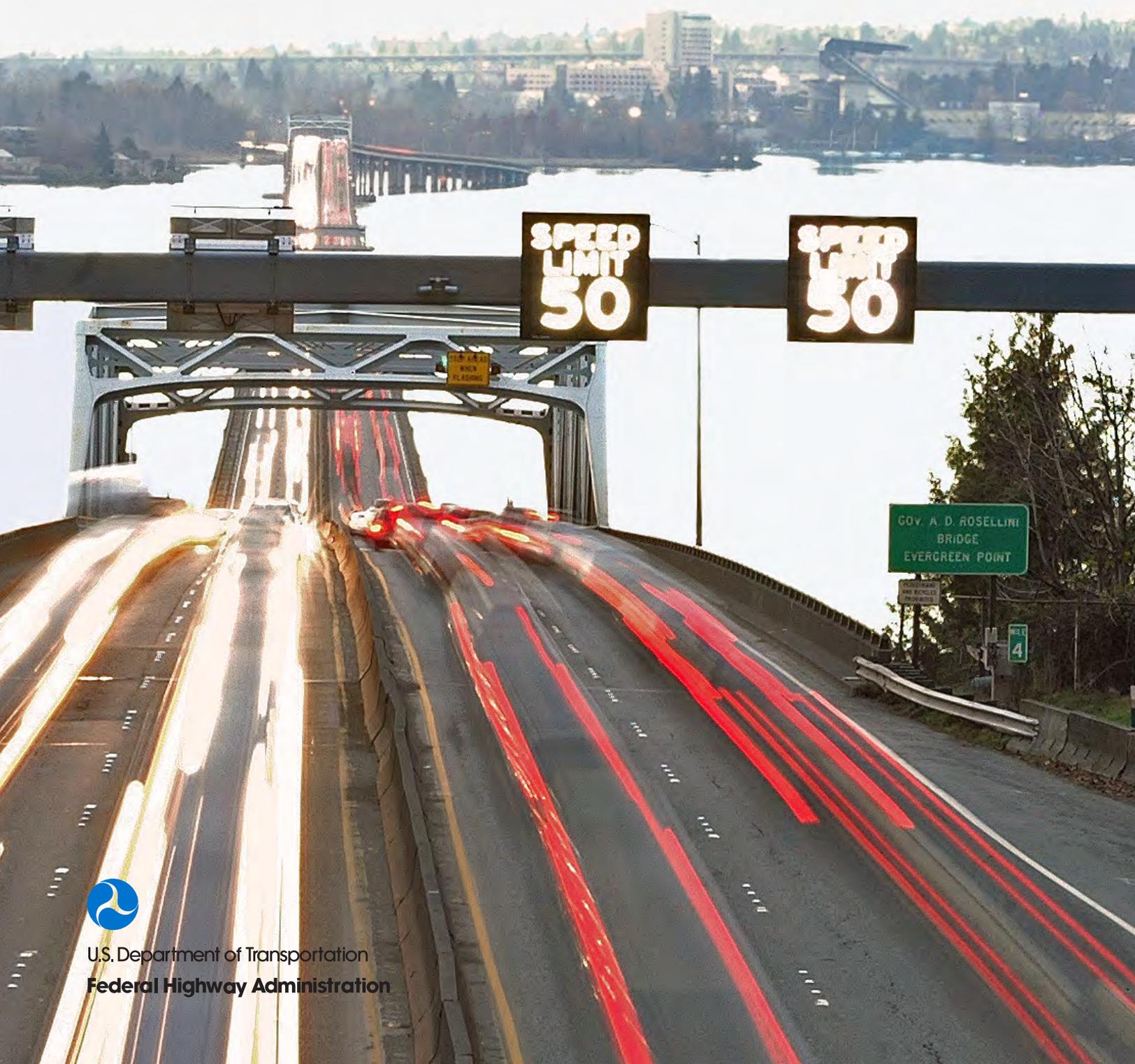


# Active Traffic Management (ATM) Implementation and Operations Guide



U.S. Department of Transportation  
**Federal Highway Administration**

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# SI\* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	Km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	Square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	Square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	Square meters	m <sup>2</sup>
ac	acres	0.405	Hectares	ha
mi <sup>2</sup>	square miles	2.59	Square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	Newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	Kilopascals	kPa

## APPROXIMATE CONVERSIONS FROM SI UNITS

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

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## ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State and Highway Transportation Officials
AMS	analysis, modeling, and simulation
ARM	adaptive ramp metering
ATDM	active transportation and demand management
ATM	active traffic management
ATSC	adaptive traffic signal control
BI	buffer index
Caltrans	California Department of Transportation
CAVs	connected and automated vehicles
CMAQ	Congestion Mitigation and Air Quality
CMAR	construction management at risk
CMM	Capability Maturity Model
DB	design-build
DBOM	design-build-operate-maintain
DJC	dynamic junction control
DLA	dynamic lane assignment
DLR	dynamic lane reversal
DMC	dynamic merge control
DMS	dynamic message sign
DShL	dynamic shoulder lane
DLUC	dynamic lane use control
DSpL	dynamic speed limit
DTMR	Department of Transport and Main Roads
EPA	Environmental Protection Agency
FAQs	frequently asked questions
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HOV	high occupancy vehicle
IDOT	Illinois Department of Transportation
INFLO	intelligent network flow optimization
ITS	intelligent transportation system
LCS	lane control sign
MAP-21	Moving Ahead for Progress in the 21 <sup>st</sup> Century Act
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
MPO	metropolitan planning organization
MUTCD	<i>Manual on Uniform Traffic Control Devices</i>
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
ODOT	Oregon Department of Transportation
PBPD	performance-based practical design
PennDOT	Pennsylvania Department of Transportation
PSE	planned special events
PS&E	plan, specification, and estimate

PTI	planning time index
QW	queue warning
SANDAG	San Diego Association of Governments
SMS	shoulder-mounted sign
SOP	standard operating procedure
STIP	statewide transportation improvement program
STP	statewide transportation plan
TIP	transportation improvement plan
TMC	traffic management center
TMS	transportation management system
TSMO	transportation systems management and operations
TTI	Texas A&M Transportation Institute
VCTIR	Virginia Center for Transportation Innovation and Research
VDOT	Virginia Department of Transportation
VMT	vehicle miles of travel
VSL	variable speed limit
WSDOT	Washington State Department of Transportation
WYDOT	Wyoming Department of Transportation
WZ	work zone

## CHAPTER 1. INTRODUCTION

Transportation professionals continue to be challenged by congestion and safety on the complex networks they build, operate, and maintain. As recurring and nonrecurring congestion increase, travelers experience longer delays, consume more fuel, and feel the impact of more crashes on their daily commutes. Agencies recognize that adding capacity is frequently outside the realm of both physical and fiscal possibility. Thus, they increasingly turn to transportation systems management and operations (TSMO) strategies to mitigate mobility and reliability impacts. Over the past two decades, agencies have explored a variety of approaches that have yielded improved freeway management, arterial management, regional coordination, and integrated corridor management. Today, most agencies have levels of operational capability, detection, and information dissemination mechanisms that would have been unimaginable two decades ago. As a result, agencies are able to leverage these investments and capabilities through the application of a wide variety of approaches to improve mobility and safety. However, agencies continue to face the challenges of changing travel patterns, growing demand, evolving traveler behaviors, limited financial resources, and increasing traveler expectations.

Active transportation and demand management (ATDM) is an agency's capability to improve trip reliability, safety, and throughput of the surface transportation system by deploying operational strategies that dynamically manage and control travel and traffic demand and available capacity, based on prevailing and anticipated conditions.<sup>(1)</sup> Through the use of available tools and assets, agencies manage traffic flow and work to influence traveler behavior in real time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, and/or maximizing system efficiency. ATDM can include multiple approaches spanning demand management, traffic management, and parking management.



**Active traffic management includes nontraditional solutions to increasing the efficiency of transportation facilities through actively and dynamically managing traffic operations.**

Active traffic management (ATM) is one of the three categories of strategies under ATDM, along with active demand management (ADM) and active parking management (APM). ATM encompasses a broad array of nontraditional solutions that agencies can deploy to increase the efficiency of their transportation facilities. This efficiency is accomplished by moving from static approaches to more actively and dynamically managed traffic

operations, which work to match fluctuating demand and varying conditions. As transportation agencies grapple with increasing congestion and fewer available funds to add capacity, temporary and permanent ATM strategies have been increasingly deployed in the United States within the last decade.

The Federal Highway Administration (FHWA) has developed this *ATM Implementation and Operations Guide* (the Guide) to assist transportation agencies interested in implementing ATM in their region, as well as those already operating ATM systems, in the pursuit of more efficient use of their networks through the implementation and operation of ATM strategies.

This chapter provides a quick guide to the topics covered in the individual chapters of the guidebook and the format used throughout the document. The remainder of this chapter presents the following sections:

- **Overview, Goals, Intent, and Audience.** This section presents an overview of the Guide, including the goals and objectives for the guidebook and the intent of the document to advance the concept of ATM.
- **Overview of ATM Strategies.** This section provides a high-level description of the ATM strategies included in the Guide along with application scenarios and examples.
- **ATDM, ATM, and TSMO.** This section describes the relationship between ATM, ATDM, and the broader TSMO concept.
- **Systems Engineering.** This section presents the systems engineering process and its importance in the development and implementation of ATM projects.
- **Chapters at a Glance.** This section provides a quick guide to the major topics covered in each of the chapters and highlights the major elements covered.

## 1.1 OVERVIEW, GOALS, INTENT, AND AUDIENCE

The objective of this Guide is to provide regional and local agencies with guidance on how to strategically and effectively implement and operate ATM strategies. The Guide describes the stepwise approach to accomplishing this implementation through the application of the system engineering process; comprehensive planning; and organizational considerations, capabilities, and design considerations. It utilizes a combination of relevant existing resources and documents along with best practices and lessons learned gleaned from early adopters to offer practical guidance. It also emphasizes the value of ATM and what these ATM strategies can offer to operating agencies as part of their broader TSMO program.

The intended audience of the Guide includes agencies interested in implementing ATM in their region, as well as agencies that have implemented ATM and are interested in guidance on operating and maintaining their ATM systems and strategies more effectively. It is anticipated that agencies can use the information in implementing new ATM applications while ensuring that their organization and project partners are capable of operating and maintaining the system efficiently. Using the information in the Guide, agencies will be able to step through the implementation process for an ATM project and ensure all aspects of designing, deploying, operating, and maintaining the resulting strategies and systems are supported. This support can include enhanced connectivity and support within a traffic management center (TMC), integration with existing technologies and legacy systems, coordination with partner agencies, and ongoing monitoring of performance measures to enhance operations to support regional goals.



ATM is the dynamic management of recurrent and nonrecurrent congestion based on prevailing and predicted traffic solutions.

ATM is the dynamic management of recurrent and nonrecurrent congestion based on prevailing and predicted traffic conditions. While ATM itself is an evolutionary concept that can theoretically be applied to any existing traffic management application or strategy (e.g., moving from time-of-day shoulder use to dynamic shoulder use), many

ATM strategies are relatively new in the United States. More metropolitan regions are interested in implementing one or a combination of ATM strategies based on interest generated from recent deployments in the United States, such as Seattle, Minneapolis, and Northern Virginia.

As FHWA has conducted ATDM technology transfer workshops and peer exchanges across the country, participating agencies have continued to ask fundamental questions about the implementation and operations of these strategies. Common topics of interest include public outreach and communications; procurement methods; enforcement and whether to make strategies regulatory or advisory; software development; systems engineering; design issues regarding gantry and sign placement; driver comprehension of signs and *Manual on Uniform Traffic Control Devices* (MUTCD) compliance; ongoing operations and maintenance; required workforce skills, abilities, and supporting institutional business processes; and how to deploy an ATM system today while taking into account a future with connected and autonomous vehicles (CAVs).

While these questions are broadly relevant to TSMO concepts and strategies, they illustrate the need for guidance on ATM strategies and their unique and challenging aspects that differentiate them from more traditional TSMO approaches. Typically, ATM strategies are more dynamic in nature; require higher infrastructure deployment needs; and are more complex with the challenges associated with driver compliance, public outreach, and enforcement.

### **The Origins and Evolution of ATM**

In response to the growing pressure for agencies to do more with less and address congestion challenges from all aspects of the network, FHWA sponsored three international technology scanning studies of Europe in 2005, 2006, and 2010 to examine the congestion management programs, policies, designs, and experiences of other countries that are either in the planning stages, have been implemented, or are operating on freeway facilities. The 2005 scan<sup>(2)</sup> focused on European approaches to demand management, including operational strategies, while the 2006 and 2010 scans focused primarily on active traffic management. The 2006 scan<sup>(3)</sup> sought information on how agencies approach highway congestion and how they are planning for and designing ATM operational strategies at the system, corridor, and project or facility level. The 2010 scan<sup>(4)</sup> focused on the geometric design issues associated with ATM.

ATM strategies have been in use internationally for several decades, and the overall success of these strategies prompted their introduction in the United States. Table 1 provides a sample of early-deployment ATM strategies overseas. While not exhaustive, the examples provided show the diversity of ATM strategies in use overseas and from which the United States adapted the strategies included in the Guide.

The concept of ATM has also evolved internationally, both with individual strategies and in combination, with experience. For example, the Department of Transport and Main Roads (DTMR) of the Queensland Government (Australia) has implemented an ATM-related initiative called Managed Motorways. The strategies included in this initiative include dynamic speed limits (DSpL), dynamic lane use control (DLUC) or flexible lane control, adaptive ramp metering (ARM), adaptive traffic signal control (ATSC), dynamic message signs (DMS) with travel time and real-time traveler information, and roadside data systems and sensors.<sup>(5)</sup> The

traffic management system behind Managed Motorways integrates real-time information into algorithms to predict traffic congestion and proactively respond to conditions.<sup>(5)</sup> Enhanced emergency services also improve incident response to improve safety. DTMR indicates that the benefits include reduced congestion, improved travel time reliability, increased capacity, reduced incidents, reduced emissions, and improved fuel efficiency. Similarly, Highways England in the United Kingdom has advanced the concept of Smart Motorways, which is an evolution of previous ATM applications. This concept involves a variety of applications, which include a controlled motorway, hard shoulder running, and all lane running, all of which utilize technology for the purpose of improving journeys and helping ease congestion.<sup>(6)</sup>

**Table 1. Sample early international ATM strategy deployment.<sup>(7)</sup>**

ATM Strategy	Country/Initial Deployment	Documentation Information/Benefits
Adaptive Ramp Metering (ARM)	Germany (1999) The Netherlands (1989)	<ul style="list-style-type: none"> <li>• Reduction in peak-period congestion.</li> <li>• Decrease in incidents at ramps.</li> <li>• Increase in average speeds during peak.</li> </ul>
Adaptive Traffic Signal Control (ATSC)	Australia (1982) United Kingdom (1981)	<ul style="list-style-type: none"> <li>• Successful at traffic-responsive operations with rapidly changing traffic patterns and demands.</li> </ul>
Dynamic Junction Control (DJC)	Germany (1999) The Netherlands (2006)	<ul style="list-style-type: none"> <li>• Reduction in overall mean travel times.</li> <li>• Reduction in vehicle delay for both mainline and merging traffic.</li> </ul>
Dynamic Lane Reversal (DLR)	The Netherlands (1992)	<ul style="list-style-type: none"> <li>• Originally deployed as a carpool lane.</li> <li>• Converted for use by all users after four months.</li> </ul>
Dynamic Lane Use Control (DLUC)	Germany (1990s) The Netherlands (1996) United Kingdom (2006)	<ul style="list-style-type: none"> <li>• Frequently used with dynamic shoulder use.</li> <li>• Often indicate variable speed limit when needed.</li> <li>• Supplemental static signs frequently used.</li> </ul>
Dynamic Shoulder Lane (DSHL)	Germany (1990s) The Netherlands (1996) United Kingdom (1996) New Zealand (1991)	<ul style="list-style-type: none"> <li>• Frequently used with DLUC.</li> <li>• Applications for bus-only lane or all vehicles.</li> <li>• Operate on left or right shoulder, but not recommended for both.</li> </ul>
Queue Warning (QW)	Germany (1990s) The Netherlands (1983, 1996)	<ul style="list-style-type: none"> <li>• Decrease in crashes, crash severity.</li> <li>• Can be combined with DSPL.</li> </ul>
Dynamic Speed Limit (DSPL)	Germany (1970s) The Netherlands (1970s) Denmark (2005) United Kingdom (2006)	<ul style="list-style-type: none"> <li>• Decrease in crashes, crash severity.</li> <li>• Used in adverse weather and work zones.</li> <li>• Slight increase in capacity.</li> </ul>

Overall, the European and Australian approach to congestion management programs, policies, and experiences resonates with transportation professionals in the United States. In general:

- Active management is essential to the European and Australian approach to congestion management, building on advancements in technology and traffic management.
- European mobility policy focuses on the traveler, and congestion management strategies center on the need to ensure travel time reliability for all trips at any time of the day.
- Transportation and traffic management operations are priorities in the planning, programming, and funding processes and critical to realizing the benefits of transportation infrastructure investment for congestion management.

- European and Australian agencies use tools to support cost-effective investment decisions at the project level to ensure that implemented strategies have the best benefit-cost ratio and represent the best investment of limited resources.
- European and Australian agencies work to provide consistent messages to roadway users to reduce the impact of congestion on those travelers.
- European and Australian agencies typically include automated enforcement tools when implementing ATM strategies.

Overall, the international experience with ATM has provided direction for the development of ATM within the United States.<sup>(8)</sup> Domestic agencies have seen similarities and commonalities in challenges and approaches that can be adapted to fit the needs of the American traveler.

### **Early ATM Adopters in the United States**

Several regions across the country have been adopters of various ATM strategies over the past decade. At the time of installation, these deployments represented state-of-the-art applications, which agencies implemented to help solve the regional mobility and safety challenges. As such, they represent a wealth of experience working to solve the challenges surrounding the planning, design, and implementation of these innovative traffic management solutions with nominal guidance at the time of deployment.

These agencies can provide their experiences in selecting, deploying, monitoring, evaluating, and enhancing various ATM strategies. As these concepts enter the mainstream of congestion management solutions, agencies looking to deploy ATM for the first time can benefit from guidance on how to strategically and effectively implement ATM strategies through the best practices and lessons learned gleaned from these early adopters. Likewise, agencies that have deployed ATM strategies in select locations on their transportation network can benefit from guidance to improve their operations based on the best practices of other agencies. This approach cannot only improve operations at the specific location but also facilitate broader deployment of ATM strategies within the agency’s jurisdiction. The following sections highlight early deployment in the United States, though they do not represent an exhaustive list of applications and active deployments.

#### ***Washington***

The Washington State Department of Transportation (WSDOT) implemented what it terms “smarter highways” on several corridors in Seattle, to include ATM signage used for incident management and roadway maintenance. The system automatically posts regulatory variable speed limits to smooth traffic flow. The first corridor to begin ATM operations in Seattle was a 7-mi segment of Interstate 5 (I-5) northbound from the Boeing Access Road to I-90 in downtown Seattle. With significant construction on the parallel State Route (SR) 99–Alaskan Way Viaduct, ATM signage was implemented to help alleviate increased traffic on the I-5 corridor. Prior to deployment, this corridor averaged 434 crashes per year, 296 of which were congestion related; WSDOT intended for the ATM deployment to reduce property-damage-only crashes by 15 percent and injury crashes by 30 percent.<sup>(9)</sup> Figure 1 shows the ATM installation on I-5 in Seattle.



**Figure 1. Photo. ATM installation on I-5, Seattle, Washington (Source: Texas A&M Transportation Institute [TTI]).**

The second corridor to begin ATM operations was SR 520 in November 2010. This is an 8-mi corridor with 70 new signs at 19 sign locations. This corridor stretches from I-5 to 130th Avenue NE in Bellevue, and originally contained a 2.75-mi gap with no system elements across the floating bridge over Lake Washington that limits the effectiveness of ATM signage operations along the SR 520 corridor. The floating bridge was replaced and now contains an ATM signage gantry midspan. Before deployment, this corridor experienced an average of 379 collisions per year, with 221 being congested related.

Finally, the third Seattle corridor with ATM signage is I-90, a 9-mi corridor from Bellevue to downtown Seattle. Operations began in June 2011 with 129 new signs at 25 sign locations. Prior to deploying ATM signage, this corridor had an average of 330 crashes per year, 200 of which were congestion related. For these deployments, WSDOT typically gathers real-time traffic information to support ATM operations using existing inductive loop detectors and fills the gaps with additional Wavetronix detectors. Side-mounted dynamic message signs (DMSs) are typically on every other gantry on both the left and right side of the highway, with remaining gantries having a standard, larger overhead DMS.

