to influence traveler behavior and mode choice to distribute demand more effectively across the freeway, arterial, and multimodal layers. This may result in improved efficiency and reduced congestion throughout the transportation network.

7.2 Case Studies Summary

Three integrated RTSMO deployments were studied and are shared within this document: the Caltrans-led I–80 ICM Project, the FDOT-led R-ICMS Program, and the GDOT-led SigOps Program. This case studies technical report is a resource for industry practitioners to gain insight into the potential opportunities and challenges related to a successful RTSMO implementation and to understand what factors may contribute to its success.

Figure 11 provides a visual representation of the regional institutional, systems, and operational integration leveraged for each of the three deployments studied.



D5 = District 5; ICM = integrated corridor management.

Figure 11. Diagram. The transportation network layer integration for each of the deployments.
Source: FHWA 2023

The level of integration across all transportation network layers depends on the goals, objectives, context, and constraints that surround the implementation of the project. As ITS technology and data sources evolve and mature, the capacity of State, regional and local agencies to attain greater levels of integration across the network layers and related system benefits will be recognized. The three case studies reviewed represent established programs that provide an example of the varying levels of institutional, systems, and operational integration.

7.2.1 Institutional Integration

Institutional integration refers to the formal, or sometimes informal, collaboration of stakeholders within a region. These agencies may be State DOTs, regional MPOs, counties, municipalities, transit agencies, advocacy groups, etc. These agencies work together to support the full lifecycle of the RTSMO deployment, including deployment planning, funding, management, maintenance, and operations.

The RTSMO deployments studied for this document rely on institutional integration:

- **I–80 ICM Program**. The *Interstate 80 Corridor Memorandum of Understanding* (Caltrans 2012) guides the I–80 ICM Project and clearly defines the components of the project, ownership, operations and maintenance, and management responsibilities, financial cost distribution, framework for cooperation and conflict resolution, and governance structure, as well as establishes the stakeholder's commitment to the project and its continued success. Although the I–80 ICM Program originally planned to integrate with the local transit providers, the program is now primarily focused on freeway and arterial integration and relies on these operating stakeholders to manage and operate the program.
- **R-ICMS Program**. The Central Florida TSM&O Consortium manages the R-ICMS Program and is leveraged as a way to share ideas, identify issues, and develop solutions collectively. Agencies are not required to participate in the program or the consortium and are able to disengage at any time. By empowering the local stakeholders, FDOT has found that commitment and engagement has been stronger because each agency is in control and does not have forced participation. The R-ICMS Program has also proven to be successful at fostering further regional collaboration and cooperation, which has been leveraged for enhanced system benefits and cost savings.
- **SigOps Program.** Institutional integration leveraged for the SigOps Program includes formal MOU agreements between GDOT and local agencies (counties and municipalities) that define roles, responsibilities, and financial obligations of each agency. Each agency has a unique arrangement with GDOT about how the traffic signals within its jurisdiction may be owned, operated, maintained, and managed. Beyond the formal agreements, collaboration and coordination are handled through regular standing meetings and established processes to manage ad hoc requests and issue resolution.

7.2.2 Systems Integration

Systems integration tends to be challenging due to the complexity of connecting diverse hardware and software components, understanding their configurations, and managing firmware updates. The emergence of new technologies further complicates integration efforts. To mitigate these challenges, industry leaders emphasize the use of standards-based systems to prevent proprietary components from limiting integration possibilities. Collaboration with IT stakeholders is also notable, involving them in project teams and planning for effective operations and maintenance throughout the project lifecycle.

Overcoming these challenges leads to numerous benefits, including enhanced transportation network management, improved efficiency, and optimized resource utilization. Successful examples of deployments that have overcome these challenges include the integration of ITS in various cities and the use of standardized communication protocols in connected vehicle initiatives.

Summary of systems integration for the three case studies:

- **I–80 ICM Program** has faced difficulties in integrating collaborating agency systems and sustaining those connections. The I–80 ICM system comprises many disparate systems, including legacy systems. One of the key lessons learned is the importance of planning for sustainable systems integration. Caltrans, as the lead agency, faced challenges with managing system configuration changes necessary to accommodate collaborating agency software and hardware updates/upgrades.