## *Northern Virginia*

One of the newest ATM installations in the country is the Virginia Department of Transportation (VDOT) system along I-66 from U.S. 29 in Centreville to the Capital Beltway (I-495) in suburban Washington, D.C. Completed in September 2015, this project was constructed to improve safety and operations along I-66 by better managing the existing roadway capacity.<sup>(10)</sup> The deployment includes variable speed limits that are advisory, QW systems, lane use control signs, and DShL. Technologies installed as part of the system include overhead sign gantries, shoulder and lane control signs, speed displays, incident and queue detection, and additional traffic cameras. An overhead sign gantry that is part of the installation is shown in Figure 2.



**Figure 2. Photo. ATM installation on I-66, Virginia (Source: VDOT).**

The new ATM system along I-66 replaced an older ATM system along the corridor that included static, part-time shoulder use and high occupancy vehicle (HOV) lanes. The older system operated along 6.5 mi of the corridor and allowed general-purpose traffic to use the rightmost shoulders only during peak periods Monday–Friday (eastbound, 5:30 a.m.–11:00 a.m.; westbound, 2:00 p.m.–8:00 p.m.). The installation was a result of the adaptation of the leftmost general-purpose lane to an HOV-2 lane concurrent with the opening of the shoulder lane (eastbound, 5:30 a.m.–9:00 a.m.; westbound, 3:00 p.m.–7:00 p.m.). Advance signage and traffic control signaling provided travelers with information on the operations, including large signs alerting drivers to nine emergency refuge areas. The shoulder was also opened to all traffic during traffic incidents and construction.<sup>(11)</sup>

## Wyoming

The Wyoming Department of Transportation (WYDOT) first implemented ATM in the form of a variable speed limit (VSL) system along I-80 between Laramie and Rawlins in 2009. This system was implemented to address weather-related closures and to reduce speeds during severe weather and wind conditions.<sup>(12)</sup> The rural application incorporated technology to monitor road and weather conditions and visibility with cameras, road and wind sensors, surface and atmospheric conditions, and speeds. Operators in the TMC are responsible for speed selection using the entire available road and weather data and the notifications of any incidents in the corridor. A photo of the VSL signs used in the corridor is provided in Figure 3.



**Figure 3. Photo. VSL sign in Wyoming (Source: WYDOT).**

WYDOT sets speeds based on reported roadway conditions, including visibility, surface conditions, and current vehicle speeds. Maintenance forepersons or the Wyoming Highway Patrol have the authority to lower speed limits, and there is no limit to the number of times the speed can drop or how long the lowered speeds must be displayed.<sup>(12)</sup>

### 1.2 OVERVIEW OF ATM STRATEGIES

ATM strategies work to maximize the effectiveness and efficiency of a facility or network while increasing throughput and safety. Characteristics of these strategies include integrated systems, advanced technology, real-time data collection and analysis, and automated dynamic and/or proactive deployment. Whether implemented individually or as a combination of applications, ATM works to optimize the existing infrastructure. The ATM strategies included in this Guide

are shown in Figure 4 and include adaptive ramp metering, ATSC, DJC, DLR, DLUC, DShL, QW, DSpL, and dynamic merge control (DMC).



**Figure 4. Graphic. ATM strategies (adapted<sup>7</sup>).**

Table 2 provides specific information on each of the ATM strategies for deployment that are addressed in the Guide. Each strategy includes other commonly used names and terms for the strategy, a descriptive definition of the strategy, the operational scenarios that the strategy can address, and the physical geography where the strategy can be applied.

**Table 2. ATM strategies for deployment in the United States (adapted<sup>7, 13</sup>).**

ATM Strategy	Definition	Operational Scenarios	Application Geography
ARM (Adaptive Ramp Metering)	The deployment of traffic signals on ramps to dynamically control the rate at which vehicles enter a freeway facility. Utilizes traffic-responsive or adaptive algorithms (as opposed to pretimed or fixed-time rates) that can optimize either local or system-wide conditions.	Recurring congestion; planned special events (PSEs)	Limited-access facilities
ATSC (Adaptive Traffic Signal Control)	The continuous monitoring of arterial traffic conditions and queuing at intersections and the dynamic adjustment of signal timing to smooth traffic flow along coordinated routes and to optimize one or more operational objectives (such as minimize overall stops and delays or maximize green bands). Also known as responsive and/or multimodal preferential signal control.	Variability and unpredictability in demand; excessive delay and stops	Arterials
DJC (Dynamic Junction Control)	The dynamic allocation of lane access on mainline and ramp lanes in interchange areas with high traffic volumes, and where the relative demand on the mainline and ramps changes throughout the day. Through the use of signs, mainline lanes can be closed or become an exit, shoulders can be opened, and so forth to accommodate entering or exiting traffic.	Heavy weaving/merge areas; work zones (WZs); PSEs	Interchanges; on/off ramps
DLR (Dynamic Lane Reversal)  <i>Reversible lane; contraflow lane; tidal flow</i>	The reversal of one or all lanes to dynamically allocate capacity of congested roads, allowing capacity to better match traffic demand throughout the day. Lane reversal could include changing the number of available lanes per direction by physically moving barriers or by signage.	AM/PM directional shift in managed lanes and/or arterials; emergency management; PSEs	Limited-access facility; multilane arterials
DLUC (Dynamic Lane Use Control)  <i>Dynamic lane assignment</i>	The dynamic closing or opening of individual traffic lanes as warranted and providing advance warning of the closure(s), typically through dynamic lane control signs, to safely merge traffic into adjoining lanes. Often installed in conjunction with DSPL, and also supports the ATM strategies of DShL and DJC.	Incident management; shoulder use; reversible lanes; managed lanes	Some or all lanes on a facility; bridges; tunnels
DShL (Dynamic Shoulder Lane)  <i>Part-time shoulder use; hard shoulder running; bus-on-shoulder; dynamic shoulder lanes</i>	The dynamic enabling of the use of the shoulder as a travel lane(s) based on congestion levels during peak periods and in response to incidents or other conditions as warranted during nonpeak periods. May be restricted to certain types of vehicles or occupants. This strategy is frequently implemented in conjunction with DSPL and DLA. Static, time-of-day approaches are not generally included in the definition.	Recurring congestion; incident management; managed lanes (occupancy-based or vehicle-based)	Any facility with available shoulders
QW (Queue Warning)	The real-time display of warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists that queues or significant slowdowns are ahead, thus reducing rear-end crashes and improving safety. QW may be included as part of DSPL and DLA strategies. Static QW signs are not included in this definition.	Recurring congestion; incident management; WZs	Spot specific, in advance of known problem areas
DSPL (Dynamic Speed Limit)  <i>Variable speed limit; speed harmonization</i>	The adjustment of speed limit displays based on real-time traffic, roadway, and/or weather conditions. Can either be enforceable (regulatory) speed limits or recommended speed advisories and can be applied to an entire roadway segment or individual lanes. This “smoothing” process helps minimize the differences between the lowest and highest vehicle speeds.	Recurring congestion; weather; incident management; WZs	Spot specific; facility
Dynamic Merge Control (DMC)  <i>Dynamic late merge; dynamic early merge</i>	The dynamic management of the entry of vehicles into merge areas with a series of advisory messages approaching the merge point that prepare motorists for an upcoming merge and encouraging or directing a consistent merging behavior. Applied conditionally during congested (or near congested) conditions, such as a work zone, it can help create or maintain safe merging gaps and reduce shockwaves upstream of merge points.	Recurring congestion; WZs	Limited-access facilities; arterials; spot specific

## Adaptive Ramp Metering (ARM)

ARM, which is applicable on limited-access facilities, is the deployment of traffic signals on ramps to dynamically control the rate at which vehicles enter a freeway facility. It utilizes traffic-responsive or adaptive algorithms (as opposed to pretimed or fixed-time rates) that can optimize either local or system-wide conditions. A variation of ARM is bypass lanes on freeway ramps. Some potential benefits of this operational strategy include:

- Delayed onset of mainline breakdown.
- Reduced mainline travel delay.
- Improved travel time reliability.
- Reduced ramp delay as freeway demands subside.
- Reduced vehicle hours traveled.
- Reduced crash rates.

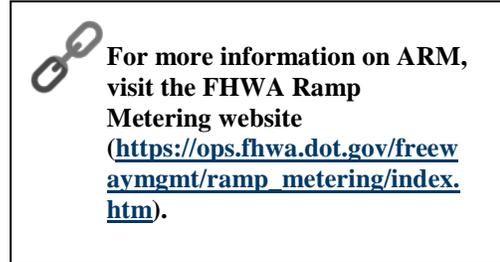
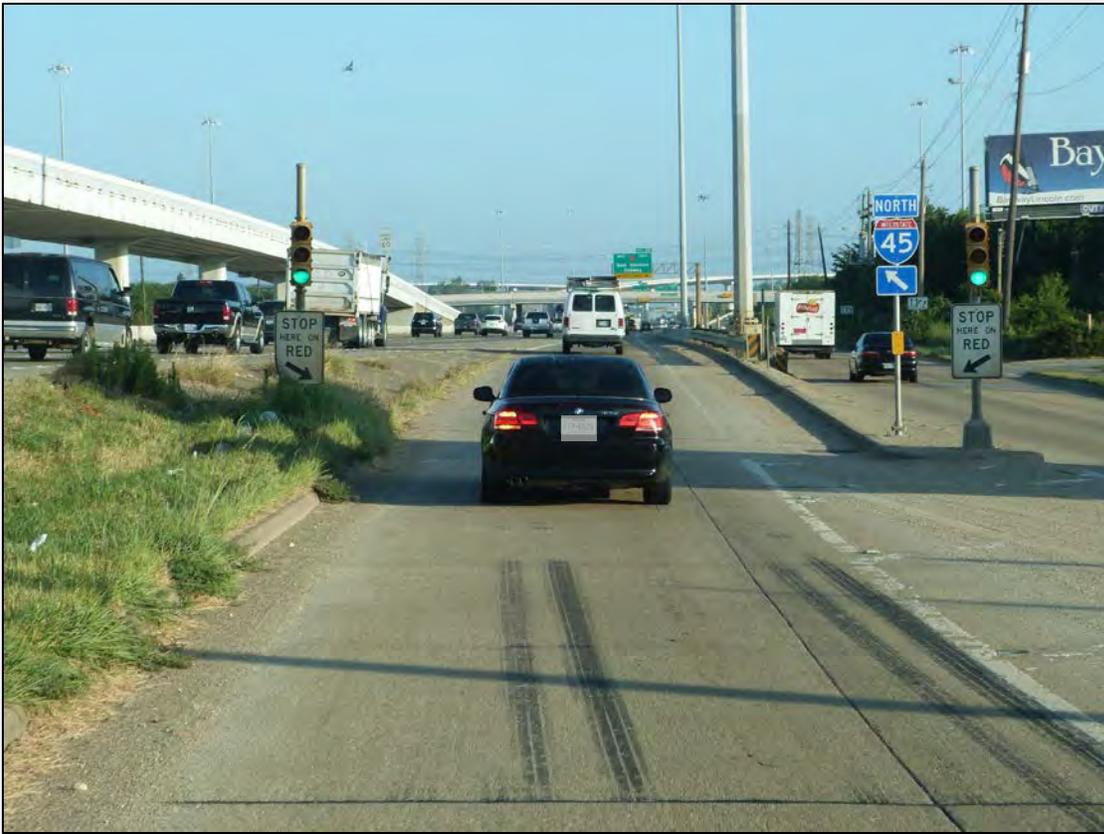


Table 3 provides a list of recent ARM applications in the United States. They represent some recent deployments that work to address broad mobility challenges in their respective regions. ARM is readily compatible with other ATM strategies, including DJC, ATSC, DLR, and dynamic shoulder use.

**Table 3. ARM example applications.**

ARM Application	Project Description	Lead Agency
Real-Time Adaptive Ramp Metering, I-680 (2011)	The ramp metering plan for southbound I-680 uses a real-time adaptive system that monitors traffic volumes and density and adjusts the ramp metering rate based on thresholds that vary by time of day set for the travel demand at each ramp.	California DOT (Caltrans)
Congestion Relief Project, I-210 (2009)	The main objective of the I-210 Congestion Relief Project is to better regulate the flow of vehicles entering the freeway system. Advanced metering equipment and algorithms are used with on-ramp meters, freeway-to-freeway connector meters, and HOV bypass lane metering as part of the deployment along a 50-mi corridor, both eastbound and westbound on I-210. <sup>(14)</sup>	Caltrans

As with traditional ramp metering, agencies may face challenges with implementing ARM within their jurisdictions. These challenges may include existing ramp geometry, heavy ramp volumes that may create queuing issues, public and/or local agency opposition, and lack of agency support.<sup>(15)</sup> Nonetheless, agencies can take a variety of approaches to mitigate these challenges and successfully implement ARM. A photograph of a ramp meter deployed in Texas is shown in Figure 5.



**Figure 5. Photo. Adaptive ramp metering on I-45, Houston, TX (Source: TTI).**

### **Adaptive Traffic Signal Control/Preferential Multimodal Control (ATSC)**

ATSC is the continuous monitoring of arterial traffic conditions and queuing at intersections and the dynamic adjustment of signal timing to smooth traffic flow along coordinated routes and to optimize one or more operational objectives (such as minimize overall stops and delays or maximize green bands). Applicable on arterials, this strategy is also known as responsive and/or multimodal preferential signal control. Variations of this strategy include dynamic signal retiming, queue jump, specialized signal timing plans, and transit signal priority. Some potential benefits of this operational strategy include:

- Reduced arterial travel time.
- Reduced arterial travel delay.
- Improved arterial travel time reliability.
- Reduced number of stops.
- Reduced intersection delay.
- Reduced queue lengths.
- Increased arterial speeds.

Table 4 provides a list of recent or pending ATSC applications in the United States. ATSC is readily compatible with adaptive ramp metering and DLUC.

**Table 4. ATSC example applications.**

ATSC Application	Project Description	Lead Agency
ATSC for McKnight Road Corridor, Allegheny County, PA (2014)	Deployment involved the introduction of ATSC to the McKnight Road (SR4003) corridor in Pennsylvania between I-279 and Perrymont Road/Babcock Boulevard in Allegheny County. It focused on evaluating and deploying ATSC, connecting traffic signals back to the PennDOT regional traffic management center, deploying and evaluating real-time traffic signal performance metrics along the corridor, and deploying dedicated short-range communications (DSRC) technology in the corridor to facilitate connected and automated vehicle research. <sup>(16)</sup>	Pennsylvania DOT (PennDOT)
Adaptive Signal Control (2015)	Project included installation of adaptive signal control (ASC) controllers and associated technology at eight signalized intersections along four-lane arterial state roadway adjacent to the airport. The project is the first deployment of ASC in Rhode Island. <sup>(17)</sup>	Rhode Island Airport Corporation
Midtown in Motion (2011)	Deployment included 100 microwave sensors, 32 traffic video cameras, and E-Z Pass readers at 23 intersections to measure traffic volumes and congestion and record vehicle travel times. The combined data are transmitted wirelessly to the city's TMC in Long Island City, allowing engineers to quickly identify congestion choke points as they occur and remotely adjust Midtown traffic signal patterns to clear traffic jams. <sup>(18)</sup>	New York, NY

ATSC is not without its challenges. For example, agencies need to ensure that any ATSC system can be integrated with legacy systems in place. Operators need to be able to transition between existing systems and the ATSC system easily, and this can be facilitated with a friendly user interface and an effective configuration tool.<sup>(19)</sup> Additionally, if compatible ATM strategies such as ARM are in operation in a corridor, coordination between the two strategies is essential to ensure efficient operation. A screenshot of the ATSC application deployed in New York City is shown in Figure 6. A photograph of the video wall from the New York City traffic management center showing camera feeds from instrumented intersections is shown in Figure 7.



**For more information on ATSC, visit the FHWA Traffic Signal Timing & Operations Strategies website at [https://ops.fhwa.dot.gov/arterial\\_mgmt/tst\\_ops.htm](https://ops.fhwa.dot.gov/arterial_mgmt/tst_ops.htm) and Adaptive Signal Control Technology website <https://www.fhwa.dot.gov/innovation/everydaycounts/edc-1/asct.cfm>.**

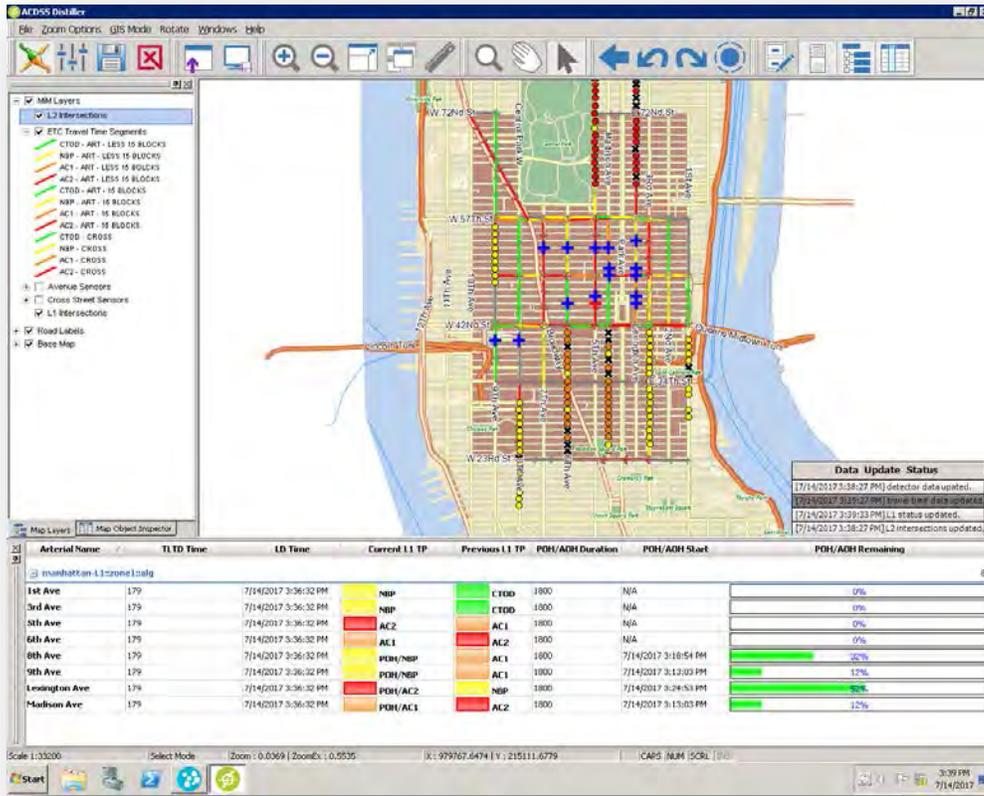


Figure 6. Graphic. ATSC application in New York City (Source: New York City Department of Transportation).



Figure 7. Photo. ATSC camera images in New York City (Source: New York City Department of Transportation).

## Dynamic Junction Control (DJC)

DJC is the dynamic allocation of lane access on mainline and ramp lanes in interchange areas with high traffic volumes, and where the relative demand on the mainline and ramps changes throughout the day. Through the use of signs, mainline lanes can be closed or become an exit, shoulders can be opened, and so forth to accommodate entering or exiting traffic. A strategy variation is dynamic turn restrictions on arterials. DJC is applicable to interchanges and on/off ramps. Table 5 provides a list of recent DJC applications in the United States. Some potential benefits of DJC include:

- Reduced travel time.
- Reduced travel delay.
- Reduced ramp delay.
- Increased travel speeds.

**Table 5. Dynamic junction control example applications.**

DJC Application	Project Description	Lead Agency
Dynamic Lanes on SR 110 (Pasadena Freeway) (2012)	Uses junction control to provide a connector lane during peak hours to I-5 northbound. <sup>(20)</sup>	Caltrans
SR 520/I-90/I-5—Active Traffic Management (2010)	Employs DJC using lane control signs. During times with heavy ramp volumes, traffic is advised to move over from the rightmost lane to reduce conflicts in the merge area. <sup>(21)</sup>	WSDOT

The deployment of DJC in Los Angeles (see Figure 8) involved opening the right shoulder on the connector ramp during the peak period to provide additional capacity to improve safety and mobility on the connector to eliminate the occurrence of drivers traveling on the shoulder of the connector during peak periods. When the junction control was active and the ramp shoulder was open, a DMS over the shoulder indicated that it was available for use as an exit lane, and a diagrammatic sign was illuminated over the second-from-the-inside lane to indicate that it could be used as a through lane or for the left exit to I-5. DJC is readily compatible with ARM, DLUC, DLR, and dynamic shoulder use.



For more DJC information, visit the *Texas Mobility Investment Priorities* website at (<https://mobility.tamu.edu/mip/strategies-pdfs/active-traffic/technical-summary/Dynamic-Merge-Control-4-Pg.pdf>). Note, the application is termed dynamic merge control on this site.



**Figure 8. Photo. Dynamic junction control signing on SR 110 (Pasadena Freeway), Los Angeles, California (Source: Caltrans).**

Agencies considering DJC to mitigate congestion of bottlenecks need to ensure the location will support the strategy. Factors that support DJC include large variations in mainline and ramp volumes and the ability to use a mainline lane or shoulder to accommodate ramp traffic.<sup>(13)</sup>

### **Dynamic Lane Reversal (DLR)**

DLR is the reversal of one or all lanes to dynamically allocate capacity of congested roads, allowing capacity to better match traffic demand throughout the day. Lane reversal could include changing the number of available lanes per direction by physically moving barriers or by signage. This strategy is also known as reversible lanes, contraflow lanes, and tidal flow, and it is applicable on limited-access facilities and multilane arterials. Some potential benefits of this strategy include:

- Increased throughput during lane reversal operations.
- Decreased travel times.
- Decreased crash rates.
- Improved level of service.

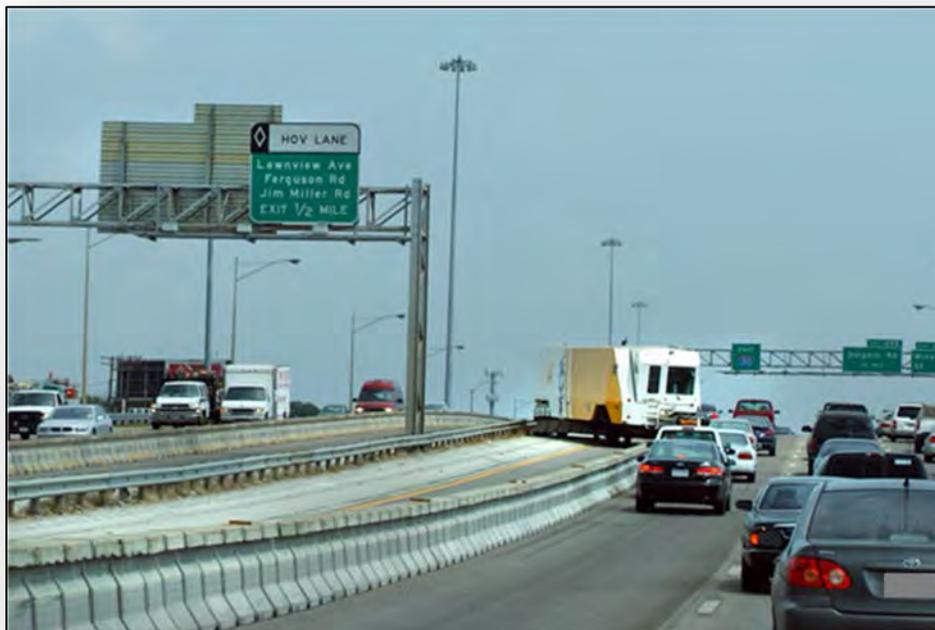
Table 6 provides a summary of recent applications of DLR in the United States. This strategy is readily compatible with DJC, DLUC, and ARM.

**Table 6. Dynamic lane reversal example applications.**<sup>(22)</sup>

DLU Application	Project Description	Lead Agency
I-15 Express Lanes, San Diego (2002)	The 20-mi facility between SR 163 and SR 78 features four lanes with a moveable barrier for optimal flexibility and capacity allocation. It provides multiple access points to the general-purpose lanes as well as direct access ramps for bus rapid transit service.	Caltrans
Reversible Lane Operation on Arterial Roadways, Washington, DC (2001)	The reversible lanes are implemented with and without dynamic signage to improve traffic flow during rush hours in corridors that predominately accommodate commuter traffic and have a distinct imbalance in directional traffic. They are also used on an ad-hoc basis for emergency evaluations, traffic maintenance in work zones, and special events.	District of Columbia DOT and Montgomery County, MD
Reversible Lanes, Arlington, TX (2009)	The city constructed a reversible lane system on two major and one minor arterial road used for event traffic at The Ballpark in Arlington and the new Dallas Cowboys Stadium at a cost of \$3 million. The system utilizes signage and dynamic overhead lane control signs.	City of Arlington

A freeway application of DLR is shown in Figure 9 along I-30 in Dallas, Texas, east of the downtown area. In this installation, a moveable barrier is used to provide a dedicated, barrier-separated HOV lane in the peak-period direction. The lane forms its own corridor within the freeway, and access is limited at only a few selected locations.

 For more DLR applications related to managed lanes, visit National Cooperative Highway Research Program (NCHRP) Report 835 (<http://www.trb.org/main/blurbs/175082.aspx>).



**Figure 9. Photo. Dynamic reversible lane on I-30, Dallas, Texas (Source: TTI).**

Typical lane reversal strategies on freeways include increasing capacity in a peak direction, providing for emergency operations (contraflow lanes), or incorporating lanes as part of a managed lane facility such as a high occupancy toll or HOV lane. On arterials, lane reversals account for directional traffic flows. The ability to reverse lanes might be an important element of traffic management response during emergencies.

DLR applications can be challenging to implement. When reversing direction, agencies need to ensure that the facility is clear so that head-on collisions do not occur. Furthermore, signing to indicate directional reversal needs to be prominently displayed and clearly understood by system users. Additionally, capacity at each end of the reversal needs to be maintained to reduce the likelihood of bottlenecks.<sup>(13)</sup>

### Dynamic Lane Use Control (DLUC)

DLUC is the dynamic closing or opening of individual traffic lanes as warranted and providing advance warning of the closure(s), typically through dynamic lane control signs, to safely merge traffic into adjoining lanes. It is often installed in conjunction with DSpl and also supports the ATM strategies of DShL and DJC. Dynamic lane assignment (DLA) is another term frequently used for this strategy, particularly on arterial facilities. Some potential benefits of this strategy include:

- Increased capacity when used with dynamic shoulder use.
- Increased lane-level volumes.
- Reduced secondary accidents.
- Compliance with posted signage during different flow conditions.
- Improved responder safety.

Table 7 provides information on two DLUC applications in use in the United States. This strategy is readily compatible with DJC, DLR, QW, dynamic shoulder use, and DSpl. DLUC can be applied to all lanes on a facility, specific lanes on a facility, or bridges and tunnels.

**Table 7. Dynamic lane use control example applications.**

DLUC Application	Project Description	Lead Agency
Virginia—I-66 ATM Project (1992/2015)	The segment of I-66 between U.S. 50 and I-495, where the case study HOV/shoulder lane combination is operational, includes three main lanes in each direction. The shoulder was opened to peak-period, peak-direction general-purpose traffic, allowing the leftmost lane to operate as an HOV lane. The most recent evolution of ATM that is now operational includes variable speed limits, dynamic lane control, and QW as part of an ATM deployment project. <sup>(23)</sup>	VDOT
SR 520/I-90/I-5—Active Traffic Management (2010)	The signs post variable speed limits and lane status information that helps to warn drivers of backups ahead and smooth out traffic as it approaches a lane-blocking incident. The overhead signs can also quickly close entire lanes and provide warning information to drivers before they reach slower traffic. <sup>(21)</sup>	WSDOT

Similar to DLR and DJC, information delivery related to the presence and operational status of DLUC is important. Clear, unambiguous lane control signage ensures system users know which lanes are open for travel and when they must vacate a lane that is closing. The VDOT application of DLUC is shown in Figure 10.



For more information related to motorist understanding of DLUC, visit <https://www.fhwa.dot.gov/publications/research/safety/16037/002.cfm>.



**Figure 10. Photo. DLUC application on I-30 in Texas (Source: TTI).**

### **Dynamic Shoulder Lane (DShL)**

DShL is the dynamic enabling of the use of the shoulder as a travel lane(s) based on congestion levels during peak periods and in response to incidents or other conditions as warranted during nonpeak periods. Use of the shoulder may be restricted to certain types of vehicles or occupants. This strategy is frequently implemented in conjunction with DSpL and DLA. Static, time-of-day approaches are not generally included in the definition. DShL is also known as part-time shoulder use, hard shoulder running, bus-on-shoulder, and dynamic shoulder use, depending on the particular application. Some potential benefits of this strategy include:



For more DShL information, see FHWA's guide on use of freeway shoulders for travel <https://ops.fhwa.dot.gov/publications/fhwahop15023/>.

- Improved level of service when shoulders are in operation.
- Reduced travel time.
- Increased travel time reliability.
- Reduced crash rates.
- Reduced crash severity.

Recent applications of DShL are provided in Table 8. This strategy is readily compatible with DJC, DSpL, ARM, DLUC, and QW. FHWA released a guide for planning, evaluating, and designing part-time shoulder use in 2016, which covers a wide variety of design and operational concepts for shoulder use and a process for planning for shoulder use on facilities.<sup>(24)</sup>

**Table 8. Recent DShL example applications.**

<b>DShL Application</b>	<b>Project Description</b>	<b>Lead Agency</b>
Virginia—I-66 ATM Project (1992/2015)	The segment of I-66 between U.S. 50 and I-495, where the case study HOV/shoulder lane combination is operational, includes three lanes in each direction. Starting in 1992, the shoulder was opened to peak-period, peak-direction general-purpose traffic, allowing the leftmost lane to operate as an HOV lane. The most recent evolution that is now operational includes variable speed limits, dynamic lane control, and QW as part of an ATM deployment project. <sup>(23)</sup>	VDOT
Priced Dynamic Shoulder Lane on I-35W (2009)	The I-35W ATM installation includes several strategies aimed at improving safety and congestion (both recurrent and nonrecurrent). One of the core strategies is a priced DShL heading into Downtown Minneapolis. <sup>(25)</sup>	Minnesota DOT (MnDOT)

Public concerns regarding safety of the lanes need to be addressed as part of the deployment. Depending on the location, there might be concern that the use of shoulder lanes for general traffic will make the traffic conditions worse by attracting more traffic to the facility. Noise concerns also need to be addressed, and the shoulder needs to be able to handle regular use either as is or with rehabilitation. Law enforcement should also be engaged early in the planning process and pushed toward being champions of shoulder use for travel. The WSDOT application of DShL is shown in Figure 11.



**Figure 11. Photo. DShL application in Seattle, Washington (Source: WSDOT).**

### Queue Warning (QW)

QW is the real-time display of warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists that queues or significant slowdowns are ahead, thus reducing rear-end crashes and improving safety. QW may be included as part of DSpL and DLA strategies. Static QW signs are not included in this definition. This strategy is typically applied in specific locations in advance of known congestion points. Some potential benefits of this strategy include:

- Reduced rear-end crashes where the warning is in effect.
- Increased travel speeds.
- Reduced speed differential.

Table 9 provides some recent examples of QW implementation in the United States. This strategy is readily compatible with DLUC, dynamic speed limit, DJC, and dynamic shoulder use. Figure 12 shows the DMS displaying a QW message as part of a work zone deployment along I-35 in Waco, Texas. Figure 13 shows the QW displays in Minneapolis.

 For more QW information, visit the *Texas Mobility Investment Priorities* website (<https://mobility.tamu.edu/mip/st-rategies-pdfs/active-traffic/technical-summary/Queue-Warning-4-Pg.pdf>).

**Table 9. Queue warning example applications.**

QW Application	Project Description	Lead Agency
Work zone end-of-queue warning system on I-35 (2012)	The project’s main purpose is to let motorists know they are approaching a queue of stopped or slowed vehicles as they approach a work zone on I-35. Slowed traffic sometimes occurs during construction, particularly when lanes are closed to accommodate work crews. <sup>(26)</sup>	Texas Department of Transportation
ATM system on OR-217 (2013)	The project uses speed advisories, QW, and travel times on OR-217 for congestion mitigation and road weather management.	Oregon DOT (ODOT)

QW systems present challenges when placed in the vicinity of rapidly fluctuating queues. If the signs or devices are not located appropriately, the queue tails might be overrun and drivers could encounter the queue before they see the sign. Alternatively, the warning signs might be placed too far from the end of the queue, and drivers will pass the sign long before encountering the queue. Regular monitoring of queue lengths downstream of these installations is needed to ensure they are located properly. Additionally, an automated system for real-time adjustments to locate queues is optimal when conditions quickly change.



**Figure 12. Photo. Queue warning work zone application on I-35, Waco, Texas (Source: TTI).**



**Figure 13. Photo. Queue warning message boards on I-94, Minneapolis, Minnesota (Source, MnDOT).**

### **Dynamic Speed Limits (DSpL)**

DSpL involves the adjustment of speed limit displays based on real-time traffic, roadway, and/or weather conditions. Speeds can either be enforceable (regulatory) speed limits or recommended speed advisories and can be applied to an entire roadway segment or individual lanes. This smoothing process helps minimize the differences between the lowest and highest vehicle speeds. Other terms commonly associated with DSpL include variable speed limits and speed harmonization. Some potential benefits include:

- Reduced difference between posted speed versus actual speed.
- Reduced speed variability.
- Reduced spatial extent of congestion.
- Reduced temporal extent of congestion.
- Reduced crash rates.
- Reduced crash severity.



**For more DSpL information, visit FHWA's *Synthesis of Variable Speed Limit Signs* (<https://ops.fhwa.dot.gov/publications/fhwahop17003/fhwahop17003.pdf>).**

Several applications of DSpL are presented in Table 10. This strategy is readily compatible with dynamic shoulder use, QW, and DLUC.

**Table 10. Dynamic speed limit example applications.**

DSpL Application	Project Description	Lead Agency
Variable Speed Limit on I-95 and I-295 (2008)	The regulatory speed limit is lowered based on road conditions and travel speeds. Specific weather variables that are monitored include precipitation types and amounts, speed drops of more than 20 mph, and other incidents that can cause a change in the VSL.	Maine DOT
Variable Speed Limit System on the PA 76 Toll Road, between MP 162 to MP 172 (2005)	The Turnpike Commission adjusts the regulatory speed limit based on visibility. Speed limits are related to visibility levels based on the stopping sight distances taken from the American Association of State and Highway Transportation Officials (AASHTO) <i>Policy of Geometric Design of Highway and Streets</i> . The Road Weather Information System (RWIS) determines visibility in fog-prone areas.	Pennsylvania Turnpike Commission
Variable Speed Limit on I-80 (2010)	WYDOT has installed 28 variable speed limit signs along a 52-mi stretch on I-80 in hopes of reducing winter driving incidents. Engineers have the ability to lower the posted regulatory speed depending on the road conditions.	WYDOT

A Texas Department of Transportation (TxDOT) application of DSpL along Loop 1604 in San Antonio, Texas, deployed as part of a pilot project, is shown in Figure 14.



**Figure 14. Photo. Pilot DSpL application in Texas (Source: TTI).**

FHWA has released a synthesis of variable speed limit signs that provides a review of current practices, experiences with deployments of DSPL in the United States, and various aspects of practices that can benefit agencies.<sup>(27)</sup>

### **Dynamic Merge Control (DMC)**

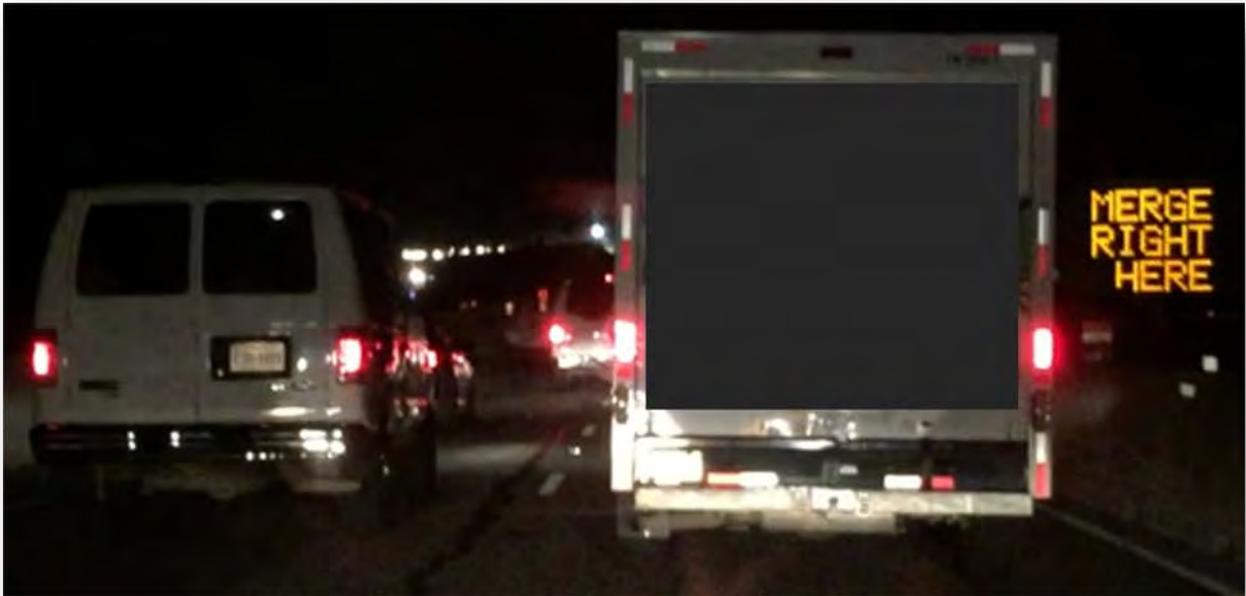
DMC is the dynamic management of the entry of vehicles into merge areas with a series of advisory messages approaching the merge point that prepare motorists for an upcoming merge and encourage or direct a consistent merging behavior. This strategy is applied conditionally during congested (or near congested) conditions, such as at work zones, and can help create or maintain safe merging gaps and reduce shockwaves upstream of merge points. The strategy is also commonly known as a dynamic late merge or a dynamic early merge. Some potential benefits of the strategy include:

- Reduced rear-end crashes where the merge is in effect.
- Increased travel speeds.
- Reduced speed differential.
- Reduced delay.

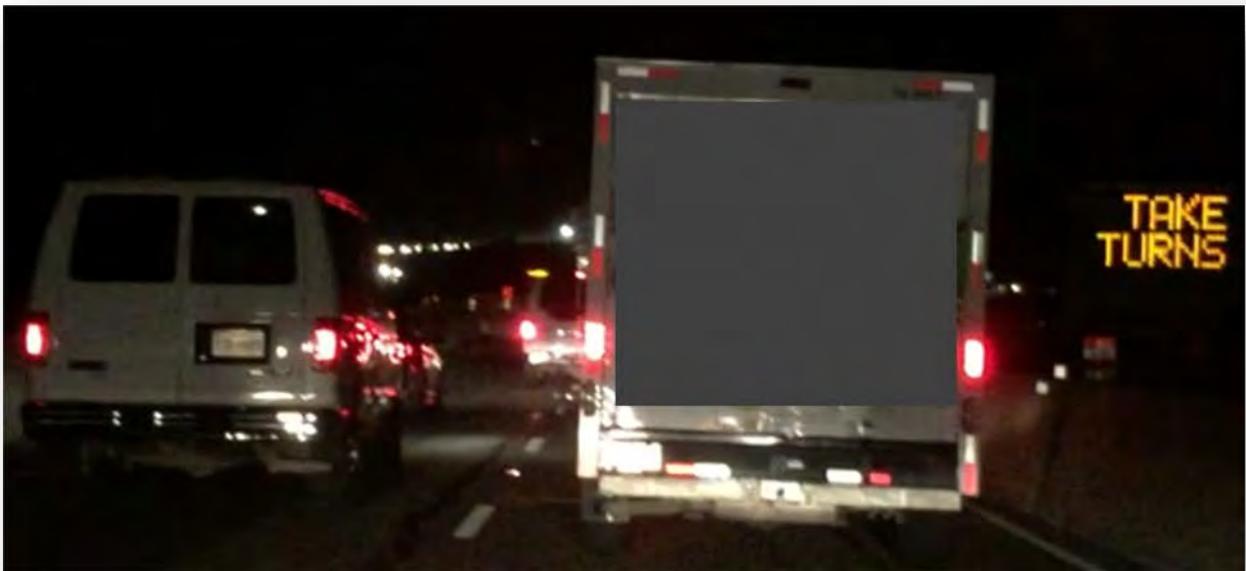
DMC is a variation of DJC, most frequently applied in work zones. It is readily compatible with ARM, DLUC, DLR, dynamic shoulder use, and QW. An example of DMC from a work zone in Texas is shown in Figure 15 and Figure 16.



**For more information on dynamic merge control in a work zone context, visit the National Work Zone Safety Information Clearinghouse ([https://www.workzonesafety.org/training-resources/fhwa\\_wz\\_grant/atssa\\_dynamic\\_lane\\_merging/](https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_dynamic_lane_merging/)).**



**Figure 15. Photo. DMC application in Texas, phase 1 (Source: TTI).**



**Figure 16. Photo. DMC application in Texas, phase 2 (Source: TTI).**

### **1.3 ATDM, ATM, AND TSMO**

As discussed previously, ATM is one of three approaches, along with active demand management (ADM) and active parking management (APM), that makes up the broader

 **ATDM focuses on the ultimate vision of dynamically managing across the trip chain and is conceptualized by the active management cycle.**

operations concept of ATDM. ATDM, as defined by FHWA, is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real time to achieve operational objectives, such as preventing or delaying breakdown conditions,

improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency. Through ATDM, agencies and regions attain the capability to monitor, control, and influence travel, traffic, and facility demand of the entire transportation system and over a traveler’s entire trip chain. This notion of dynamically managing across the trip chain is the ultimate vision of ATDM.<sup>(28)</sup> This ultimate vision is conceptualized by the active management cycle shown in Figure 17. With active management, agencies continually monitor a particular system and use that information to assess system performance. Performance benchmarks are then evaluated and dynamic actions are recommended to improve performance. Once the selected dynamic actions are implemented, the agency continues monitoring to determine the impacts of those actions, assesses performance, and modifies actions accordingly.<sup>(28)</sup> ATM includes the strategies that focus on the traffic once it enters the transportation network.