- **R–ICMS Program** has successfully integrated a number of varying systems throughout the region. Extensive communication network integration has been relied on to support the connectivity of systems. FDOT has established and grown a regional workforce knowledgeable and skilled within network communications. The FDOT Program Manager, who has a background in network communications and recognizes the importance of these skills, has led this effort. Furthermore, the consultant contracts with which the program is structured encourage broader system access and knowledge, making system integration more efficient.
- **SigOps Program** leverages a robust communications network as well as contracting mechanisms for the efficient deployment of similar architectures and systems. GDOT encourages consistent software and hardware deployments to efficiently integrate collaborating agency systems through shared access and cost savings. GDOT provides local agencies with traffic signal controller local and central managing software. In addition, local agencies throughout the State also have access to GDOT procurement contracts, which typically offer lower costs on hardware/software. This shared access has created an environment that is more efficient to integrate and upgrade, which has led to statewide expansion and innovative upgrades.

7.2.3 Operational Integration

Integrating the operations of RTSMO relies on all stakeholders understanding and supporting the goals and objectives of the regional system. The integration of operations can cause agencies to modify their SOPs, which may not align directly with their internal goals and objectives. For example, ramp metering timing may need to be adjusted from the optimal timing patterns to also avoid causing spillback congestion on adjacent arterial facilities. Furthermore, collaborating agency leadership should support the modifications to operations through institutional arrangements, and operators should trust that the systems integrated to support the deployment are fully functional, accurate, and reliable.

The RTSMO programs studied for this document have implemented operations integration in the following ways:

- **I–80 ICM Project** primarily focuses on operating during incidents or large events to support more efficient travel. Caltrans relies on incident management authority to apply preapproved traffic signal flush plans and traveler information messages along adjacent arterial corridors. The operational integration for this project has been facilitated through the institutional integration framework.
- **R-ICMS Program** relies on predefined operational scenarios that recommend operational activities during congested conditions. The managing operators are able to consider and accept/deny system recommendations on a case-by-case basis. This ability provides collaborating agencies with the control and opportunity to gain confidence in the system. However, this flexibility could lead to varying implementation of arterial traffic signal timing plans should an agency not implement recommendations. FDOT has been successful in gaining the trust and integration of collaborating agency operations.
- **SigOps Program** operates collaboratively with stakeholders in varying ways depending upon their institutional arrangements. In most cases, GDOT has the authority to lead operations independently during emergency events. In day-to-day conditions, network operations rely on arterial and freeway monitoring, pretimed traffic signal timings, advanced traffic signal strategies, and regular coordination.

7.2.4 Transportation Network Integration Summary

Table 3 summarizes the network interfaces within the institutional, systems, and operational integration framework for the three RTSMO case studies reviewed.

Table 3. Summary of regional transportation systems management and operations integration and network interfaces.

Network Interfaces	Institutional			Operational			Systems		
Freeway-Arterial	I–80 ICM	R-ICMS	SigOps	I–80 ICM	R-ICMS	SigOps	I–80 ICM	R-ICMS	SigOps
Freeway-Multimodal	-	R-ICMS	-	-	-	-	-	-	-
Arterial-Multimodal	-	R-ICMS	-	-	R-ICMS	SigOps	-	R-ICMS	SigOps

- = No data.
R-ICMS = Regional Integrated Corridor Management System.

As mentioned previously, deployments rely on varying integration based on the goals and constraints of the implementation. Each agency and deployment is different. The three case studies reviewed provide a good representation of mature systems within the industry. There is not a deployment known to date that fully achieves institutional, systems, and operational integration throughout all transportation network layers. However, recognizing opportunities for maturation and growth provides a chance to consider whether further benefits may be realized.

The case studies reviewed are representative of industry trends and demonstrate the opportunity for maturation of integration with the multimodal network layer. In addition, it should be noted that each of the case studies considered the potential to influence demand with traveler information but was not able to capture or evaluate the impact of these efforts.

8 RTSMO Deployment Next Steps

This Case Studies Technical Report represents the findings of a comprehensive literature review as well as the case studies presented above with the intent of providing information to potential deployers throughout the industry. The following sections provide high-level resources that may be referenced when considering RTSMO deployment next steps with a focus on the systems engineering process and the value that applying systems engineering practices can add to a RTSMO deployment. As part of the systems engineering process, use cases are developed to illustrate how the system will be used to accomplish specific goals of a deployment. Example RTSMO use cases are presented as a representation of how regional integration is leveraged to efficiently manage specific scenarios, with one use case broken down into steps and described in full detail.

8.1 RTSMO Systems Engineering Overview

Systems engineering is an interdisciplinary approach that directs the management of complex systems throughout the project life cycle. It emphasizes a holistic perspective that considers the efficient and effective interactions of different components in a system. The systems engineering process helps ensure that project managers have a clear understanding of user needs and allows them to effectively control and track project requirements (USDOT 2022).

Implementing a systems engineering approach to guide a RTSMO deployment can be necessary due to the complex nature of regionally integrated systems. It is critical to design and develop a system with a shared understanding of the institutional, systems, and operational concept.

8.1.1 Systems Engineering 'V' Diagram

The 'V' diagram shown in **Figure 12.** Diagram. Systems Engineering 'V'.

Source: USDOT is a graphical representation commonly used in systems engineering to illustrate the relationships between different stages of development, from the initial concept to the final product. The 'V' diagram begins on the left side with concept exploration followed by the development of a Concept of Operations, which outlines the intended functionality of the system, which guides development of the systems requirements and provides context for design decisions. The left side of the 'V' represents the decomposition of high-level requirements into detailed specifications, while the right side represents the integration and validation of these components. The 'V' shape illustrates the traceability of requirements from the top level down to the individual components and back up during testing and validation, ensuring that each requirement is met and validated throughout the development process (USDOT 2022).

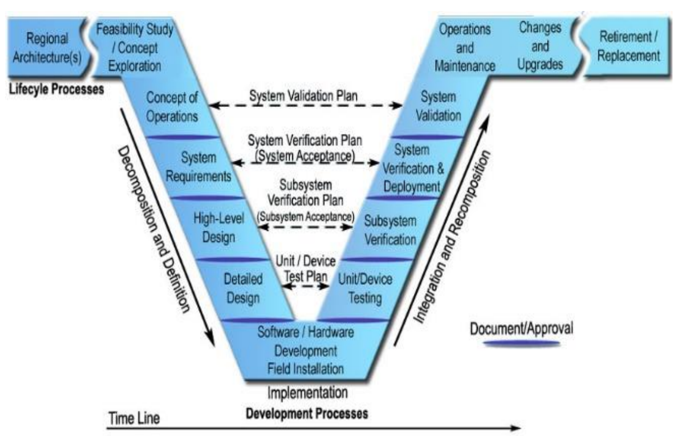


Figure 12. Diagram. Systems Engineering 'V'.
Source: USDOT

8.1.2 Value of Systems Engineering

Effective systems engineering provides a structured approach to managing complexity, reducing risk, and increasing the project's likelihood of success. System engineering increases the capacity of project managers to align the goals and objectives of the project with user needs to develop system requirements to support the procurement process. Systems engineering reduces the risk of the system not meeting the needs and objectives of the project by linking these to system design early in the project cycle. Research has proven that investing in systems engineering at the onset of a project can save 10–20 percent of the budget (INCOSE 2014).

Systems engineering can play a crucial role in the success of RTSMO deployments as it helps effectively address the complex challenges associated with coordinating diverse transportation systems while considering the interdependencies and interactions necessary for institutional, systems, and operational integration at a regional level. In addition, through requirement analysis and stakeholder engagement, systems engineering helps identify and prioritize user needs and requirements, enabling RTSMO deployments to focus on delivering solutions that align with stakeholders' goals and expectations.

Guidance and support for applying systems engineering principles are currently available online. The **FHWA "Systems Engineering for ITS" website** (USDOT 2022) provides resources such as:

- "**Concept of Operations" web page** includes an overview of the components and process of developing a concept of operations (ConOps).
- "**Developing Requirements" web page** provides insights on developing requirements.
- "**ITS Specific Publications" list** provides published guidance documents and examples.
- "**Example View by Deliverable" documents** provides example systems engineering documentation from past ITS projects.

In addition, the regionally integrated deployment literature that was reviewed for this case studies technical report included several example systems engineering documents that can be reviewed for reference (**Appendix III**).

8.2 Use Cases for Regional Transportation Systems Management and Operations

Use cases are tools for capturing the interactions between the system and its users. They ensure that the system is responsive to the needs of the user and subsequently enable the system to achieve the goals and objectives of the stakeholders. The intersection between institutional, operational, and system areas of regional transportation systems management occurs when the system is used to support attainment of regional transportation goals and objectives. Use cases articulate how the system is used to attain one or more operational objectives.

Throughout the review of RTSMO deployments, common use cases were discovered and provide a tangible method of understanding the use and value of regional integration. The RTSMO example use cases are representative of how regional integration is being leveraged to efficiently manage different scenarios such as significant incidents, major construction activities, and major special events. Application of each use case will vary slightly, depending on the region in which the deployment takes place and the specific project requirements.