**Figure 17. Graphic. The Active Management cycle.<sup>(28)</sup>**

ATDM—and by association ATM—is part of the broader concept of TSMO. TSMO is more than a group of strategies or technologies; it is founded on the guiding principles of managing and operating the transportation system in an integrated, active, and performance-driven manner. ATDM focuses specifically on the active management principle of TSMO.

TSMO includes strategies that are dynamic, predictive, proactive, performance driven, continuously monitored, and supply and demand oriented. These types of strategies also describe ATDM and ATM, making them the active piece of the TSMO puzzle. Thus, the implementation of ATM strategies within the TSMO context presents agencies with an opportunity to progress

from static operations toward fully dynamic and proactive operation and management of transportation systems.

## 1.4 SYSTEMS ENGINEERING

Systems engineering is an essential component in the development of an ATM project. Implementing ATM often requires adopting new supporting operating systems or making substantial modifications to existing software platforms and systems. A systems engineering analysis will help to outline key system considerations, identify connectivity needs, and detail system technology options and alternatives. It is also a required component for an ATM project that is using Federal funds, per 23 CFR 940.<sup>(29)</sup>



System engineering is an essential component in ATM project development, and the Vee diagram can be readily adopted to ATM projects and meet Federal requirements.

The Vee diagram is widely adopted as the standard for representing the systems engineering process for intelligent transportation system (ITS) projects. Figure 18 shows the process in the context of the transportation/ITS technology planning and implementation life cycle. The FHWA California Division and Caltrans developed the *Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3.0*,<sup>(30)</sup> which

outlines the process from start to finish. Although developed in California, it is applicable for any State or regional agency developing transportation technology projects. The California guidebook developed the Vee diagram shown in Figure 18 to show up-front planning activities, including concept exploration, systems engineering management plan development, and regional ITS architecture development as a foundational element in the process. The right side of the diagram shows increasing levels of detail in the planning, beginning with exploring the concept for ATM, developing a Concept of Operations (ConOps), and moving through more detailed definition tasks of requirements, design, and implementation.

Systems engineering is more than a requirement. The intent of using the systems engineering process to develop transportation technology projects is to reduce risk, verify functionality at key steps, document key project decisions, and get stakeholder consensus at strategic points in the process. The left side of the Vee diagram primarily represents key planning activities: these steps identify needs and problems that need to be fixed, consider different concepts and alternatives, and get input and feedback from a variety of stakeholders (users) on priorities and issues.

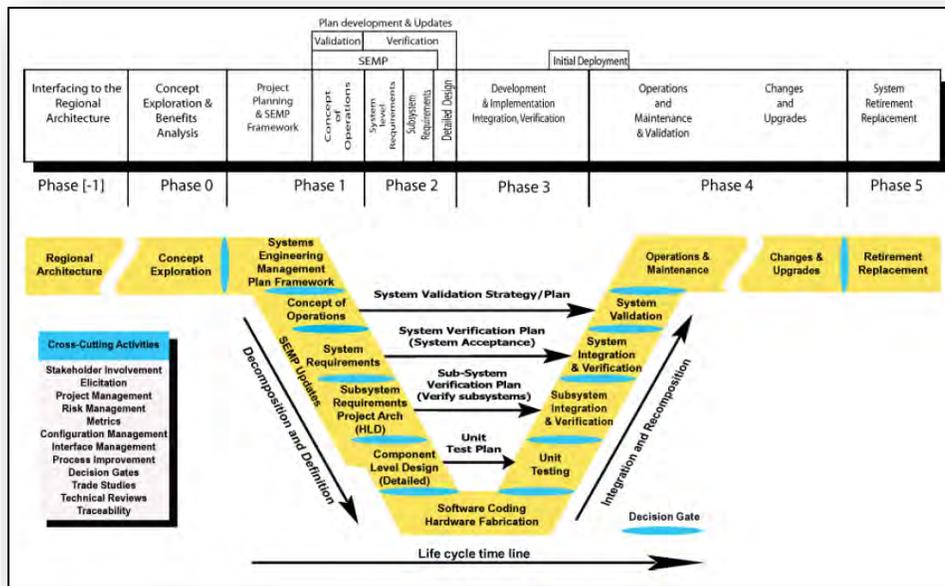


Figure 18. Diagram. Systems engineering Vee diagram and the system life cycle.<sup>(30)</sup>



**ATM Application:** When using the systems engineering process for an ATM project, an agency will need to incorporate specific ATM elements into various documents developed as part of the project. For example, WSDOT incorporates specific ATM information in its design requirements for ITS projects. In addition to general information related to VMS, WSDOT includes detailed requirements for VMS at ATM sites, including:

- Specific installation locations to support dynamic operations for ATM strategies.
- Unique sign spacing requirements for ATM applications.
- Placement of ATM-related VMS in relation to exit ramps and on-ramp merge areas.
- The use and specifications for lane control signals to communicate lane-specific traffic control information associated with ATM strategies.
- The use, placement, specifications, and appropriate messages for side-mounted signs.
- Use of full-size and small VMS along with specifications, placement, appropriate message, and co-location with and placement with lane control signals.

*Intelligent Transportation Systems Design Requirements, 2016, WSDOT,*  
<http://www.wsdot.wa.gov/NR/rdonlyres/1C4C6252-17AD-429B-98BA-265E06926B3B/0/Designrequirements.pdf>.

At some stage of the planning, the need is identified for a specific ATM project; this is where agency project development and programming processes would integrate the identified ATM project into a transportation improvement plan (TIP), statewide transportation improvement program (STIP), congestion management program, or related effort where an ATM project is assigned funds and a programming year. In other cases, agencies might opt to implement ATM projects with available or discretionary funds without including an ATM project in a TIP/STIP. The cost and complexity of ATM would necessitate inclusion in a more formal TIP or STIP

document, or in some cases, a longer-range planning document. The ability to incorporate ATM projects in to the TIP and STIP help these projects compete on a level playing field with more traditional capacity improvements and emphasize the agency culture committed to ATM.

## 1.5 CHAPTERS AT A GLANCE

This Guide is divided into six chapters. The titles of each chapter and the major topics covered are highlighted below.

- **Chapter 1—Introduction.** An overview of the document, an introduction to ATM and its context within the overall transportation framework, and a quick guide to the topics covered in the individual chapters are provided in this chapter.
- **Chapter 2—Planning and Organizational Considerations.** This chapter provides a discussion on the aspects of an agency’s approach to planning and developing policy to support ATM.
- **Chapter 3—Design Considerations.** This chapter reviews the design features and processes that agencies need to consider when moving forward with ATM projects.
- **Chapter 4—Implementation and Deployment.** This chapter describes the approach to implementing and deploying ATM strategies in a region, including legal issues, stakeholder engagement, and public outreach and involvement.
- **Chapter 5—Operations and Maintenance.** This chapter provides a narrative on operations and maintenance issues agencies will face once ATM strategies go online.
- **Chapter 6—Summary.** This chapter reviews the guidance document and emphasizes its goals, objectives, and intended audience, as well as the importance of ATM in supporting TSMO and congestion management.

A list of all references cited within the chapters is included at the end of the document.

## CHAPTER 2. PLANNING AND ORGANIZATIONAL CONSIDERATIONS

Planning for an active traffic management (ATM) implementation is a multifaceted and complex process. Since ATM still represents an emerging strategy in many regards, with it comes new approaches needed to effectively plan for ATM and integrate ATM into current plans and planning processes. This chapter provides an overview of planning-level and organizational approaches that agencies need to consider when developing ATM for a corridor or across a region. This chapter includes the following sections:

- **Planning for ATM Operations.** This section discusses specific efforts that an agency undertakes to plan for operations, including scenario planning, use of data, and the difference between planning from a corridor perspective versus subareas.
- **Organizational Capability for ATM Operations.** This section provides an overview of the organizational capability concepts that support successful ATM operations on a regional basis.
- **Setting Objectives and Performance Measures for ATM.** This section describes the importance of identifying objectives and performance measures for regional operations.
- **Analysis, Modeling, and Simulation.** This section discusses the types of analyses that an agency can conduct to assess the feasibility and potential impacts of ATM strategies on specific corridors.
- **Programming and Budgeting.** This section describes strategies for programming and budgeting for ATM strategies on a regional basis.

### 2.1 PLANNING FOR ATM OPERATIONS

Planning for ATM operations requires leveraging of ongoing efforts and institutional partnerships in a region. These partnerships serve as the foundation for such efforts as freeway management and operations, regional traffic incident management, and arterial traffic management and operations. As transportation systems management and operations (TSMO) has become more mainstreamed into agency operations, agencies have recognized that there is a need for increased focus on the institutional elements of a regional transportation operations strategy. Planning for operations is structured around an objective-driven, performance-based approach, as illustrated in Figure 19. The rationale for this approach is to link planning and operations to improve transportation decisions to effectively enhance the overall network by ensuring investments work to meet regional goals and objectives.<sup>(31)</sup>



For more information on how agencies have incorporated ATM into planning efforts, visit VCTIR's website ([www.virginiadot.org/vtrc/main/online\\_reports/pdf/13-r1.pdf](http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf)).



**Figure 19. Diagram. Objective-driven, performance-based approach to planning for operations (adapted<sup>31</sup>).**

As a result, a TSMO program plan that incorporates ATM strategies will typically go beyond traditional infrastructure and deployment needs and identify how agencies and regions can address ATM project planning, life-cycle costing of equipment and other infrastructure investments, operations and maintenance of the ATM systems which can be more complex than traditional intelligent transportation systems (ITS) investments, institutional collaboration for various scenarios and ATM strategies, and other parameters. Specific aspects of planning for ATM operations can include scenario planning, using data in planning, planning in subareas as opposed to corridors, and engaging stakeholders, all of which are essential for successful ATM implementation.

### **Scenario Planning**

Scenario planning entails the development of ATM strategies within a given context. Scenarios can vary by specific environmental or background characteristics, such as deploying ATM strategies during planned events (work zones or special demand generator) and in response to incident or emergency conditions (closed lanes or inclement weather). Preferably, agencies should describe ATM operational scenarios from a user perspective, inclusive of typical day-to-day operations. A predetermined ATM operational plan can detail how normal, or recurrent, ATM operations would function in addition to specific scenarios that would necessitate change or unique application. For example, if dynamic shoulder use is to be deployed along a facility,

the operating agency needs to determine how that shoulder will be managed in the event of an incident. Potential scenarios could include (a) opening the shoulder to traffic if not already operational to help alleviate congestion caused by the incident, or (b) closing the shoulder to traffic if already open to accommodate emergency response personnel to access the incident. In either scenario or some other variation, the operating agency needs to determine how the strategy will be deployed, for what purpose, for what duration, and identify other stakeholders and partners need to be incorporated into the decision to implement the scenario. Planning elements that may be included within an ATM scenario plan are agency roles and responsibilities, traveler information needs specific to the dynamic nature of the ATM strategies, system interoperability (how different components of the ATM systems interact and communicate with other ITS infrastructure in place and any legacy systems), stakeholder roles, and risk allocation. Simulation exercises can help agencies assess various ATM scenarios and operational strategies by evaluating the impact of specific components or the inclusion of select user groups.

### **Use of Data in Planning**

The use of data for planning ATM strategies principally involves collecting accurate and reliable data. Overall, data needs are linked to monitoring and modeling needs. Data enhance an agency's ability to determine the extent and duration of congestion and system performance and to estimate potential performance benefits on the network of an ATM strategy.<sup>(32)</sup> For operational purposes, data often require detailed granularity that can allow analysts to examine the potential for incremental changes at specific locations. Longitudinal data are necessary for seasonal and year-to-year comparisons. Data needs are typically driven by the establishment of performance metrics, as defined by the regional needs and goals of the project or program.

Sources for data can vary. Data for ATM may originate from regular data collection programs or special studies, usually in conjunction with implementing a new ATM strategy. A range of entities can provide data on a continual or regular basis, and may include internal agency groups or private third parties. Examples include travel demand models, transportation management center data, transit ridership records, crash records, third-party mobility data, or citation data.<sup>(32)</sup> More agencies are relying on private entities to provide data, particularly for measuring mobility and congestion. Agency coordination is important in the planning phase to facilitate data sharing, help determine ATM strategies to implement, and prioritize corridors and areas for those strategies. As ATM strategies are incorporated into the planning process, agencies need to ensure that data is identified and collected to support the performance measures used in that process.

### **Subareas vs. Corridors**

Planning for operations of ATM strategies should be undertaken within the overall context of a region. As part of an overall TSMO approach, agencies should include ATM and how it can play a role in operational planning within a subarea or within a corridor. A subarea is a defined portion of a region, and planning within that segment of the region is accomplished in greater detail with respect to analyses and recommendations for TSMO opportunities.<sup>(33)</sup> This subarea can include a municipality, an activity center, a downtown, or some other logical segment of a region. A corridor is typically comprised of a collection of parallel routes either within or through a region and incorporates all of the transportation services provided within that travel shed.<sup>(34)</sup> As an agency considers ATM in the region, it must understand how ATM strategies

may enhance mobility and operations within either of these regional elements. While planning for ATM may be similar for both elements, an agency should consider any specific nuances of these strategies in meeting mobility and livability goals, particularly any strategies that might support mode shift and mobility choices for system users.

### Stakeholder Engagement

Most major transportation improvement projects use effective stakeholder engagement and support to ensure successful implementation. Due to the nontraditional nature of ATM, outreach is necessary to inform critical audiences about basic concepts, purposes, and expected outcomes for each strategy. Audiences typically include impacted stakeholders, project champions, elected and appointed officials, media, and the public. Project champions can generate support both within and outside the implementing agency. Champions can initiate dialogue and help to ease the planning process that can involve multiple stakeholders. Champions do not need to consist of elected officials, and can consist of prominent individuals from the business community or volunteer organizations. Stakeholders can include representatives from county and city agencies, enforcement personnel, transit agencies, and emergency services. Effective strategies for stakeholder engagement may include forming an internal working group to discuss critical issues, developing outreach materials (e.g., short one-to-two-page handouts), hosting information booths at public events, and implementing targeted social media campaigns.



Visit FHWA's website for more information on planning for TSMO within subareas (<https://ops.fhwa.dot.gov/publications/fhwahop16074/index.htm>) and along corridors (<https://ops.fhwa.dot.gov/publications/fhwahop16037/index.htm>).



***ATM Application:*** The conventional transportation planning process can be adapted to accommodate planning for ATM strategies by modifying the process to address unique aspects of ATM. Specific adaptations that support ATM projects focus on operations projects, which are inherently different from traditional capital improvement projects. Specific enhancements to the conventional transportation planning process that can support ATM projects include:

- Incorporating processes in addition to projects in the planning process by describing ATM deployments as operations initiatives.
- Emphasizing performance measures for ATM strategies over technologies to incorporating reliability-based metrics to present operational investments on an equal level with capacity investments.
- Explicitly including ATM operational strategies into the traditional planning process, including within the context of other regional goals, to help secure allocated funding.
- Estimating benefits of ATM operational strategies at a sketch planning level to include in the long-range planning process.

*Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies, 2012, VCTIR 13-R1,*  
[http://www.viriniadot.org/vtrc/main/online\\_reports/pdf/13-r1.pdf](http://www.viriniadot.org/vtrc/main/online_reports/pdf/13-r1.pdf).

Washington State Department of Transportation (WSDOT) initiated stakeholder engagement during the feasibility study for the I-5 ATM deployment. The agency incorporated such efforts as workshops and regional forums in the initial stages and involved representatives from Federal

Highway Administration (FHWA), Washington State Patrol, Puget Sound Regional Council (PSRC), elected officials, decision makers, and local agencies. Virginia Department of Transportation (VDOT) required communications and outreach for the I-66 project development and deployment, including the development of a comprehensive communications plan that incorporates procedures for public outreach with stakeholders, elected officials and agencies; media relations that included paid advertising, media events, and media protocols to share information and promote consistent messages; a comprehensive communication program to educate motorists and stakeholder groups; and project branding. <sup>(35)</sup>

## **2.2 ORGANIZATIONAL CAPABILITY FOR ATM OPERATIONS**

ATM is a significantly more integrated approach toward real-time operations and rests on a foundation of robust systems management. Funding, right-of-way constraints, and environmental impacts limit the ability of agencies to implement traditional capacity improvements such as widening to add new lanes to meet increasing traffic demand. Thus, a significant shift from the historic build and maintain mission of many organizations to a more formal, programmatic approach to operating facilities for improved travel time reliability and congestion reduction is needed. ATM strategies offer innovative solutions to increase capacity during peak times of demand as a lower-cost, quicker solution that can be implemented within the existing right-of-way. Because of this characteristic, aggressively and proactively managing transportation systems, and ATM specifically, is a new mission for many agencies. Agencies with a very low level of capability in systems management and operations are probably not ready for ATM deployment, lacking the adequate business processes, supporting technology, and required workforce to be effective.

Organizational Capability Maturity Model (CMM) tools can assist transportation agency managers with self-assessments of their organization's development in six dimensions: (a) business process, (b) systems and technology, (c) performance measurement, (d) culture, (e) organization and workforce, and (f) collaboration. Such tools can help guide the development of institutional architectures and a more formal systems operations and management program that includes the adoption of ATM strategies (see references 36, 37, 38, and 39).

Broadly, these tools can be used by agencies to address the non-technological challenges involved in creating a TSMO program. Moving TSMO activities and projects into mainstream agency practice is a key pathway to agency success in adopting and implementing ATM as a formal consensus-driven approach to identify the institutional barriers that prevent the successful implementation of operational strategies or programs. The levels of organizational maturity defined by the FHWA CMM, as shown in Figure 20, move from level 1 with some programs mostly information and champion driven, to level 2 with some developed processes, to level 3 where performance is measured and programs are formally budgeted, to level 4 where formal partnerships exist and performance-based improvements are the norm.



**Figure 20. Graphic. The four levels of organization maturity (adapted<sup>40</sup>).**

The FHWA Traffic Management Capability Maturity Framework (TM CMF) is structured around these four levels of organizational maturity for the aforementioned six dimensions of capability. The TM CMF includes a self-evaluation tool for an agency to understand its current levels of capabilities.<sup>(41)</sup> Based on the level at which an agency resides for each dimension, a list of actions that the agency can undertake to advance its capabilities to the next level is provided. High-level capabilities in the six dimensions are certainly not a prerequisite for an agency to

**The Traffic Management Capability Maturity Framework can help guide the development of ATM strategies and ensure agencies are capability of successfully implementing and operating ATM to meet regional goals.**

successfully deploy and operate ATM strategies, though at a minimum, an agency should at least be on its way to level 2. However, as an agency matures in these six dimensions to level 3 and level 4, it will be better equipped and more effective at proactively managing ATM deployments.

The six dimensions of organizational capability described below can be used to help agencies identify the current state of their operations programs and to provide guidance for improved

levels of program effectiveness. These dimensions represent the key areas where an organization’s capability will have a measurable impact on its ability to be operations focused.

### **Business Processes**

Scoping, planning, evaluation, and budgeting processes are key business process elements to examine. Evidenced from various statewide operations plans and ITS strategic plans, the role of operations strategies is becoming increasingly clear. With the emphasis on planning for operations, leading departments of transportation (DOTs) are developing robust practices to include operations strategies such as ATM in the planning, programming, and prioritization processes. Given the broad range of operational strategies and the experimental nature of ATM strategies, agencies may need to address and modify business process elements for greater consideration and adoption of ATM strategies. Agencies may try to leverage funding for ATM

from nontraditional sources. Many agencies have implemented ATM projects as part of a larger, more comprehensive project that may already be in the planning stages.

## **Systems and Technology**

The systems and technology dimension considers how agencies are responding to the upgrading, replacement, and integration of systems in the world of rapidly changing technologies. Nationally, operations agency personnel and management have an excellent understanding of the systems approach, architecture use, and standardization, especially for ITS projects that are federally funded and thereby require the use of systems engineering. While some operational strategies have become fairly standard and commonplace, the ongoing maintenance, management, replacement, and upgrading of systems is a challenge to most organizations, and these challenges will most likely also apply to ATM systems, which involve new technology that is unfamiliar to many agencies. Additionally, the dynamic nature of ATM systems requires significant sensor and communications investment that increases the complexity of the ITS infrastructure needed to operate the systems. Thus, agencies will need to ensure that the capabilities are in place to support these complex systems and ensure reliable operations to optimize performance.