This section provides an overview of how a use case is constructed and applied to highlight the dependencies between the areas/integration elements (institutional, operational, and systems) of a RTSMO program. Coordination of activities across the areas of a RTSMO program is critical to successfully applying operational strategies to support attainment of operations goals and objectives at a regional scale. The remainder of this section is organized as follows:

- **Section 8.2.1** provides an example use case and presents how a use case is organized. This example specifically focuses on how regional integration is being leveraged to manage significant incidents along a major interstate.
- **Section 8.2.2** discusses additional RTSMO example use cases that demonstrate how regional integration can enhance safety, mobility, and reliability.

8.2.1 Example Use Case – Major Incident Management Event

The following use case represents the actions that occur during a major incident management event as described below. This use case, while informed in part by the findings of the case studies, represents a compilation of institutional, operational, and systems actions to support the use case goal.

Use Case Description. A major vehicle crash along a major interstate (i.e., I–80) impacts the interstate and an adjacent corridor. Multiple lanes are blocked, and congestion has increased significantly within the area impacting traffic on a regional scale.

Objective: Apply regional operational strategies to minimize safety and mobility impacts of the incident, including:

- Minimize the duration, extent, and overall impact of the incident.
- Provide travelers with actionable, reliable, and timely information and guidance.

Participating agencies (primary actors). Primary actors of the system include the ICM operator, freeway operator, arterial operator, transit operator, incident responders.

Other users (secondary actors). Secondary actors of the system include the ICM corridor management team, third-party traveler information providers, travelers.

Preconditions. ICM system in place, with predeveloped operational response plans enabled for automatic activation. For the purposes of this example, it has been assumed that an ICM featuring a DSS that generates and coordinates operational strategies to maximize corridor throughput during nonrecurrent capacity constraining events is being used.

Table 4 presents the significant incident management example use case within the context of institutional, operational, and systems integration elements.

Table 4. Major incident management example use case.

Use Case Step	Institutional	Operational	Systems
1 – Detect Incident. An initial incident report can come from various sources (state/local police, FSP, TMC, 911 call, etc.) but is typically captured officially in a 911 CAD system technology-based automatic incident detection can also supplement.	• Interagency agreements covering mutual response protocols and coordination protocols to ensure that monitoring capability and incident information is shared with all stakeholders.	• Maintenance and active monitoring of detection infrastructure. Business rules on what constitutes a "detected incident."	• 911 CAD interconnect system and interfaces to consolidate and centralize incident information. • Detection, field communications, and analytic systems to infer incident from the data.
2 – Verify Incident. Typically, TMC operator will use CCTV or field reports to verify incident and enter it into incident management system.	• Interagency agreements allowing cross-jurisdictional access to the systems and facilities to support verification of incidents and reporting functions to other agencies.	• Operating agency field personnel who can verify incident (maintenance, incident response) assigned to corridor and available.	• CCTV and mobile detection/verification technology (vehicle-based, drone, etc.).
3 – Incident response. Simultaneously, update information in incident event system—some information may be prepopulated, but manual entry and update necessary (e.g., two lanes blocked)	-	• Field personnel who can respond to incident (maintenance, incident response, fire, police, medical) assigned to corridor and available.	• 911 CAD interconnect system. • Incident command system (ICS) to lay out response protocols and who's in charge.

Use Case Step	Institutional	Operational	Systems
4 – Assess Corridor and Forecast Conditions. System will continually assess operations taking in stream of multisource data, including incident information. Processes to forecast future conditions based on new events, changes in measures, etc.	• Interagency data sharing agreements.	• Establish core performance measures aligned with key operational objectives.	• Decision support system. • Centralized data hub to aggregate real-time data, calculate performance measures. Center-to-center (C2C) communications. • Modeling (e.g., online real-time simulation).
5 – Activate DSS. DSS activation triggered by some performance threshold.	• Agreements around business rules to guide the range of alternatives that can be "suggested" by the DSS. Examples include: no diversion allowed on routes with school crossings between 7 and 8:30 a.m. and between 2:30 and 4:30 p.m.; prearranged diversion routes and timing patterns.	• Business rules to determine DSS activation triggers.	• A DSS that can maintain a set of preidentified response plans.
6 – Generate operational response strategy(ies). Incorporates predeveloped scenario responses with dynamic or real-time modeling capabilities.	• Interagency agreements about what kinds of responses will be supported under what conditions (feeds into the business rules).	• Development of incident response plans.	• A DSS that can integrate the plans/business rules.

Use Case Step	Institutional	Operational	Systems
7 – Select Response Strategy. Alternatives may be presented to system user for selection or modification or else automatic selection based on certain parameters or system configuration.	• Specialized RTSMO training for operators. • Agreements on sharing control and automation of systems.	• Operators to interact with the DSS and be able to decide which parts to implement. • Traffic engineer input or review to provide expertise as needed.	• DSS that presents potential actions.
8 – Implement Response Strategy. Interfaces for control to operational systems. Notifications to stakeholder agencies.	• Mutual aid agreement (to allow agencies to operate on others' facilities). • ITS and communications maintenance plans and agreements.	• RTSMO response notification and communication procedures. • Personnel available for IT support, ITS, and communications maintenance.	• C2C interfaces between RTSMO system and modal operational systems. • Reliable systems and communications with high availability.
9 – Monitor and Evaluate Response. Continuously monitor and reevaluate/revise response strategy.	-	• RTSMO operator is available to monitor conditions and make modifications to response strategies as needed.	• System capable of monitoring, incorporating changes in conditions to update response activities.
10 – Return to Normal. Return system to normal operations when conditions warrant.	-	• RTSMO operator to make determination to terminate response activities.	-

Use Case Step	Institutional	Operational	Systems
11 – Terminate Incident Event. Manual closing out of the incident and clearing all response vehicles from the scene.	-	• Operator terminates event based on communications with incident responders.	-
12 – Regional Collaboration and After-Action Reporting. The RTSMO team reviews the recent significant incident response, reviews performance data, and discusses potential opportunities for operational, systems, and institutional improvements.	• Commitments and agreements among corridor stakeholders to engage in after-action reviews for RTSMO operational improvements.	• Have the appropriate personnel involved who can speak to operational performance.	• Have system data available for review and assessment/modeling. • System capable of incorporating historical corridor performance data to improve response plans.

8.2.2 Common RTSMO Use Cases

This section presents common RTSMO use cases that were identified during the literature and case study review. These examples represent scenarios in which a RTSMO deployment is leveraged to enhance safety, mobility, and reliability.

- **Major Incident Event.** As fully described above in **section 8.2.1**, a RTSMO deployment can be leveraged to greatly improve the response to significant incidents. This type of event may result in the closure of a major thoroughfare in the region and involve the implementation of detours along adjacent corridors. The system can detect and alert TMC operators, who can verify and coordinate with first responders. This can be followed by selecting an appropriate response plan to manage the traffic demand on the freeway and arterials. The implementation can be coordinated with the local agencies along the diversion routes, for the duration of the closure.
- **Emergency Management.** Emergency management use cases may include unexpected natural/other disasters such as bridge collapse, chemical spill, etc. Similar to a significant incident, this type of event could result in the closure of a major interstate or arterial in the region or perhaps widespread closures in the case of a large weather event. Detours may be necessary for an extended period if there is significant damage. RTSMO systems are used to detect and alert TMC operators of roadway anomalies, who can verify and coordinate a response. Response plans may not be predetermined for large-scale emergency events, depending on the extent and duration of the closure needed. RTSMO systems are used to actively assess and monitor roadway conditions and can be used to quickly respond at a regional level. By having RTSMO systems in place, the transportation network is able to be actively managed and customized regional response plans to accommodate the diversions are possible due to the standing institutional agreements and shared systems. Quick action and response is made possible with coordination among local agencies at a regional level, who are accustomed to working together to operate the regional network.
- **Major Construction Project.** When a major construction project that affects a primary thoroughfare in the region, over a long period of time, is being planned, it serves as a catalyst for regional coordination, which in turn can become the genesis of a RTSMO deployment. For example, the FDOT D5 R-ICMS (RTSMO deployment) was developed to support the construction activities of the I-4 Ultimate project as described in **section 5**. The ICMS serves as a tool to mitigate impacts from the planned detours during construction. The response plans are developed expressly to handle these planned detours. The freeway and arterial managers monitor travel times, volumes, alerts, and recommendations of response plans. The system performance reports are reviewed, and operational refinements are implemented as needed.
- **Major Planned Event Management.** RTSMO systems are regularly used to manage major planned events that impact traffic regionally. The RTSMO system becomes an invaluable tool that can be used to actively manage the ingress and egress of the event to provide a safer, better experience for travelers. The RTSMO system is used to manage the arterial network such that local law enforcement who are regularly tasked with physically directing traffic at a signalized intersection, no longer need to be exposed. Regional stakeholders leverage their RTSMO systems to support efficient movement of eventgoers, which has been recognized as supporting the region's

economic development as larger events are able to be efficiently managed and bring more business to the area.