## **Performance Measurement**

Performance measurement plays a significant role in garnering public support for an agency's projects. It is also used to gauge how well an agency performs and the public perception of that agency's performance. With respect to ATM, agencies should be ready to define the problem metrics, establish measurable goals, and measure system performance when considering ATM strategies for the region. Measuring performance of ATM strategies needs to be better understood, thereby emphasizing its importance as a capability dimension. As noted previously, reliability performance metrics along with specific data needs to determine those metrics can be effective measurements for ATM strategies. Additionally, the metrics identified for use need to clearly relate to those regional goals and objectives that the ATM strategies are intended to help meet. Related to performance measurement is the ability to collect the ATM system data upon which those metrics are based.



**For more information on assessing agency capability, visit FHWA's Business Process Frameworks website (<https://ops.fhwa.dot.gov/tsmoframeworktool/>).**

## **Culture**

Agency culture is important in promoting ATM throughout an organization. A new role as an active operator of a system or network to improve throughput, reduce congestion, and increase travel time reliability requires leadership vision, communications, and changes in the organizational decision making. ATM deployments need to be supported by the respective agency decision makers, and constant engagement and communication are essential to promote ATM as a core operating philosophy. Increased education and outreach to policy makers and decision makers within the agency can help to facilitate this cultural transition.

## Organization and Workforce

State and other operating agencies are always challenged with retaining quality operations employees, attracting additional quality staff, and determining the need for training on subjects such as lessons learned from other agencies in the deployment of operational strategies, costs/benefits of operational strategies, and technology. The challenges of maintaining a skilled workforce equally apply to ATM operations, which will likely require a greater number of skilled staff, specifically at the transportation management center (TMC). Dynamic operations, which are likely to be 24 hours a day, 7 days a week, can require additional staffing and skills an agency may not have. Furthermore, the technologies supporting these strategies may be more complex than traditional ITS deployments. Comprehensive training is needed for agency staff to become familiar with the functionalities of new systems prior to deploying new ATM strategies.

## Collaboration

The collaboration dimension continues to increase in importance with respect to operations since congestion issues on highway networks are not bound by the organizational or geographic boundaries. As congestion spreads to encompass broader areas, more formal partnerships and collaborations will be required. Agencies recognize the importance of collaboration, especially at an operational and implementation level, yet formal relationships are infrequent and hard to document. Many ATM strategies may benefit from or require data, cooperation, and agreements that span multiple agencies, making collaboration necessary. Involvement of other stakeholders, such as law enforcement agencies, is also necessary for successful ATM strategies.

From an ATM perspective, these six dimensions serve as a good organizing framework for the agency. Assessment of the capability levels for an individual agency is relatively straightforward and useful input for determining areas of improvement that will help to assure successful ATM operations.

### 2.3 SETTING OBJECTIVES AND PERFORMANCE MEASURES FOR ATM

ATM strategies usually require more regular monitoring and maintenance of performance, given the significance of overall program goals and scrutiny of newly implemented strategies. Agencies and stakeholders should try to match suitable performance measures to individual goals



Key performance measures for analyzing ATM strategies include travel time reliability, delay, reliable throughput, fuel consumption, emissions, and crashes.

and objectives. The selection of performance measures should also be driven by the capability to collect data and the level of analysis necessary for calculation. Table 11 provides a summary of common objectives and performance measures for selected ATM strategies. It is important that these objectives be SMART: specific, measurable, attainable, realistic, and time-bound.<sup>(32)</sup>

**Table 11. ATM objectives and performance measures.**

<b>ATM Strategy</b>	<b>Objectives</b>	<b>Performance Measures</b>
ARM (Adaptive Ramp Metering)	Delayed onset of mainline lane breakdown by X minutes by year Y; reduce mainline lane travel delay by X minutes by year Y; reduce ramp delay as freeway demands subside by X minutes by year Y; reduce vehicle hours traveled by X percent by year Y; reduce crash rates by severity and facility type by X percent by year Y.	Mainline lane travel time; duration of mainline breakdown; time of mainline lane breakdown; mainline lane delay; ramp delay; crash rate; crash severity.
ATSC (Adaptive Traffic Signal Control)	Reduce arterial travel time by X minutes by year Y; reduce arterial travel delay by X percent by year Y; improve arterial travel time reliability by X percent by year Y; reduce number of stops by X percent by year Y; reduce intersection delay by X minutes by year Y; reduce queue lengths by X percent by year Y; increase arterial speeds by X mph by year Y.	Arterial travel time; arterial travel time index; arterial travel time reliability; intersection delay; number of vehicle stops at intersection; queue length; arterial speed.
DJC (Dynamic Junction Control)	Reduce travel time by X minutes by year Y; reduce travel delay by X percent by year Y; reduce ramp delay by X minutes by year Y; increase travel speeds by X mph by year Y.	Mainline lane travel time; duration of mainline lane breakdown; time of mainline lane breakdown; mainline lane delay; ramp delay; crash rate; crash severity; mainline lane speed.
DLR (Dynamic Lane Reversal)	Increase throughput during lane reversal operations by X percent by year Y; decrease travel times by Z minutes by year Y; decrease crash rates by severity and facility type by X percent by year Y.	Mainline travel time; mainline lane delay; mainline lane speeds; throughput; crash rate; crash severity.
DLUC (Dynamic Lane Use Control)	Increase capacity when used with dynamic shoulder use by X percent by year Y; increase lane-level volumes by X percent by year Y; reduce secondary accidents by X percent by year Y; increase compliance with posted signage during different flow conditions by X percent by year Y; improve responder safety by reducing crashes involving responders by X percent by year Y.	Travel time; delay; throughput; crash rate; crash severity; crashes involving responders.
DShL (Dynamic Shoulder Lane)	Reduce travel time by X minutes by year Y; increase travel time reliability by X percent by year Y; reduce crash rates by severity by X percent by year Y.	Mainline lane travel time; mainline lane delay; mainline lane travel time reliability; mainline lane speed; crash rate; crash severity; throughput.
QW (Queue Warning)	Reduce rear-end crashes where the warning is in effect by X percent by year Y; increase travel speeds by X mph by year Y; reduce speed differential by X mph by year Y.	Crash rate; crash severity; mainline lane speed; speed differential.
DSpL (Dynamic Speed Limit)	Reduce difference between posted speed versus actual speed by X percent by year Y; reduce speed variability by X percent by year Y; reduce spatial extent of congestion by X distance by year Y; reduce temporal extent of congestion by X minutes by year Y; reduce crash rates by severity by X percent by year Y.	Speed differential; speed variability; mainline lane travel time; mainline lane travel speed; time of mainline lane breakdown; duration of mainline lane breakdown; physical length of mainline lane breakdown; crash rate; crash severity.
DMC (Dynamic Merge Control)	Reduced rear-end crashes where the merge is in effect by X percent by year Y; increase travel speeds by X mph by year Y; reduce speed differential by X percent by year Y; reduce travel time delay by X minutes by year Y.	Travel time; delay; crash rate; crash severity; speed; speed differential.

## **Travel Time Reliability**

Travel time reliability is a key aspect of performance that symbolizes the larger effect of day-to-day variation in travel conditions. Traditional measures related to travel speed and delay do not capture the dimension of reliability, so other metrics are typically used. Specific characteristics help guide the selection of travel time reliability performance measures, as defined by specific goals, availability and quality of data, and geographic scope and intent of the program. Common reliability metrics include the planning time index, buffer index, and number of days below specified threshold.

The buffer index (BI) is a measure of travel reliability that can account for the varied distribution of travel times due to nonrecurrent congestion. Traffic incidents, crashes, and the weather all count as causes of nonrecurrent congestion. The BI is equivalent to the extra time travelers must add to their average travel time when planning trips. Specifically, the BI is defined as the ratio of the difference between the 95th percentile and average travel times to the average travel time.

The planning time index (PTI) represents how much total time a traveler should allow for ensuring on-time arrival, as opposed to additional time represented from the BI. PTI is useful because it can be compared to the travel time index. The difference between the PTI and the travel time index is the use of the 80th percentile (or 95th percentile, depending on the situation) travel as opposed to the average travel time. The PTI is usually greater than the BI because the PTI is influenced more by nonrecurrent congestion. Data can be aggregated by peak hour, peak time period, and daily time periods.

The concept of assessing the number of days per month operating below a set speed threshold is meant to capture a measure of travel reliability that is more readily understood by the traveling public. It can be easier to grasp the notion of days of unsatisfactory performance, as opposed to a dimensionless buffer or planning time index. This measure can be best captured through aggregating data by tolling zone to evaluate where degradation exists in the corridor.

## **Congestion Management**

Beyond travel reliability, multiple dimensions of mobility should be assessed within an ATM performance measurement program. Commonly, an appropriate characterization of performance should include the extent of congestion, or the size of the population and user groups impacted by degraded conditions. Vehicular and person-based throughput are typical measures used to describe the extent of congestion. The number of bottlenecks within a corridor or defined subarea is another commonly used metric.

Vehicle throughput is a measure of performance that assesses, as a whole, the number of vehicles served by a facility or a system. The measure is usually calculated by using data collected by traffic counting equipment that may be installed temporarily (e.g., automated traffic recorders) or as part of existing ITS components. All State DOTs are required to collect and maintain databases with historical vehicle count data for highways that are part of the National Highway System, which includes most major roads and streets.

Person throughput is a measure of performance that assesses, as a whole, the number of people served by a facility or a system regardless of particular travel mode used. The measure is

commonly calculated by conducting vehicle occupancy counts to gather a sample of the number of passengers per vehicle per mode (since knowing the number of all the passengers within a vehicle is limited by currently applied technology) and multiplying that figure by the number of vehicles by detected mode. People riding transit are usually counted by factoring the number of detected transit vehicles by the average ridership per route, typically given in an operations report.

The number of bottlenecks is an easy-to-describe metric for describing mobility challenges, especially for nontechnical audiences. This metric identifies the number of known problem locations that could be listed within an improvement plan. Bottlenecks can be grouped by either specific corridors or a geographic subarea.

## Safety

Safety is an important goal that often justifies the purpose and funding of implementing an ATM strategy. Compared to mobility and congestion, assessing safety-related performance usually requires years to collect enough baseline data to justify a statistical sound evaluation process that supports valid conclusions. The selection of specific metrics is related to the overall safety goals for the program, the availability and quality of data, and the type of geography for the assessed ATM strategy.

## Sustainability and Livability

Performance related to sustainability and livability is usually tied to metrics that assess environmental characteristics. Oftentimes within an ATM context, environmental measures include elements that entail emission of volatile compounds and local impacts on noise. An assessment of air quality entails quantifying the change in ozone precursors over time, specifically nitrogen oxides (NO<sub>x</sub>) and carbon monoxide (CO). Energy and fuel use, as measured by gallons of gasoline, is another metric that can be associated with assessing environmental impact.



***ATM Application:*** Agencies in the U.S. that have deployed ATM strategies have selected various objectives and performance measures for their specific ATM deployments at both the planning and operational stages. Examples include:

- Throughput (adaptive ramp metering) [DVRPC].
- Crashes, lane speed variance, average speed, (dynamic speed limits, queue warning) [Mn/DOT].
- Primary crashes, secondary crashes, severity of crashes, incident duration, congestion, reliability, throughput, emissions, fuel consumption (speed harmonization, queue warning, hard shoulder running) [VDOT].
- Crashes, crashes during construction, crash severity (dynamic speed limits, dynamic lane use control, queue warning) [WSDOT].
- Travel time, crashes, crash severity, queue lengths, speed differential (dynamic speed limits) [GDOT].
- Speed, speed variation, speed limit compliance (dynamic speed limits) [WYDOT].

## 2.4 ANALYSIS, MODELING, AND SIMULATION

Simulation and modeling exercises help project sponsors and agencies evaluate various ATM strategies at either the planning, design, or operational stages. The process to undergo an analysis or develop a simulation entails the integration of specific components, usually consisting of a set of scenarios, data, model environment, and decision support system. Sets of scenarios provide planners with a number of options regarding lane closures, differing traffic patterns, and varied levels of demand. Collected data support elemental input for analysis. Model environments characterize the format and arrangement for the processes of computations and assumptions. Decision support systems provide the basic framework for evaluating different choices, based on estimated measures of effectiveness.

Planners often use a variety of tools and models to simulate various ATM strategies. Based on practice, no mandate or preference exists to use a specific tool or software package. However, the analysis of specific ATM strategies may benefit from one type of model or simulation over another.

Approaches to modeling include microscopic, mesoscopic, and macroscopic (e.g., travel demand analysis), usually defined by the scale of analysis and whether the exercise is more focused on understanding microscopic traffic impacts (e.g., vehicle headway) or macroscopic travel behavior (e.g., trip generation and distribution). Table 12 provides an example summary of a few application scenarios, and analysis types for select ATM strategies for use by agencies.



**FHWA has developed a guide agencies can use for the highway capacity and operations analysis of ATDM strategies. It is available on the FHWA website (<https://ops.fhwa.dot.gov/publications/fhwahop13042/index.htm>).**

**Table 12. Modeling and simulating ATM.**

ATM Strategy	Application Scenarios	Analysis Tool Type
ARM (Adaptive Ramp Metering)	Use signal optimization to determine entry flow rates, storage space, acceleration distance, and entry flow rates using algorithm (i.e., Asservissement linéaire d'entrée autoroutière [ALINEA]).	Travel demand model, microscopic simulation
ATSC (Adaptive Traffic Signal Control)	Help design roadway capacity, turning bays, storage lengths	Travel demand model, microscopic simulation
DJC (Dynamic Junction Control)	Use junction control to dynamically allocate lane access; increase capacity/time-dependent closures.	Microscopic simulation
DLR (Dynamic Lane Reversal)	Determine emergency management, incident management, special events, and long-term congestion implications	Microscopic and mesoscopic simulation
DLUC (Dynamic Lane Use Control)	Determine optimal locations of where to place dynamic lane control signs mounted over traffic.	Microscopic and mesoscopic simulation
DShL (Dynamic Shoulder Lane)	Focus on incident management planning, managed lanes.	Microscopic and mesoscopic simulation
QW (Queue Warning)	Determine optimal locations of dynamic message signs (DMSs).	Microscopic simulation
DSpL (Dynamic Speed Limit)	Determine policy-related questions regarding speed reduction limits, time-of-day implementation.	Microscopic simulation

FHWA has sponsored a variety of research efforts related to the development of analysis, modeling, and simulation (AMS) active transportation and demand management (ATDM) and

dynamic mobility application test bed planning, development, and evaluation. These efforts include the development of an initial screening report, a test bed preliminary evaluation plan, and a series of foundational research efforts assessing an AMS concept of operations (ConOps), capabilities assessment, and analysis plan.

## Mobility Analysis

Mobility is often a strong goal and objective that drives the planning for implementing ATM strategies. Oftentimes, the tools used for assessing impacts rely on simulations and modeling at either the microscopic or mesoscopic level. These modeling approaches entail an assessment of traffic flow and driver behavior within specific segments of a highway network, particularly dynamic lane changes and dynamic shoulder use strategies.

Larger-scale macroscopic models consider impacts to the greater transportation network using data and assumptions about speed, flow, and density. Macroscopic models can be very useful for evaluating ATM strategies based on changing driver route choice, as opposed to lane choice. QW is an example of an ATM strategy that would benefit from macroscopic modeling. Other tools and modeling packages that could be utilized for mobility analysis might include State and regional travel demand models, tools based on the *Highway Capacity Manual*, and traffic signal optimization tools.



For more information on ATDM research results related to modeling, visit FHWA's ATM website at <https://ops.fhwa.dot.gov/atdm/research/index.htm#completed>.

## Safety Analysis

Safety is another common goal and objective for implementing ATM. However, the analytical and modeling packages for ATM are limited compared to similar tools for mobility analysis. A major consideration is the reliance on historical and longitudinal data for an effective safety analysis. Usually, a minimum of 3 years of crash and incident data are required to undergo a statistically valid assessment. The long time period is required to consider the impacts of possible outliers, including specific weather incidents or special generators of traffic demand. Safety-related data are limited to the instruments used for reporting incidents and crashes. Crash reports do not often include space to report incident locations for specific lanes, which would be required for dynamic lane or shoulder use strategies. Reports may also include erroneous geocoded location data that do not match exactly where the incident occurred. Similar traits exist when using incident data from TMCs. Given the characteristics and limitations on the use of safety data for analysis, project sponsors should manage expectations about safety analyses.

## Environmental Analysis

The Clean Air Act requires the Environmental Protection Agency (EPA) to set limits on the amount of certain pollutants allowed in the air. Urban areas that exceed EPA standards are said to be in nonattainment. States are required to develop an implementation plan to bring the area back into



For more information on environmental analysis, visit EPA's model website <https://www.epa.gov/moves>.

compliance, or its cities face losing vital Federal funding. Common pollutants of concern include NO<sub>x</sub>, CO, and volatile organic compounds. In addition, particulate matter is a concern for some areas around the country. ATM might be seen as a mechanism for addressing air pollution as part of a larger TSMO program that emphasizes system efficiency and overall mobility improvements. Agencies can estimate emissions for ATM strategies for vehicles with a variety of modeling tools, one in particular being EPA's emissions rate program called Mobile Source Emissions Model (MOBILE). Three key activity measures for estimates include vehicle miles traveled, speed, and vehicle type. Other mobile source emissions models include MOtor Vehicle Emissions Models (MOVES).

## Benefit-Cost Analysis

Agencies should consider both the short- and long-term financial considerations of implementing ATM. Previous guidance and research highlights the possible benefits and cost components of specific ATM strategies. However, individual strategies are rarely implemented alone but rather introduced as a complement to a greater transportation improvement program. Specific tools and analytical approaches can help support the generation of valid benefit and cost estimates. FHWA developed an *Operations Benefit/Cost Analysis Desk Reference*<sup>(42)</sup> and the Operations Benefit/Cost Analysis Tool for Operations Benefit-Cost Analysis (TOPS-BC)<sup>(43)</sup> and User's Manual<sup>(44)</sup> to help guide practitioners in estimating benefits and costs of implementing various TSMO strategies, inclusive of ATM. The desk reference provides the ability to investigate the range of impacts based on similar previous deployments and includes default cost data for



***ATM Application:*** FHWA sponsored a project to develop multiple simulation testbeds and transportation models to evaluate the impacts of CV dynamic mobility applications (DMA) and ATDM strategies. For the Chicago testbed, researchers modeled the ATM strategies of DShL, DLUC, dynamic speed limits, and ATSC. Some high-level research questions considered in the study within the broader context of DMA and ATDM included:

- Are ATDM strategies more beneficial when implemented in isolation or in combination?
- What ATDM strategy or combinations of strategies yield the most benefits for weather related operational conditions?
- What ATDM strategies or combinations of strategies conflict with each other?
- Which ATDM strategy or combinations of strategies will be most beneficial for certain modes and under what operational conditions?
- Which ATDM strategy or combinations of strategies will be most beneficial for certain facility types (freeway, transit, and arterial) and under which kind of weather related operational conditions?
- Which ATDM strategy or combinations of strategies will have the most benefits for individual facilities versus system-wide deployment versus region-wide deployment and under which kind of weather related operational conditions?

*Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs: Evaluation Report for the Chicago Testbed, Report FHWA-JPO-16-387, 2017, [https://ntl.bts.gov/lib/62000/62100/62176/FHWA-JPO-16-387\\_2.pdf](https://ntl.bts.gov/lib/62000/62100/62176/FHWA-JPO-16-387_2.pdf).*

estimating overall life-cycle costs (capital, replacement, and continuing operations and maintenance).

## 2.5 PROGRAMMING AND BUDGETING

Partnerships and collaborations are often essential to implementing ATM, particularly through the programming and budgeting process. Securing funding for transportation projects is highly competitive given the nature of limited and constrained resources. Federal policy mandates and guides many components of planning, programming, and funding projects. ATM strategies can be included within an improvement or long-range plan once an agency or project sponsor determines that it can complement or improve upon statewide, regional, or local goals. However, ATM strategies will have to compete with other projects to gain approval for funding.

The processes that comprise the programming elements of planning will differ from State to State and will entail the steps that agencies must undergo to select projects for funding. Project sponsors often develop a decision-based framework with financial considerations for implementation. States and regions, as represented by metropolitan planning organizations (MPOs), coordinate their efforts through the development of the long-range transportation plan, taking into consideration changes in overall demand and improvements to the transportation system. MPOs are required to develop short-range transportation improvement programs (TIPs) that can include select ATM strategies if those projects are estimated to have a high priority. States are also required to develop similar short-range plans, commonly known as a statewide transportation improvement program (STIP). Projects listed within a TIP have committed funding set aside for implementation.



**ATM Application:** The operational planning study prepared for Georgia Department of Transportation for Metro Atlanta, includes the ATM strategies of hard shoulder running, variable speed limits, queue warning, dynamic merge control, dynamic ramp metering, and variable/dynamic ramp closures. The study document outlines potential steps toward identifying potential funding sources. Potential sources identified include federal sources and categories, state funding sources, as well as local funding sources. Specific programs are discussed, and a matrix of potential projects and eligible funding sources provides direction to agency personnel and regional partners in identifying resources for future endeavors.