- **Regional Arterial Management.** RTSMO systems are used to provide regional arterial management. RTSMO systems are governed by local agency institutional agreements and are comprised of integrated signal management subsystems that leverage shared operational procedures. Regionally significant corridors are monitored and operated collaboratively across jurisdictional boundaries to provide more efficient movement of travelers.
- **Normal Operations/Regional Congestion Mitigation.** Typically, RTSMO systems are deployed to address a specific need such as significant incidents or a major construction project. However, these systems are increasingly being used to actively mitigate and manage day-to-day congestion at a regional scale. Once the RTSMO system is deployed and institutional agreements have provided a framework for shared systems and operational procedures, RTSMO integrated systems and performance data are used to inform normal operations. More efficient timing plans may be implemented to mitigate congestion on the freeway and arterial networks, TSP or emergency vehicle preemption (EVP) may be deployed along a multijurisdictional corridor, cameras may be shared to provide a regional perspective on operations, as well as many other possibilities depending on the deployment. The use of RTSMO systems is evolving as agencies are realizing the benefits beyond their original intent. Furthermore, the institutional frameworks that are established to support these integrated systems also provide a valuable mechanism to coordinate and leverage opportunities at a regional scale.
- **Regional Transit Operations.** A regional transit operation may deploy transit priority, and dedicated bus lanes across multiple jurisdictions aims to enhance the efficiency and reliability of public transportation services. The system might utilize various technologies and strategies to prioritize transit vehicles, ensuring they adhere to schedules and maintain on-time performance. Key operational elements include:
    - **Traffic Signal Priority (TSP):** The implementation of TSP enables transit vehicles to communicate with traffic signals, allowing them to request priority treatment at intersections. This ensures smoother transit flow by minimizing delays caused by traffic congestion.
    - **Integrated Communication Systems:** Communication infrastructure enables seamless coordination between transit vehicles and traffic management centers across multiple jurisdictions. Real-time data exchange facilitates dynamic adjustments to traffic signal timings and transit operations, optimizing overall system performance.
    - **Collaborative Planning and Governance:** Effective collaboration among multiple jurisdictions and transit agencies, is crucial for the success of regional transit operation. Joint planning, policy development, and governance structures ensure alignment of objectives and coordinated implementation efforts.
    - **Regional Integrated Freeway and Arterial Operations:** RTSMO deployments are being leveraged to optimize the flow of vehicles across arterial and freeway facilities by employing a combination of strategies and technologies to manage traffic effectively and enhance overall system performance. These deployments are being leveraged during normal operating conditions to further optimize the network.

Key freeway operational strategies such as ramp metering, variable speed limits, lane management, incident detection help regulate traffic flow and reduce congestion on major highways. These measures aim to maintain optimal traffic flow and improve safety. When integrated with arterial operational strategies such as adaptive traffic signal timing, dynamic routing, etc., regional traffic congestion is reduced.

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Appendix III Database of Deployments

Table 5 provides a summary of resources reviewed for this effort. Cited references can be found in **Appendix I**.

Table 5. Deployment review summary.

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
1	I–15 Integrated Corridor management (ICM)	San Diego Association of Governments (SANDAG)	Keep traffic moving smoothly in each direction of travel on I–15.	ICM	Dynamic pricing, managed lanes, transit signal priority (TSP), adaptive signal timing, ramp metering	Freeway, arterial, transit, travel demand	Site demonstration and evaluation document	2015
2	U.S. 75 ICM	Dallas Area Rapid Transit	Increase corridor throughput, increase travel time reliability, improve incident management.	ICM	Dynamic pricing, transit/ramp signal priority	Freeway, arterial, transit, travel demand	Concept of operations	2010
3	SigOps Program	Georgia Department of Transportation (DOT)	Monitor and optimize traffic flow to provide a more efficient and safer commute for the public.	Active traffic management (ATM)	Signal optimization	Arterial *Freeway coordination during large events	Website	Current