*Metro Atlanta Operational Planning Study, Georgia Department of Transportation, 2014,*  
<http://www.dot.ga.gov/BuildSmart/Studies/ManagedLanesDocuments/OPSPFinalReport.pdf>.



## CHAPTER 3. DESIGN CONSIDERATIONS

The design of an active traffic management (ATM) system can be a complex endeavor. An agency needs to consider the various features and processes related to design when moving forward with ATM projects. These features and processes include the Concept of Operations (ConOps); requirements development; physical design; performance-based practical design; technology, procurement, and testing; and impact of connected and automated vehicles (CAVs) on ATM. The following sections are included in this chapter:

- **Concept of Operations.** This section presents the topic of a ConOps and its importance in the development and implementation of ATM projects within a jurisdiction.
- **Requirements.** This section provides an overview of identifying system requirements for an ATM strategy or deployment.
- **Design Elements.** This section provides an overview of the physical design elements that are essential to successful operations of ATM strategies and that agencies should consider.
- **Performance-Based Practical Design.** This section provides an overview of the concept of performance-based practical design (PBPD), highlighting case studies demonstrating PBPD through the analysis of ATM strategies.
- **Technology, Procurement, and Testing.** This section presents the design aspects of the technological components of ATM strategies, including procurement and testing of the technology and integration with existing systems.

### 3.1 CONCEPT OF OPERATIONS

A ConOps addresses many important planning-level questions and is among the essential early steps of the systems engineering process. This stage of the project establishes needs; documents existing systems, stakeholder roles, and responsibilities; identifies priority ATM functions; and identifies longer-term requirements (such as maintenance) that can be integrated into budgeting, procurement, and implementation activities.<sup>(45)</sup> The ConOps should build off the components in the regional intelligent transportation systems (ITS) architecture; however, in some cases, the ConOps provides important input to updates needed for the regional ITS architecture. The ConOps also provides valuable input to the field and software design needs, which are addressed in later sections of the guidebook.

It is essential to get broad stakeholder input as part of this process because ATM likely affects multiple stakeholders. Part of the ConOps process is to address key decisions that need to be made, such as enforcement, coordination across modes (freeway, arterial, and transit), long-term funding needs, and ability to leverage existing systems. The ConOps creates a basis for defining specific user requirements, system functional requirements, and more detailed design in later phases of the system development process. There is some flexibility in terms of level of detail and items included as part of a ConOps for ATM. A ConOps typically



For more information on developing a ConOps, visit FHWA's Systems Engineering Guidebook for ITS (<https://www.fhwa.dot.gov/cadiv/segb/files/segbversion3.pdf>).

includes the following elements and sections, although States and regions are encouraged to view these typical elements as a starting point rather than a prescriptive template.

## Scope

Within the ConOps, the scope section provides a brief description of the planned ATM project and its overall purpose.<sup>(46)</sup> It should include an overview of the system that will be built and describe the area the system will cover. It briefly describes the purpose of the system, highlights major goals and objectives to be achieved (and what specific issues will be addressed through ATM), identifies the intended audience of the document, and sets the boundaries for the system. This section also describes an overarching vision for ATM in a particular region or for a specific corridor. Multiple stakeholders should be involved in defining the scope, goals, objectives, and vision for the ATM system.<sup>(47)</sup>



The ATM ConOps scope should include an overview of the ATM project and the specific purpose for the ATM strategies, including which specific regional challenges the strategies are intended to address. Typical regional needs might include congestion, safety, travel choices, and travel reliability.

For the initial ATM deployment in Seattle, Washington State Department of Transportation (WSDOT) included additional information in the ConOps. The document included background information on ATM so that partnering agencies would be familiar with the concept.<sup>(48)</sup> Specific sections included a description of each of the operational strategies that were included along with major goals and objectives for the project. For each individual ATM strategy to be implemented, the document provided a description of the strategy, early applications either in the United States or

overseas, and photographs to illustrate the concept. Additional background information that could be beneficial to the intended audience of the ConOps might include a description of a ConOps<sup>(49)</sup>; the project need<sup>(50)</sup>; inclusion of the project vision, mission, and goals; and project stakeholders and intended audience.<sup>(51)</sup>

## Reference Resources

This section of the document lists all the references used to develop the ATM ConOps as well as other sources of alternative information relevant to the system's development or refinement. These might include business processes, regional concepts of transportation operations plans, long-range transportation management plans, regional ITS architectures that may impact ATM system development, concept feasibility, and alternative analyses studies. WSDOT included additional background information related to ATM, specifically the original Federal Highway Administration (FHWA) report on ATM that introduced the concept to the United States.<sup>(48)</sup> Pennsylvania Department of Transportation (PennDOT) included supporting references related to the need for transportation systems management and operations (TSMO) and ATM, website links, and related ConOps for active transportation and demand management (ATDM) implementation.<sup>(51)</sup> Virginia Department of Transportation (VDOT) included a link to State government codes that would have an impact on the application of variable speed limits along with background information on the VDOT Smart Travel Program Plans.<sup>(49)</sup>

## User-Oriented Operational Description

This section contains the ATM strategies and tactics to be employed using the system, policies and constraints impacting how the system operates, which personnel will be using the system and how, interactions among stakeholders, and sequence of actions taken in a response. It also describes the various stakeholders and their roles and responsibilities. A key focus of this section is to describe the ATM system from various user vantage points. This information could include



User-oriented operational descriptions of each ATM strategy are essential to the overall ConOps. These descriptions provide details about the proposed systems, the anticipated users, how the users will interact with the strategies, and what organizational and system-specific goals and objectives met by deploying the strategies.

operational processes and roles of all the project stakeholders, including State/freeway operations traffic management, local traffic management, transit operators, traffic incident responders, and travelers themselves, among others. WSDOT provided specific details for each ATM application included in the ConOps, presented the overall proposed system, described user classes and stakeholder needs, and presented the operational goals and objectives for ATM in the region.<sup>(48)</sup> PennDOT took a slightly different approach and included specific descriptions of the system from each of the stakeholder groups, including the State, local municipalities, the regional metropolitan

planning organizations (MPOs), FHWA, the local county, and transit, to name a few.<sup>(51)</sup> Additionally, PennDOT included a description of the current system in operation along I-76 to set the stage for how the ATM system would need to integrate with what was already in place.

## Operational Needs

This section describes, at a high level, what stakeholders need and want the ATM system to do, including specific problems on a corridor that need to be addressed (such as recurring bottlenecks or safety issues); specific functions that technology can support; and operational needs. ATM operational needs could include infrastructure and tools to support project objectives, new processes, improved coordination among partnering agencies, addressing specific bottlenecks or safety issues on a specific segment of roadway, and a range of other user-



Operational needs for ATM should include a description of the users who will benefit from the ATM deployment, existing operations systems and management that will be instrumental in the ATM deployment, and stakeholders that have a vested interest in the ATM project and its overall successful operations.

specific needs. Identifying and organizing needs helps to provide a level of traceability through the different stages of more detailed design. This approach also allows an agency to map requirements and design elements back to specific needs, which helps to ensure that the system is meeting the identified objectives. VDOT described the operational needs in two contexts: during construction and after construction.<sup>(49)</sup> WSDOT described the operational needs that were not currently being met by the system as well as the needs for staffing, data support, and a communications structure.<sup>(48)</sup> PennDOT presented

current technologies in use that would require enhancements to support the ATM implementation.<sup>(51)</sup>

## System Overview

This section gives a general description of what the ATM system will do, when, and how. It identifies and describes regional and/or corridor goals and objectives for the system, as well as what information is needed for a decision and from where and how frequently this information is gathered (i.e., interfaces). The ATM system overview also should include a project-level



The ATM system overview describes overarching ATM considerations, capabilities, functions, and key elements likely to interface, support, or impact the strategies. These elements might include the ITS architecture, external systems, CVs, ICM, communications, data collection and monitoring, tolling, etc.

architecture, showing the relationships of the different system components, how they will interface with existing systems and stakeholder agencies, and what information will be shared among new and legacy systems. High-level schematic diagrams can show relationships among systems, while more detailed diagrams can show more specific interfaces and information/data exchanges. WSDOT provided high-level descriptions of the operational features of its ATM system, including the context within the National ITS Architecture; integration with its current ITS infrastructure and programs; major system components; necessary interfaces with external

systems; and proposed capabilities and functions of the system.<sup>(48)</sup> PennDOT described the proposed strategies and focused on the technology, components, applications, and standards needed for successful implementation of each strategy.<sup>(51)</sup>

## Operational and Support Environments

This section provides a description of the required physical, operational, and support environments in which the ATM system must operate. It includes information on the facilities, equipment, computing hardware, software, personnel, operational and support procedures, and so



Operational and support environment information should include system costs for the major ATM elements, operations and maintenance costs, deployment and life cycle information, as well as any impacts agencies need to consider during deployment, including that related to retrofitting on existing facilities, and user and support involvement that may be more complex than that with traditional capital projects.

forth necessary to operate and maintain the deployed system. In particular, the impact on personnel needs to be considered (e.g., Are new personnel needed to support the new system? Can current personnel be realigned to meet the needs of the new system?). Cost information, even at the planning level, must be identified early in the process. This section should also include some details on longer-term operations and maintenance needs, including life-cycle costs of equipment, operation and maintenance requirements of the new system, new training requirements, and new agreements needed. WSDOT's ATM ConOps included capital costs for ATM elements, as well as estimated operations and maintenance costs for

the major components of its initial ATM system.<sup>(48)</sup> PennDOT included high-level system costs and factors considered in developing conceptual cost estimates; maintenance costs broken down by component, life cycle, and annual costs per device; general operational costs; and a deployment concept based on early-action, short-term, and long-term implementation of ATM.<sup>(51)</sup> Additionally, PennDOT provided information on the support environment that would impact and/or be elemental for successful implementation. Information contained in this section included a regional operational research model project, planned arterial enhancements, communications, the regional TMC, enforcement, and public outreach and education.

## Operational Scenarios

This section describes how the system will be operated under different circumstances and situations. Scenarios are developed from a user's perspective and might include typical day-to-day operations of the ATM (typical AM and PM commutes), operations during planned events (such as a work zone or a special event that significantly impacts traffic flow and volumes), and incident or emergency conditions (such as severe weather, an incident blocking lanes, or an evacuation). This section should detail how the system would operate, what changes would be necessitated, how agency/responder roles would change, and what information would be communicated to travelers and to agencies. Scenarios should describe, in enough detail, how the system is envisioned to operate, how different systems will interact, how stakeholders will operate and interact with the ATM system, and what the impact or benefit will be to the user on



**ATM operational scenarios should include all of the scenarios under which the strategies will operate—both recurrent and nonrecurrent conditions—and how the operating agency will manage them. The scenarios need to reflect current operations and incorporate new protocols to accommodate the dynamic operations.**

the road. A simulation exercise is a good complement to the operational scenarios; items detailed in this section and others of the ConOps can provide valuable inputs into a simulation. WSDOT included various scenarios (i.e., normal operations, incident situations, work zone/maintenance, and queue spillback) and included a description of the provision of traveler information and anticipated opportunities and constraints of the system.<sup>(48)</sup> PennDOT structured the scenarios by ATM strategy and provided information for each on free flow, recurring congestion, lane restriction, weather conditions, complete closure, and nonrecurrent congestion.

## Summary of Impacts

This section summarizes key impacts as a result of implementing ATM. This section can also serve as a record of key decisions made for the ATM. Typically, impacts are organized into:

- Operational impacts, such as new data sources, new processes, and new systems.
- Organizational impacts, such as necessary new staff, new training, and new lines of communication among stakeholders.
- Impacts during development, including how current and new systems will operate in parallel, how changeover to the new system will occur, and what stakeholders will expect during development/testing/implementation.



Ohio DOT's draft ConOps for a statewide ATM study, which incorporates all critical elements, is available online

([ftp://ftp.dot.state.oh.us/pub/Comm/I-275-SmartLane/ATDM%20Draft%20ConOps/ODOT%20Draft%20ATM%20ConOps%20\(9%2015%2016\)v3.pdf](ftp://ftp.dot.state.oh.us/pub/Comm/I-275-SmartLane/ATDM%20Draft%20ConOps/ODOT%20Draft%20ATM%20ConOps%20(9%2015%2016)v3.pdf)).



**ATM Application:** The ConOps document for the WSDOT I-5 project incorporated all of the document elements discussed in this section. Specific items of note that provide ATM-related detail include the operational scenarios, which describe how the ATM strategies will operate along the facility. The operational scenarios document how the dynamic speed limits, dynamic lane use control, queue warning, and dynamic shoulder lanes will operate along both basic freeway segments and managed lanes segments.

The scenarios include operations during normal conditions, incident situations, in work zones or during roadway maintenance, and during queue spillback. Traveler information is also discussed along with a summary of anticipated benefits. Opportunities and constraints associated with the proposed ATM system are also included. Each scenario presents visual examples and sign sequencing of the planned overhead sign gantries as well as information on enforcement of the ATM strategy, operations, staffing needs, and maintenance.

*Active Traffic Management Concept of Operations, Washington State Department of Transportation, 2008, <http://www.wsdot.wa.gov/nr/rdonlyres/73ac9a17-6178-4271-b3a9-91911bd1c8c6/0/finalatmconceptofoperations.pdf>.*

### 3.2 REQUIREMENTS

Requirements serve as the foundation of any ITS components of an ATM system. Their importance cannot be overstated because an agency uses them to determine what the ATM system must do, and they serve as the benchmark against which an agency will verify that the ATM system was built correctly.<sup>(46)</sup> These requirements should include both functional requirements (i.e., what the system is supposed to do) and performance requirements (i.e., how well the system accomplishes its functions). Additionally, an agency should establish environmental and nonfunctional requirements that establish under what conditions the system is required to function to meet its performance goals. An agency should develop a system and subsystem requirements document in preparation for ATM implementation. This document should include the following information to clearly describe the requirements of the proposed ATM system<sup>(46)</sup>:

- Overview and scope of the system and the specific ATM strategies to be included therein, including full identification; ATM system purpose, goals, and objectives; history of

system development, operation, and maintenance; project stakeholders and users; and current and planned operating sites for individual and/or multiple strategies.

- Reference documents needed to support the requirements, including background research, documentation of similar applications in other locations, regional program plans, and other resources.
- All requirements for the ATM system, including functional requirements, performance requirements, interface requirements, data requirements, nonfunctional requirements, enabling requirements, and constraints.
- Verification methods for each requirement of the system, including demonstration, testing, analysis, and/or inspection for the specific environmental requirements under which the ATM strategies should function.
- Supporting documentation that can enhance understanding of the requirements.
- Traceability matrix that traces the requirements to higher-level requirements and user requirements.
- Glossary of terms, acronyms, and definitions.

Requirements are a critical element of procurement documents, such as with a plan, specification, and estimate (PS&E) package prepared for construction or as part of a request for proposals for a design-build project. In these cases, and others, the agency can ensure that the ATM system deployed meets the intended goals and objectives and operational performance.



**The development of a safety specification for the ATM control system for English motorways is available online**  
<http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=976B73DDAA3DC7973E2F90B80733D6AF?doi=10.1.1.483.8439&rep=rep1&type=pdf>.

### 3.3 DESIGN ELEMENTS

The general design elements of an ATM application or overall system can be divided into two broad categories: civil and technology. Individual elements within these categories are needed to deliver the complete system. Detailed design documents developed should comprise detailed requirements that should map back to defined functional requirements established in the ConOps. Detailed design documentation varies for the different portions of an ATM system but should include PS&E and detailed requirements and system architecture.

Civil elements of the design include the typical roadway elements such as pavement design, roadway geometrics, pavement markings, striping, structures, gantries, and static signing. Field equipment includes the technology components located along the roadway to monitor and manage transportation within the corridor, the communications network needed to access and integrate the field equipment, and the central equipment necessary to control the field equipment. The field equipment includes closed-circuit television (CCTV) cameras, message signs (dynamic, changeable, variable), detection, lane control signals, ramp meters, highway advisory radios, and other supplemental technologies as defined within the selected ATM strategies.<sup>(52)</sup> The communications network can include fiber-optic cables, wireless radio links, leased communication lines, and in some unique cases, cellular links to remote equipment.

As with other ITS-related systems, central equipment includes communications and network components located within the operations center that integrate all the field equipment and provide the infrastructure to operate the technology installed in the field. This equipment includes an array of racks, servers, the local area network, and interconnections between these



**ATM strategies require both civil elements as well as technology elements such as communication, network components, and field equipment. The technology and software elements are critical elements in all applications as they support real-time dynamic operations, which is a cornerstone of ATM strategies.**

elements. Table 13 presents a summary of the ATM strategies as presented previously along with the possible civil and technology design components associated with their implementation and operation. It is important to note that software is a required element for each strategy and is critical to an effective delivery of the defined solution. The following sections provide information on some of these more critical design elements and how agencies should consider these elements when implementing ATM strategies.

**Table 13. Possible ATM design elements by strategy.**

Core Design Element	Adaptive Ramp Metering (ARM)	Adaptive Traffic Signal Control (ATSC)	Dynamic Junction Control (DJC)	Dynamic Lane Reversal (DLR)	Dynamic Lane Use Control (DLUC)	Dynamic Shoulder Use (DShL)	Queue Warning (QW)	Dynamic Speed Limit (DSpL)	Dynamic Merge Control (DMC)
<b>CIVIL ELEMENTS</b>									
Overhead gantry and/or side-mounted sign; hybrid			X	X	X	X	X	X	X
Static signage	X		X	X	X	X	X	X	X
Interchange geometrics	X		X	X	X	X			X
Pavement markings			X	X		X			X
Emergency pull-offs						X			
<b>TECHNOLOGY ELEMENTS</b>									
Signal controllers	X	X							
Control software	X	X	X	X	X	X	X	X	X
Detection	X	X	X	X	X	X	X	X	X
Closed-circuit television cameras			X	X	X	X	X	X	X
Controller upgrades	X	X							
Communication	X	X	X	X	X	X	X	X	X
Lane control signals			X	X	X	X		X	X
Access control system to prevent wrong-way movements				X					
Enhanced corridor lighting			X	X	X	X	X	X	X
Overhead warning beacons				X			X		
DMSs			X	X	X	X	X	X	X

### Geometric Design

Agencies need to assess interchange geometrics when implementing such ATM strategies as adaptive DRM, DJC, or DLUC. For example, ramp modifications may be necessary to accommodate additional capacity for ramp metering strategies. Additionally, ramp modifications and merges at the interchange may be required to accommodate lane configurations for DShL, depending on whether the shoulder use runs through the interchange or traffic must exit at a

ramp. The specific operational option can impact ramp bridge widths, ramp or mainline pavement markings, retaining walls under bridges, and other geometrics of the interchange. Designing an ATM system that will minimize geometric changes at interchanges is recommended to minimize construction costs of the system.

The use of the shoulder as a travel lane introduces additional civil design requirements of the ATM system. Shoulder use can be implemented on either shoulder of the roadway but is not recommended for both at the same time. Design elements of any ATM strategy that may have a fundamental impact on the facility should include pavement and signing designs and general design requirements that must be satisfied prior to implementation, including controlling criteria and minimum American Association of State Highway and Transportation Officials (AASHTO) values.<sup>(24)</sup> These include but are not limited to:

- Design speed.
- Lane width.
- Shoulder width.
- Horizontal alignment.
- Superelevation.
- Vertical alignment.
- Grade.
- Stopping sight distance.
- Cross slope.
- Vertical clearance.
- Lateral offset to obstruction.
- Structural capacity of bridges.<sup>(24)</sup>



**Geometric design elements need to be carefully assessed when developing ATM strategies. For example, agencies need to decide how to handle dynamic shoulder lanes at interchanges, whether they want to construct emergency refuge areas, or whether there is sufficient storage on ramps to handle queues from adaptive ramp metering.**

With DShL deployments, an agency may choose to install a small emergency refuge area beside the shoulder. These areas, spaced at periodic intervals, provide motorists a place to pull out of the shoulder traffic in the event of an incident. However, these pull-off areas do not need to meet the same pavement requirements as the shoulder since vehicles are not using them as a travel lane.

Emergency pull-off areas or emergency refuges (also noted as turnouts) provide a safe location for motorists who are experiencing some kind of emergency to remove themselves from the flow of traffic. These areas should be large enough to

accommodate vehicles experiencing mechanical failure as well as those involved in a collision. Additionally, they can be used by law enforcement or emergency vehicles, if necessary. These pull-off areas should be at least 16 ft wide and long enough to provide adequate space for whatever purpose they need to serve.<sup>(24)</sup> The spacing between the emergency pull-offs is largely determined by the availability of space and the anticipated demand based on the roadway

characteristics. Emergency pull-offs can also be co-located with maintenance pull-off areas to cut down on required space and construction costs.