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
4	Florida District 5 ICM	Florida DOT	Improve travel time efficiency, travel time reliability, and to perform incident management throughout the network by meshing freeway operations with arterial operations.	ICM	Dynamic shoulder running, ramp metering, TSP, adaptive signal control	Freeway, arterial, transit, travel demand	National Operations Center of Excellence (NOCoE) case study and website	2019, current
5	I–805 Active Transportation and Demand Management (ATDM) Concept	SANDAG	Maintain trip reliability, maximize person throughput. Minimize person delay. Leverage institutional coordination.	ICM	Bus on shoulder, queue warning, adaptive signal timing, ramp metering	Freeway, arterial, transit, travel demand	Concept of operations	2016
6	I–805 transit-only lanes (TOL) (Enhanced ATDM concept deployment)	SANDAG	Improve schedule reliability of transit buses.	ATM	Dynamic shoulder use, transit/ramp signal priority	Freeway, transit	Initiation charter	2019

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
7	Virginia—I–66 ATM Project (no longer active)	Virginia DOT	Improve operations, roadway safety and incident management.	ATM	Dynamic lane use control, dynamic speed limits, queue warning, hard shoulder running	Freeway, travel demand	Evaluation	2018
8	I–210 Connected Corridors Pilot	California Department of Transportation (Caltrans)	Move people and goods in the most efficient manner possible. Seeking solutions to improve how freeways, arterials, transit, and parking systems work together.	ICM	Adaptive ramp metering, signal synchronization, rerouting, park-and-ride integration	Freeway, arterial, transit, travel demand	Concept of operations	2015

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
9	I–110 Dynamic Corridor Congestion Management	Caltrans District 7	Identify and evaluate proactive congestion management concepts that make fullest use of all system capacity to address the certain congestion increase the district and the South Bay region will face over the next 10–20 years.	ICM	Dynamic routing, adaptive ramp metering	Freeway, arterial, transit, travel demand	Corridor study	2013
10	I–80 Integrated Corridor Management	Alameda County	Manage congestion, improve safety, and maximize flow for all modes and incorporate measures to reduce air pollution.	ICM	Dynamic routing, adaptive ramp metering	Freeway, arterial, transit, travel demand	Concept of operations	2010

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
11	Bell Road Adaptive Signal Control Technology	Arizona DOT, Maricopa County DOT	Manage a congested corridor.	ATM	Adaptive signal control	Arterial	NOCoE case study	2018
12	U.S. 23 Active Traffic Management	Michigan DOT	Mitigate peak-hour congestion, shorten incident response times, and improve safety.	ATM	Dynamic shoulder lanes, dynamic speed advisories, queue warning	Freeway	Evaluation	2022
13	Traverse City Adaptive Signal Control Technologies	Michigan DOT	Reduce congestion, improve travel time reliability, reduce traffic crashes, monitor and measure traffic operations to make regular adjustments.	ATM	Adaptive signal control	Arterial	NOCoE case study	-
14	I–24 SMART Corridor	Tennessee DOT	Improve travel time reliability.	ATM	Dynamic routing, ramp metering	Freeway, arterial	Corridor study, project website	2014, current

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
15	Streets Project	City of Dubuque	Improve mobility, reduce congestion, improve safety, provide information to travelers.	ATM	Integrated traffic signal system, dynamic rerouting	Arterial, travel demand	Systems engineering—concept development summary	2018
16	Integrated Transportation Management Program	Delaware DOT	Reduce congestion and delay, improve safety, reduce operating costs, improve system performance.	ICM	-	Freeway, transit, travel demand	Integrated transportation management strategic plan	2017
17	I–95 Express Toll Lanes	Florida DOT	Reduce congestion on I–95.	Active demand management (ADM)	Dynamic pricing	Freeway, travel demand	Lessons learned	2010
18	OR-217 ATM System	Oregon DOT	Improve travel time reliability and safety.	ATM	Dynamic speed limits/advisories, queue warning	Freeway	ATM summary	2015

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
19	State Route 520/I-90 and I–5 ATM	Washington State DOT	Provide advance notice of conditions causing congestion, and incrementally direct drivers to reduce speeds and change lanes as necessary to ease congestion.	ATM	Dynamic speed limits/advisories, dynamic lane use control	Freeway	ATM report	2013
20	I–405 Express Lanes	Orange County Transportation Authority	Provide safe, reliable, predictable commute. Optimize throughput. Increase average vehicle occupancy.	ADM	Managed lanes, dynamic pricing	Freeway, travel demand	Website	-
21	I–105 Express Lanes	LA Metro	Increase vehicle throughput and person throughput, reduce delay.	ADM	Managed lanes, dynamic pricing	Freeway, travel demand	Corridor study and evaluation	2013