## **Infrastructure Design**

ATM strategies can present unique challenges with infrastructure design. For example, shoulder pavement is not designed to the same specifications as general-purpose lanes in many locations across the country. This situation presents a challenge if an agency would like to implement DShL. If more traffic is going to utilize the shoulder as a travel lane, improvements to the shoulder pavement may be needed. The structural and geometric design of the shoulder should be compared to that of a travel lane. The following sections provide discussion on specific design features that may be impacted by the deployment of ATM strategies along a facility.

### ***Shoulder Pavement***

Shoulder pavement should be able to handle significant traffic if an agency plans on implementing DShL. As such, rebuilt shoulders may be necessary to meet minimum acceptable shoulder design, while striking a balance between keeping the shoulder in its current condition or fully reconstructing it to meet general-purpose lane standards. Costs would certainly play a role in the development of a project. If a region is going to embrace DShL as a matter of policy, then



**Infrastructure design elements need to be carefully assessed when developing ATM strategies. For example, allowing traffic to operate on the shoulder may impact traditional design features such as vertical clearance, pavement, drainage, lateral offset to obstruction, and stopping sight distance, which may require design exceptions prior to construction.**

there should be some consideration given to incorporating design standards into future reconstruction/resurfacing that would prepare the shoulder for future use as a lane. This would be much more cost effective than having specific contracts to go back and reconstruct the pavement.

If agencies considering DShL do not plan on replacement or reconstruction of a new shoulder for the installation, they will need to secure a design exception from FHWA <sup>(24)</sup>. This is the same guidance given to agencies converting a full-width shoulder to a high occupancy vehicle (HOV) lane as a lower-cost treatment for congested corridors.

Clearly, those vehicles allowed to use the shoulder will impact the required pavement structure. If heavy vehicles present a structural challenge, an agency may prohibit them from using the shoulder.

### ***Fixed Objects***

The implementation of ATM strategies may impact the clear zone, either through the installation of additional roadside equipment (e.g., shoulder-mounted signage) or the proximity of moving traffic to fixed objects. For example, fixed objects may be within the clear zone if DShL, DLU, or DLR is in operation, and if drivers leave the roadway, they have a higher chance of striking an object before recovering. Thus, agencies will want to ensure that new objects are outside the clear zone, remove fixed objects if possible, relocate them beyond the clear zone, or shield them with barriers if they are in a place where they are likely to be struck.<sup>(24)</sup>

### ***Vertical Clearance***

Typically, the deployment of ATM-related strategies may require the installation of new structures, such as overhead gantries and sign bridges. It is important that any new structures meet existing clearance minimums. Additionally, these strategies may also have an impact on vertical clearance with existing devices such as sign bridges. If an agency cannot mitigate a clearance that does not meet standards, then it needs to request a design exception. Furthermore, this clearance issue may impact those vehicles allowed to use the shoulder as a travel lane. High-profile vehicles may be prohibited from using the lane if necessary. Advanced warning of the low clearance may also be an option.

### ***Drainage Treatment***

If a facility is to be modified or retrofitted as part of an ATM deployment, drainage might present a challenge if vehicles will travel on any part of the facility that was originally designed for drainage or runoff storage during rain events. Typical approaches to mitigation might include (a) moving inlets to the shoulder that will not be used for travel, (b) retrofitting inlets to allow unimpeded crossing, and/or (c) reinforcing existing or installing new inlets. The costs and operational impacts associated with the various approaches need to be evaluated and put within the context of the overall facility to determine the best solution to the drainage inlet challenge.

### ***Rumble Strips***

As with drainage treatments, any existing rumble strips on shoulders may present a challenge with strategies that may incorporate travel on the shoulders. A typical mitigation approach is to either move or removed existing rumble strips so that they would not be in the wheel path of the driving surface. Another approach is to move the rumble strip to the middle of the shoulder so that vehicles straddle the strip. This allows vehicles to use the shoulder without having the negative noise and vibration effects of rumble strips. Allowing for rumble strips does provide agencies with their original benefits without adversely affecting the operation of an ATM strategy that involves use of the shoulder.

### **Design Exception Process**

In most instances, agencies can implement an ATM strategy on an existing facility with no significant impacts on the overall design of the facility. However, some ATM strategies may require changes to the roadway in order to accommodate the strategy, and the design of the facility may not meet the minimum design criteria required for facilities that are part of the National Highway System. Thus, the implementing agency will need to request a design exception from FHWA. Until such time that FHWA develops specific guidance for these cases, agencies should request design exceptions for any ATM project that may violate traditional design standards and policies for roadway facilities.<sup>(24)</sup>

Typically, agencies submit design exception requests to the FHWA division office in their State. As part of that request, the agency must explain why it is not feasible to meet the design criteria. Additionally, the agency should identify the impacts of the substandard features associated with the design exception and how the agency plans to mitigate those standards. For example, mitigation factors for substandard geometry associated with DShL may include:

- Reduced speeds when the shoulder is in use.
- Annual average daily traffic in ranges where *Highway Safety Manual* analysis predicts a reduction in crashes with narrowing of the shoulder and addition of a lane.
- Use on commuter facilities during commuting periods with a high percentage of familiar drivers.
- Trucks prohibited from the shoulder.
- Extensive monitoring of the facility with ITS and/or patrol vehicles.
- Emergency refuge areas.
- DLU signage allowing closure of the shoulder if it is blocked by a disabled vehicle.<sup>(24)</sup>

Agencies should review the specific requirements of design exception requests for their State and factor that review process into the overall review and approval of plans for the project.



**Guidance related to design standards and design exceptions on the NHS is available online (<https://www.fhwa.dot.gov/design/standards/qa.cfm>). Information on mitigation strategies for design exceptions is also available online at FHWA's website (<https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/index.htm>).**

### Traffic Control Design

For ATM to be effective, motorists must understand what application is operational so that they behave accordingly. For example, with DShL, motorists need to know whether they are allowed in the shoulder, the proper placement of their vehicle laterally within the shoulder, and whether the use of the shoulder lane is in a state of flux. Agencies rely on various types of traffic control devices to communicate dynamic operations to motorists. Additionally, drivers need to understand lane control signs (LCSs) and dynamic message signs (DMSs) that might be used in ATM applications as well as the signage associated with DSpL.

Currently, the Manual on Uniform Traffic Control Devices (MUTCD) contains language regarding the use of LCSs and DMSs. However, most of the lane control signal language targets reversible lane applications, not congestion or lane closures on freeways or shoulder use. Thus, agencies implementing DShL as part of their ATM program have used engineering judgment to design, implement, and operate the signage used for DShL. This process has led to the implementation of several symbols that are not currently included in the MUTCD, and also the use of supplemental text on LCSs (e.g., MERGE, CLOSED, and 1 MILE) to help explain their intended meaning. Furthermore, the MUTCD provides no guidance with respect to supplemental pavement markings and static signing that also might convey shoulder use information to travelers. In the absence of this guidance, agencies have often installed a solid stripe on the outside edge of the shoulder and installed static regulatory or warning signs indicating when shoulder use is available.

With respect to the use of LCSs within the freeway environment, previous research has shown that the steady downward green arrow is essentially



**Agencies that would like to experiment with new traffic control devices for ATM strategies that are not currently addressed in the MUTCD should review the process for obtaining experimentation approval for new devices (<https://mutcd.fhwa.dot.gov/experflow.htm>).**

understood by all motorists. Although not quite as uniformly comprehended, the steady red X also seems to have a strong inherent meaning to motorists. Overall, there continues to be a need for symbols that clearly and distinctly convey (a) when a lane is closed ahead and the direction in which the motorist needs to vacate the lane, and (b) when a lane is open but motorists should use extra caution (see references 53, 54, 55, 56, and 57).

Additional research related to LCSs and variable speed limit signing showed that participants frequently interpreted the ATM signs correctly as the signs were presented in sequence for a given scenario. Some errors included interpreting advisory DSpL signs as regulatory speed limit signs, incorrectly interpreting green overhead guide signs, misinterpreting the lane closed ahead sign with a legend, and confusing the meaning of the lane open with caution options (both static and flashing).<sup>(58)</sup>

With respect to QW, the latest edition of the MUTCD provides guidance on the use of static warning signs to alert drivers to stopped traffic in advance of roadway segments that regularly experience traffic congestion as a function of posted or 85<sup>th</sup>-percentile speed, traffic conditions, and sign legibility distance.<sup>(59)</sup> Current guidelines range from 100 ft to 1,350 ft, depending on the speed and conditions. However, it is important to note that the possible dynamic application of these signs is not specifically addressed in the guidance. Guidance related to the use of permanent changeable message signs (CMS) is also provided in the MUTCD<sup>60</sup>, which may address some dynamic operations as long as messages meet the standards and guidance of good message design included in this section.

### **Additional Traffic Control Devices**

Additional signs and pavement markings are frequently used by agencies to supplement information related to ATM strategies. Typical messages that may be displayed on DMSs in conjunction with various strategies, such as with DShL, DJC, DLUC, or QW, might include messages indicating specific operational or weather conditions or providing guidance information to travelers. With respect to DMS messages, as long as the message meets the standards and guidance of good message design, it is appropriate for use in the United States. An example of a signing used as part of DShL in Seattle is shown in Figure 21.



**Figure 21. Photo. DShL signing, Seattle, Washington (Source: WSDOT).**

### **MUTCD Experimental Approval Process**

Many of the ATM signs and procedures for such applications as DLUC and variable speed limits, as used in Europe and in the initial ATM implementations in the United States, are not currently described in the MUTCD.<sup>(61)</sup> A request to FHWA for experimental approval is necessary for any messaging or signage that is not compliant with or included in the MUTCD.<sup>1</sup> As such, a request to experiment should be factored into the overall design and development process and timeline to ensure approval is received prior to implementation. Early coordination with FHWA is recommended on MUTCD issues.

### **ITS Design**

The backbone of a successful ATM application is technology. Having the ability to know in real time what is happening on the facility and being able to dynamically and proactively deploy any ATM strategy is essential. To that end, ITS and other technological applications are part of a

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<sup>1</sup> Described in more detail on the FHWA MUTCD website: <http://mutcd.fhwa.dot.gov/condexper.htm>.

robust and flexible system that is available to facilitate the dynamic aspect of ATM. The following sections highlight specific technology needs for ATM.

### ***Hardware***

A considerable amount of field hardware may be necessary for ATM deployment. This hardware includes equipment to effectively communicate to travelers that an ATM strategy is in operation as well as hardware that helps provide information to system operators in real time. This equipment may include<sup>(3,62)</sup>:

- Overhead sign gantries or shoulder-mounted sign structures spaced appropriately.
- Lane control signals installed on gantries or shoulders that indicate lane use or shoulder availability.
- DSPL sign provisions or consideration with the design of LCSs.
- DMSs to convey ATM-related information, including queues, speed limits, and shoulder use.
- Closed circuit televisions (CCTVs) along the corridor to allow operators to check for obstacles (disabled vehicles, debris, etc.) or incidents before opening or closing lanes or the shoulder to traffic and to monitor operations.
- Roadway sensors to facilitate advanced incident detection.
- Roadway sensors to gather traffic-related data.
- Automatic vehicle detection in any emergency refuge areas.

Overhead guide signs can facilitate the operation of ATM strategies by adapting to the current width of the roadway. In other words, when specific lanes are open to traffic, guide signs could provide information to direct travelers to open lanes, including the shoulder lane as if it were a permanent travel lane. This can be accomplished with either DMSs or rotational prism signs that are blank when the ATM strategy is not operational.

### ***Connectivity***

All of the hardware installed on the facility may have direct connectivity with the regional transportation management center (TMC) that is responsible for operating and monitoring the ATM deployment. The connectivity should be capable of providing field-related information in real time so that the most recent information about operational performance is available to system operators. The method of establishing this connectivity varies depending on the field hardware deployed and the preexisting connectivity in the corridor.

### ***Data***

At a minimum, the following data—all of which can be provided by in-field hardware—are necessary for successful implementation of an ATM system because they provide critical information to the system operators regarding facility conditions that might warrant deployment of a specific strategy:

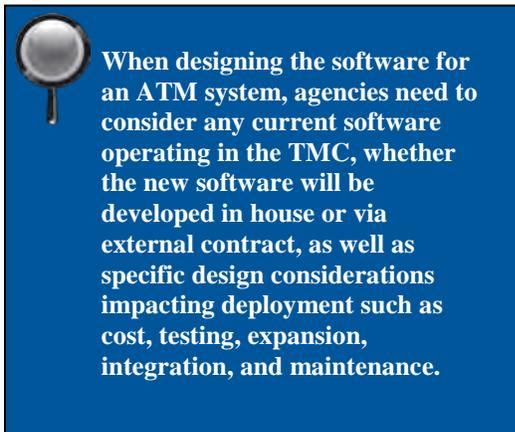
- Traffic volumes.
- Travel speeds.

- Occupancies.
- Incident presence and location.
- Shoulder availability.

## Software Design and Integration

Along with both the civil and technology aspects of the ATM system (ATMS), careful consideration of the software that operates the system should be reviewed and determined. This section highlights considerations needed to determine whether current software is sufficient or if new software is warranted to operate the ATMS.

The objective of the proposed ATMS is to gain the capability to dynamically adjust traffic operations along the corridor in real time based on scheduled/reoccurring or unscheduled events.



An example is opening the shoulder for vehicle use during recurring peak-period congestion or in response to nonrecurring weather, traffic, crash, or special event conditions. The system operators will utilize a robust ATM software solution that will monitor conditions along the corridor and alert them when deviations from the expected standard conditions occur.

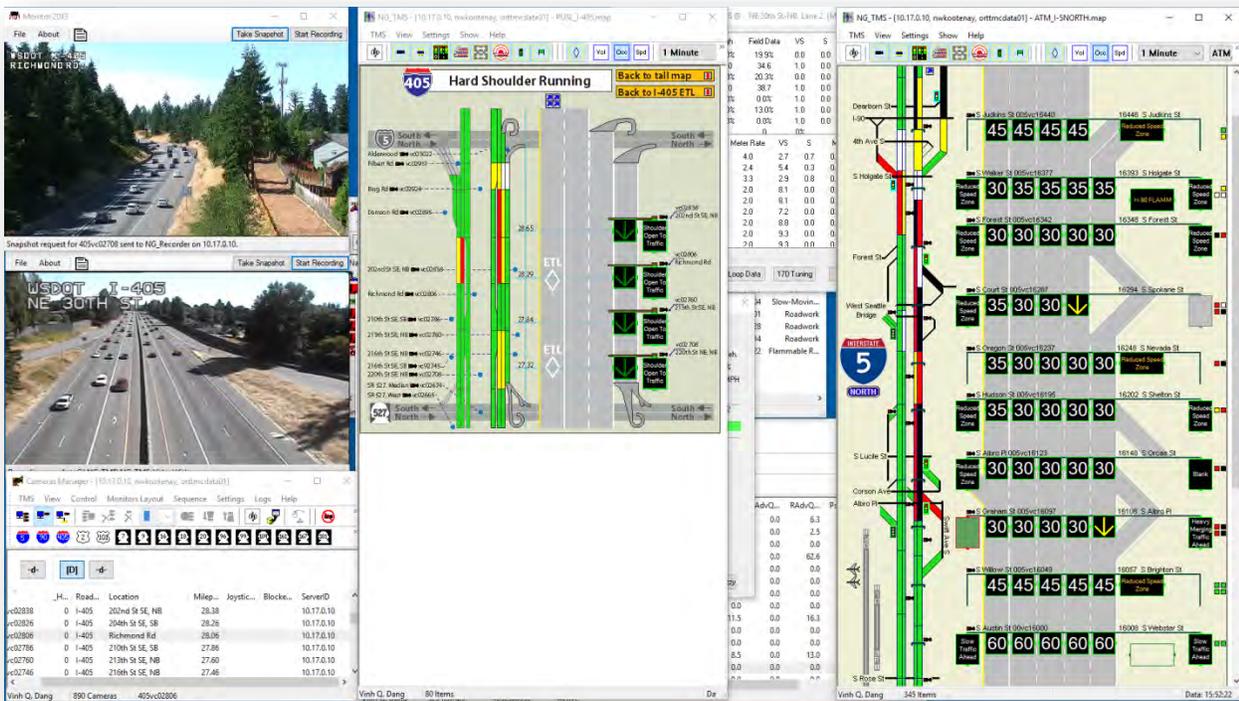
The operators then will be able to respond to the deviations based on recommendations from the software. They will utilize the software to provide information or instructions for motorists, such as lane closures or speed reductions. The ATM

software recommendations need to be quick, precise, and fluid so that operators can respond in a timely manner. ATM software should incorporate a relatively high level of automation based on the granularity of the information at the lane and ramp level, the volume of data relative to the density of the time intervals that the data are collected, and the amount of information to be communicated to the road user.

### *Current Software*

Several States currently have existing ATMS software that is used to operate ITS devices outside an ATMS. If an agency currently uses an ATMS software solution, it should be assessed to determine the capabilities relative to operating the new ATMS. If the existing software cannot support the ATM strategies identified, the magnitude of required software modifications should be evaluated.

Typically, ATMS software developed solely for freeway or arterial operations does not offer modules or algorithms dedicated to managing components of an ATMS. Currently, the footprint of ATM deployments in operation within North America is relatively limited. Moreover, two of the pioneer North American deployments (WSDOT and Minnesota Department of Transportation [MnDOT]) utilize software that was developed in-house. An example of the ATM software used in Seattle is illustrated in Figure 22.



**Figure 22. Illustration. WSDOT ATM software, Seattle, Washington (Source: WSDOT).**

If an agency is looking to utilize its existing ATMS software, the current software’s capability and functionality must be assessed against the software requirements defined for the ATM implementation to assess the level of effort required. The software requirements will be derived from the ConOps and other system engineering documents developed during the project planning phase. In addition, the software requirements will align with any standard operating procedures (SOPs) developed for the ATM deployment and any existing ATMS software platform(s) with which the ATM software must be integrated.

The current vendor should be involved in refining the software requirements in order to promote effective software modifications of the existing software. Additionally, the current vendor should be involved with stakeholder meetings to facilitate a better understanding of the identified changes needed within the software and to support better coordination of the modifications.

### *New Software with Existing Software*

States that are considering a new solution for the ATM system while they currently have ATMS software should be very mindful of the advantages and disadvantages of having two systems operating devices at the same facility and/or even operating the same devices.

If the devices are located in an area that may not always operate as an ATM, then the software requirements should include operational changes for primary control and message types on the signs. The priority level or response plans may change or deviate a bit from statewide initiatives

since one software solution will need to be the primary control. If this is not agreed upon, there could be conflicts between operators and software during ATM operations. This situation runs the risk of decreasing drivers' perceptions and resulting in an unreliable system.