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
22	I–75 Northwest Corridor Express Lanes “Go-Live” Taskforce	Georgia DOT	Improve mobility and provide reliable trip times throughout metro Atlanta.	ATM	Reversible express lanes	Freeway, travel demand	NOCoE case study	2018
23	I–205 ATM Johnson Creek–Columbia River	Oregon DOT	Improve safety and reliability on the segment.	ATM	Dynamic speed limits/advisories	Freeway	Summary sheets	2016
24	State Route 51 Adaptive Ramp Metering	Arizona DOT	Reduce traffic congestion and increase freeway service levels.	ATM	Adaptive ramp metering	Freeway	NOCoE case study	2018
25	I–580 Express Lane	Alameda County	Congestion relief, enhanced operational and safety improvements, reliable travel time savings.	ADM	Dynamic pricing	Freeway, travel demand	Evaluation	2018

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
26	I–880 Express Lane: Oakland to Milpitas	Metropolitan Transportation Commission (MTC)	Provide a more reliable trip, ensure use of all lane capacity, reduce carpool cheating, provide tool to manage traffic flow.	ADM	Dynamic pricing	Freeway, travel demand	Fact sheet	2019
27	I–270 Variable Advisory Speed Limits	Missouri DOT	Improve traffic flow, prevent breakdown, reduce congestion and delay, and improve safety.	ATM	Dynamic speed limits/ advisories	Freeway	Evaluation	2010
28	U.S. 23 Flex Route	Michigan DOT	Improve peak hour directional traffic flow, incident management and corridor operations and safety.	ATM	Flexible route	Freeway	NOCoE case study	2017
29	Midtown in Motion	New York City DOT	Ease congestion in Midtown Manhattan.	ATM	Adaptive traffic signal control	Arterial, bicycle, pedestrian	Press release	2012

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
30	New York City DOT TSP	New York City DOT	Enhance the movement of transit through traffic signal coordination.	ATM	TSP	Arterial, transit, travel demand	Evaluation	2017
31	I–84 Variable Speed Limit (VSL)	Oregon DOT	Improve safety, improve road closure process to reduce impact on all users, improve resource efficiency.	ATM	Dynamic speed limits/advisories	Freeway	Feasibility study	2018
32	I–5 and I–405 VSL	Oregon DOT	Smooth traffic flow and reduce crashes.	ATM	Dynamic speed limits/ advisories	Freeway	Evaluation	2015
33	I–75 Low Visibility Warning System	Tennessee DOT	Improve safety during low visibility.	ATM	Dynamic speed limits/advisories	Freeway	Best practices review—road weather	2006

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
34	Sam Houston Tollway ATM	Texas DOT	Improve customers' quality of life. Improve safety, reliability, mobility.	ATM	Adaptive ramp metering, access modifications, high-occupancy vehicle (HOV)/ high-occupancy toll (HOT) lane modifications	Freeway	Congestion mitigation plan presentation	-
35	State Route 520 Lake Washington Urban Partnership ADM	Washington State DOT	Reduce traffic congestion in major urban areas.	ADM	Dynamic pricing	Freeway, travel demand	Fact sheet	2009
36	I–405 Dynamic Corridor Ramp Metering System	Caltrans District 7	Improve movement on the freeway.	ATM	Dynamic ramp metering, dynamic traffic signal control	Freeway	Annual report	2014
37	Oakland County SCATS Signal System	Road Commission for Oakland County	Improve travel time improvements and safety.	ATM	Adaptive traffic signal control	Arterial	ATM deployment presentation	2018

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
38	I–880 ICM	MTC	Create a system such that all facilities will function as an integrated transportation network. Enhance safety, efficiency, mobility, and transportation choices.	ICM	Dynamic routing	Freeway, arterial, transit, travel demand	Concept of operations	2008
39	ConnectSmart Program	Texas DOT Houston District	Improve safety, reduce congestion, improve air quality, and promote a more accessible and equitable system.	ATM	Dynamic routing	Freeway, arterial, transit, travel demand	Website	-

ID	Deployment	Lead Agency	Deployment Goal	Program Areas	Strategies	Transportation Network Layer	Resource	Resource Year
40	U.S. 36 Express Lanes	Colorado DOT	A multimodal solution to alleviate congestion along the corridor by combining managed (HOT) lanes, Bus Rapid Transit (BRT) service, and commuter bikeway.	ATM	Dynamic messaging signs, HOV/HOT/BRT express lanes, commuter bikeway	Freeway, transit, bicycle	Website	-

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Office of Operations

1200 New Jersey Avenue, SE

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