### ***Design Considerations***

There are several factors to consider when designing or detailing software requirements:

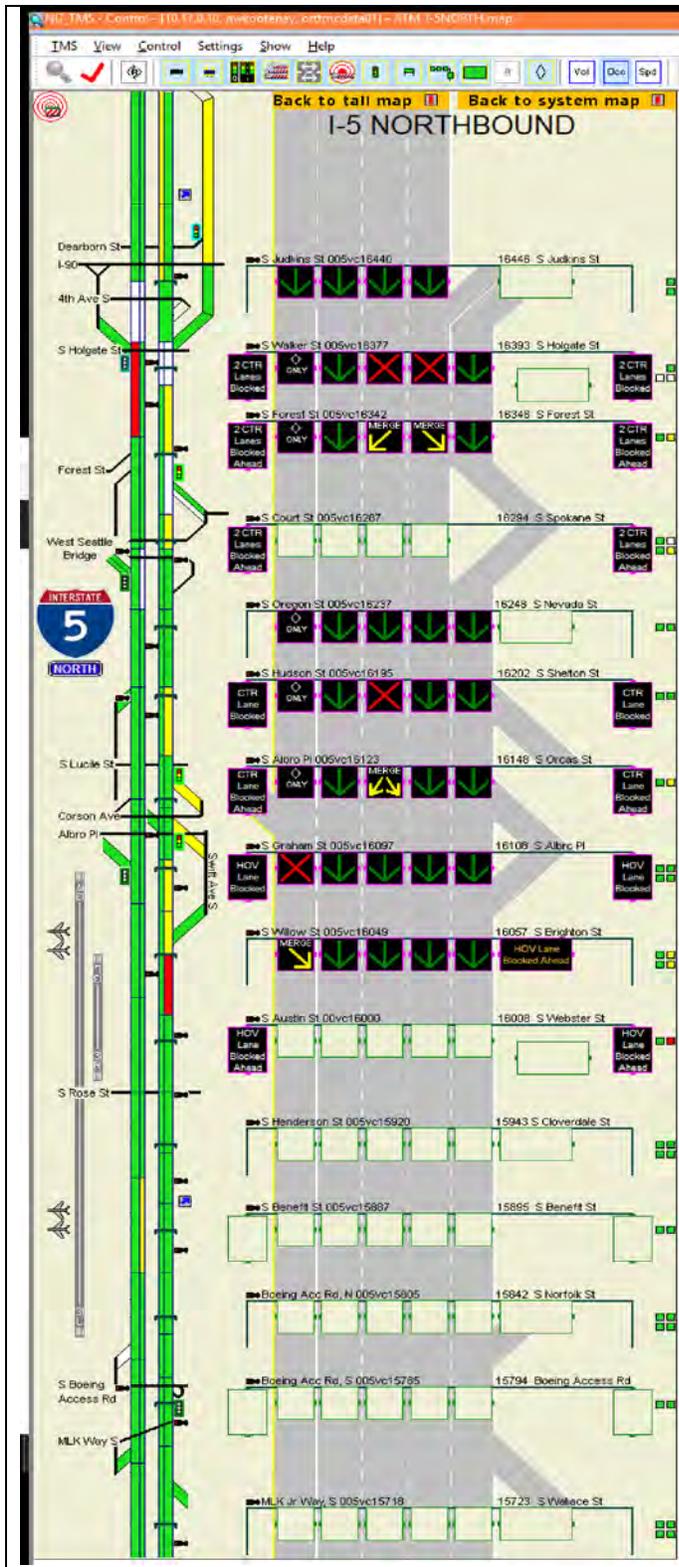
- Cost of the modifications—Is the cost within budget?
- Implementation time—Will the software development be completed prior to the construction of the design?
- Changes to operation standard operating procedures (SOPs)—Do the SOPs need to be updated to reflect software changes or ATM changes?
- Impacts for operators—Are the changes to the user interface intuitive?
- System impacts—Is the system mainly automated or semi-automated?
- Compatibility with information technology (IT) —Are the changes or new software compatible with the current IT network, security, and so forth?
- Agency source ownership—Does the agency want to own the source code?
- Available support—Will the vendor or State personnel be able to support the software?
- Software interactions—Is the software capable of interacting with other software (i.e., vendor software)?
- Expansion—Is the software capable of expanding if additional ATM strategies are needed?
- Testing—Although testing activities will take place during the implementation stage, can a structured software-testing framework be developed that aligns with the central component and roadside component's schedule and testing?
- Maintenance—Similar to any technology implementation, effective maintenance is key to the consistent operation of the ATM corridor. Can maintenance be achieved through either a commitment from an agency's information technology department or a maintenance contract with the selected software vendor?
- Configuration management—As field equipment is upgraded or updated, it is important for the agency to apply configuration management principles to all elements of the system. Will changes in configuration affect the utility of the software, and can they be managed to avoid impacts to the performance of the overall system?

An example of the control interface that WSDOT uses to consider implementation alternatives is illustrated in Figure 23.

## **3.4 PERFORMANCE-BASED PRACTICAL DESIGN**

Performance-based practical design is an approach to decision making that helps transportation agencies better manage their infrastructure investments. The process helps ensure that agencies meet their system-level needs and performance priorities within the context of limited resources.<sup>(63)</sup> Related to context-sensitive solutions, PBPD allows agencies to use a variety of operational and safety analysis tools to evaluate and compare the performance of various alternatives or projects.

ATM projects are a logical fit for PBPD. As discussed previously, agencies conduct thorough analysis and simulation to assess ATM strategies for their jurisdictions. Simulation and modeling exercises help them evaluate various ATM strategies throughout the development process, from the planning stage to the operations. This approach focuses on performance improvements that benefit both the project and the overall system. Furthermore, PBPD allows an agency to analyze each element of a project in terms of value, need, and urgency to help maximize the return on the investment, which is the overall objective of ATM strategies as they relate to the goals of TSMO.



One click places the red X just downstream of the incident. This will populate 3 gantries full of LCSs and shoulder-mounted signs (SMSs) associated with the incident location. Operator reviews, overrides if needed, then accepts and deploys.

Scenario 1:

Two center lanes blocked. 2 red X's are placed just downstream of the blockage. SMS reads "2 CTR lanes blocked." Upstream gantry has yellow merge arrow LCS directing approaching traffic to the adjacent lanes. The remaining LCSs are displaying green arrow indicating the open lanes.

Scenario 2:

Similar to scenario 1 with only one center lane blocked. The upstream gantry has double merge arrows pointing to the 2 adjacent lanes.

Scenario 3:

When HOV lane is blocked, HOV traffic can merge to any available GP lane. When the GP lane adjacent to the HOV lane is blocked, traffic in this GP lane can only be directed into the adjacent GP lane, not into the adjacent HOV lane, unless the operator overrides and opens the HOV to all.

**Figure 23. Illustration. WSDOT ATM control interface and preview panel (Source: WSDOT).**

### 3.5 TECHNOLOGY, PROCUREMENT, AND TESTING

ATM projects require a significant amount of technology along with software and software integration. As such, the implementation of an ATM system follows that of a traditional ITS project, which requires an integrated ATMS platform to recognize the full benefits of an ITS deployment. Delays in the software development and deployment can be mitigated by operating the ITS subsystems using the ITS subsystem vendor software (e.g., vendor-provided DMS software). For an ATM implementation, the overall system relies on integrating subsystems to gain benefits of the overall solution. The integrated software must be operational and ideally have all interfaces with new or legacy platforms in place prior to activating the ATM system.

#### Software Delivery Models

The procurement and deployment of software can be achieved through a diverse range of delivery methods. At this point in the North American market, there are a limited number of ATM software packages in place and fully operational.<sup>(64)</sup> For both WSDOT and MnDOT deployments, the agencies chose in-house resources to develop their ATM software. This approach built upon the existing ITS platforms and provided an effective approach for expanding



ATM software can be procured in-house or via contract commercial development. Two strategies for the overall development can be the development of the software as an extension or module of an existing operational platform or as a standalone platform. It is important that the software align with the ATM ConOps and interface with any legacy platforms that might be used for ATM operations.

existing infrastructure to support the ATM system. In the case of VDOT, the department requested that its current ITS software vendor modify the existing commercial ATMS offering to incorporate the ATM functionality. In the case of Ohio Department of Transportation (ODOT), the agency acquired the services of a software developer to enhance its existing ATMS software.

As shown with the sampling of existing implementations, agencies have yet to demonstrate a true trend in the development and deployment of ATM software. While software procurement choice is a design decision, incorporating the software development, training, and acceptance during implementation is critical to the successful

operations of the ATM on day one. Regardless of the software procurement choice (in-house development as an extension or module of the existing platform; in-house development as a standalone platform; commercial development as an extension or module of the existing platform; or commercial development as a standalone platform), it is critical to address the following items during implementation:

- Confirm all software requirements with the selected solution provider as soon as practical.
- Confirm that all software requirements align with the identified standards and components that will be utilized as part of the ATM project.
- Confirm requirements necessary for interfacing with legacy platforms as identified for effective ATM implementation.

- Confirm that software requirements align with the ATM ConOps so the system will deliver the stakeholder’s vision.
- Refine ATM SOPs during the requirement development and software implementation.
- Develop a training plan and user manual to support the implementation of the software.
- Develop a comprehensive laboratory environment that consists of actual devices in concert with simulated devices in order to simulate and test the operational, safety, and failure modes of the ATM system.

## Software Development Resources

Software development for an ATM system can be overwhelming for an agency even if ATMS software is in place. Since ITS projects are required to follow the systems engineering process, applying these tools to the software component facilitates a more efficient implementation. The primary goal for the software development is to ensure from day one that the built system achieves all of the defined requirements and performs how the agency had envisioned. The following available systems engineering resources provide an agency with key activities, testing recommendations, and recommended development practices to manage the progression of the software within the defined budget and schedule.

- FHWA Systems Engineering Guide—Section 4.6.
- Institute of Electrical and Electronics Engineers—Standard 29148-2011 Systems and Software Engineering.
- Caltrans Systems Engineering Guide (<http://www.fhwa.dot.gov/cadiv/segb/>).



***ATM Application:*** MnDOT developed an infrastructure-based queue warning system along westbound I-94 and southbound I-35W in Minneapolis. The objective of the system was to detect traffic conditions in which crashes might occur and to deliver warning messages to drivers to increase their awareness of these conditions, potentially reducing the crash frequency along the facility. The system architecture involved a three-layer design including a crash probability layer, the control algorithm, and system control. The system was designed to interface with the existing ATM systems operating in the region. Prior to full operations, the system was tested, calibrated, and validated to ensure it was operating properly. As part of this validation, an alarm efficiency score (AES) was developed as a metric to better fit the real-time driver warning system and to ensure that the system was not overly conservative in its operation.

*Development of a Queue Warning System Utilizing ATM Infrastructure System Development and Field Testing, Report MN/RC 2017-20, Minnesota Department of Transportation, 2017, <http://dot.state.mn.us/research/reports/2017/201720.pdf>.*

## Traceability, Requirements, and Testing

As discussed previously, the systems engineering Vee diagram presents a traceability process to verify that the developed system meets the defined requirements. This approach provides a step-by-step process for system, subsystem, and unit-level requirement development. Each step further refines the previous to ultimately create the detailed design requirements that are used for development of both the PS&E package and software. These steps are represented on the left side of the Vee diagram.

Each step along the first half of the Vee should include either a test plan (for the detailed requirements), a verification plan (for the system and high-level requirements), or a validation plan (for the user needs). During the implementation of the system, each plan should be applied as the project team moves up the right side of the diagram. Each testing and verification step should only occur once the previous step has been completed and accepted. The final validation step maps back to the initially identified user needs (as per the ConOps). This final test is intended to confirm that the system was built acceptably, the system works appropriately, and the software was developed accurately. The WSDOT ATM testing facility used to test equipment prior to installation is shown in Figure 24, while the ATM signs undergoing testing are shown in Figure 25.



**Figure 24. Photo. WSDOT ATM testing facility (Source: WSDOT).**



**Figure 25. Photo. WSDOT ATM sign testing (Source: WSDOT).**

## Material Procurement

Contrary to typical civil projects or isolated ITS projects, ATM projects can involve a complex combination of materials necessary for implementation.<sup>(65)</sup> In addition, they can require larger than typical quantities of certain elements, such as small DMSs or structural steel. For certain technology field components, such as over-lane dynamic message signs or variable speed limit signs, time to acquire the components should be viewed as critical path items. Likewise, acquiring certain components and protocols to support software development, testing, and training is critical and should be programmed in advance of the field element quantities. Components that must be tested with legacy platforms or platforms being developed by others outside of the ATM also should be ordered in advance to provide a structured testing process.

In support of effective project delivery, lead time and sequencing are critical concerns for overhead sign mounting structures. Given that many construction methods for these types of units may require a complete road closure, it is important that the structures be made available as defined by the project schedule. Also, it is important that a strong inspection regime be in place to confirm the specifications necessary for an ATM structure. While overhead sign structures are relatively standard roadway components, gantries for an ATM environment may have cable access points, internal cable raceways, or special mounting bracket accommodations that differ from standard structures.

The inspection regime for an ATM project is similar to that of any other ITS project. The inspection regime should be continuous throughout the project and comprise factory and pre-installation/construction-level, subcomponent-level, component-level, subsystem-level, and system-level inspection and testing. This applies to both technology items such as signs and communications as well as nontechnology items such as conduits and foundations. A strong



**ATM Application:** The following list is an overview of some key lessons learned by agencies with respect to implementation of an ATM solution:

- ATM systems require more precision and skill to implement than conventional traffic management systems do. As a result, enhanced education on ATM technologies and operational needs, particularly within the managing agency, increases the potential for a project's success.
- The procurement of durable, high-quality signs can be a critical element in the implementation of a successful ATM network.
- An ATM system should always supplement traffic management rather than be used as the primary method of improvement for a corridor.
- Continuous communication between the project managers and the software developers while the software is being tested will result in a more functional and effective overall system.
- Establishing a requirement traceability matrix at the onset of the project helps keep the team focused, expedites reviews, and minimizes conflicts and the need for extended issue resolution.
- It is recommended to advance the design beyond 30 percent during the development of design-build procurement documents. Advancing the design further will enable an agency to facilitate advance construction and procurement of material, both of which have a long lead time.

inspection regime requires that thorough documentation be submitted and approved throughout the project as opposed to a single submittal at the end. A strong inspection regime includes a rigorous evaluation of the built and under-construction project elements compared to the project specifications and requirements. In addition, the inspection regime maintains a level of distance between the construction/implementing team and the inspection team. These entities can be members of the same company, but the inspection regime should be an integrated component of the overall quality assurance/quality control (QA/QC) process that provides a fresh set of eyes on the works.

## CHAPTER 4. IMPLEMENTATION AND DEPLOYMENT

This chapter provides a review of the approach to implementing and deploying active traffic management (ATM) strategies in a region. Particular topics include legal issues, stakeholder engagement, and public outreach and involvement. This chapter presents the following sections:

- **Construction and Scheduling.** This section describes construction strategies associated with ATM, including how an agency may build the ATM solution.
- **Legal Issues.** This section reviews any circumstances under which a regional agency may face legal limitations that will need to be addressed prior to implementation and deployment.
- **Stakeholder Engagement, Public Outreach, and Involvement.** This section discusses the importance of stakeholder engagement throughout the implementation and deployment process for ATM strategies.

### 4.1 CONSTRUCTION AND SCHEDULING

Once a project is at the implementation stage, construction and scheduling play a key role in a successful rollout. The following subsections provide an overview of various project-related topics associated with construction and scheduling.

#### Project Delivery

Agencies continue to adopt alternate delivery vehicles for ATM deployments and, in some cases, alternate finance and funding methods. Table 14 provides examples of different project delivery methods that could be used for ATM projects, though the examples may not necessarily be specific ATM projects.<sup>(66)</sup> Additional consideration for project delivery includes involving ATM with existing reconstruction or maintenance projects. ATM could be used as a tool to assist with directing traffic on, off, and along a freeway during construction. A number of strategies as well as devices could be implemented depending on the need of the contractor and the length of the project. The devices implemented could consequently remain after the reconstruction/maintenance project has been completed and then utilized for operational needs. Implementing during this stage may reduce the overall total costs for an ATM system since it would not be a full build. Additional phases could be implemented at a later stage once additional funding is available.



**A software or system deployment procurement using federal-aid funds may be an engineering or service contract rather than a traditional construction contract. Engineering is defined as professional services of an engineering nature as defined by state law. For engineering contracts, qualifications-based selection (QBS) procedures in compliance with the Brooks Act must be followed. Service contracts (non-construction, non-engineering in nature) are to be procured in accordance with the Common Rule (49 CFR Part 18) (<https://www.gpo.gov/fdsys/pkg/CFR-2009-title49-vol1/pdf/CFR-2009-title49-vol1-part18.pdf>).**

**Table 14. Alternate project delivery methods (adapted<sup>7</sup>).**

Method	Advantages	Disadvantages	Example
Design-Build (DB)	<ul style="list-style-type: none"> <li>• There is one contract/one team.</li> <li>• Method uses a single point of accountability.</li> <li>• Less contingency funds are needed due to minimal change orders.</li> <li>• Overall project delivery schedule is more efficient (design/construction can occur at the same time).</li> </ul>	<ul style="list-style-type: none"> <li>• Owner needs to identify the effort up front in order to complete the project within budget.</li> <li>• Design changes after construction can be costly.</li> <li>• Minimal owner involvement over the design and construction occurs.</li> <li>• Since there is one team, there may be conflicting interests.</li> </ul>	Virginia, Washington (system minus gantries)
Design-Bid-Build (DBB)	<ul style="list-style-type: none"> <li>• Method clearly defines the roles of all parties.</li> <li>• Design changes can be adjusted prior to construction.</li> <li>• Design is completed prior to construction.</li> <li>• Owner controls the quality of the design and construction.</li> <li>• More reliable price exists for construction since the design has been completed.</li> </ul>	<ul style="list-style-type: none"> <li>• Method uses two contracts/two teams—not necessarily related.</li> <li>• Longer project delivery schedule is needed since construction typically occurs after design.</li> <li>• Owner is at risk for design errors during construction.</li> <li>• Since design is complete, the contractor may impose more change orders due to design issues.</li> </ul>	Washington (gantry only), Minnesota
Design-Build-Operate-Maintain (DBOM)	<ul style="list-style-type: none"> <li>• Method includes integrated procurement through a single contract that capitalizes on efficiencies.</li> <li>• Long-term maintenance program can be tailored to address ongoing needs.</li> </ul>	<ul style="list-style-type: none"> <li>• Owners relinquish much of the control they have under traditional procurement.</li> <li>• Needs not identified up front will not be met for the duration of the contract.</li> </ul>	Virginia
Construction Management at Risk (CMAR)	<ul style="list-style-type: none"> <li>• Method provides preconstruction services.</li> <li>• Certain construction components can be fast-tracked prior to full design approval.</li> <li>• Contractor's input and perspective into planning and design stages is included.</li> </ul>	<ul style="list-style-type: none"> <li>• CMAR can be costly to the owner.</li> <li>• Advisory services end with preconstruction—the CMAR would then be operating at risk during construction.</li> </ul>	Arizona (Phoenix Downtown Traffic Management System)
Public-Private Partnership (P3)	<ul style="list-style-type: none"> <li>• Method is able to provide alternative funding sources.</li> <li>• Risk is on the private sector.</li> <li>• Additional efficiencies and innovations in construction, scheduling and finance exist.</li> </ul>	<ul style="list-style-type: none"> <li>• Greater emphasis is placed on required expertise.</li> <li>• Proposal process is more expensive.</li> </ul>	Denmark, England, Germany

In a design-build (DB) context, the DB solution provider will participate earlier in the project development. Depending on the scope of services defined, the role of the DB team can range from supporting to leading any of the individual elements of the project development. While most of the operations and specific ATM strategy coordination—such as law enforcement agencies, first responders, and tow recovery services—typically would be handled by the agency (or on behalf of the agency by consultants or contractors), it is expected that the DB team would

play a large role upon appointment. Alternatively, the selected delivery method could be a design-build-operate-maintain (DBOM) solution where the scope would include operations and maintenance responsibilities. The DBOM team would be involved with the development of SOPs and the integration of maintenance activities for ATM components in coordination with current ITS and roadway operations and maintenance.

While DB and DBOM represent options for project delivery, the agency remains the ultimate owner of the facility (as with the traditional design-bid-build approach). In the concessionaire model, which could part of a DBOM or P3, a third-party concessionaire typically operates the facility under a long-term lease. In such an arrangement, the concessionaire takes on many of the obligations and liabilities as the owner. As such, the concessionaire will have an even greater stakeholder responsibility. This includes a larger public outreach and marketing role, especially if there is the option of revenue generation through toll collection as a component of the facility. Additionally, the concessionaire becomes responsible for the establishment of formal memorandums of understanding with local transportation agencies and local law enforcement and public safety agencies.



**Information on the Federal Highway Administration (FHWA) Major Project Delivery Process for some innovative delivery methods is available on FHWA's website**  
[https://www.fhwa.dot.gov/major\\_projects/defined.cfm](https://www.fhwa.dot.gov/major_projects/defined.cfm),  
[https://www.fhwa.dot.gov/ipd/alternative\\_project\\_delivery/define/d/](https://www.fhwa.dot.gov/ipd/alternative_project_delivery/define/d/).

These delivery methods involving a concessionaire may be appropriate for projects that involve tolling, such as the I-4 Ultimate project in Orlando, Florida that includes express toll lanes, ([https://www.fhwa.dot.gov/ipd/project\\_profiles/fl\\_i4ultimate.aspx](https://www.fhwa.dot.gov/ipd/project_profiles/fl_i4ultimate.aspx)) or the Capital Beltway High Occupancy/Toll (HOT) Lanes on I-495 ([https://www.fhwa.dot.gov/ipd/project\\_profiles/va\\_capital\\_beltway.aspx](https://www.fhwa.dot.gov/ipd/project_profiles/va_capital_beltway.aspx)), which could also incorporate ATM strategies as part of the deployment. To support success of the ATM implementation, the relationship between the concessionaire and the ultimate end owner must be well codified in the concessionaire agreement. Additionally, the relationships between the two must be cultivated during the design and build phases of the project to prepare for operations on day one. The agreement should include conditions that mitigate the likelihood of the concessionaire to operate with certain financial motives (e.g., to generate revenue sufficient to finance borrowing costs and/or to generate an operating profit).

CMAR contracts provide benefits when transportation improvements are needed immediately, and when the design is complex, difficult to define, or subject to change and/or has several design options.<sup>(67)</sup> They are also beneficial when a high level of coordination is needed with external agencies, which may be applicable to ATM projects.

## **Coordination**

During implementation, a crucial partner to involve in all facets of the project implementation will be the contractor. The contractor should be a leader in facilitating the stakeholder coordination effort. Many of the attributes of a good contractor are self-evident and follow well-known project management practices. These include:

- Ability to prepare and maintain a proper resource-weighted schedule with a clearly delineated critical path.
- Establishment of proactive, frequent, transparent communications with clear and unambiguous progress reporting.
- Development and maintenance of thorough documentation through delivery of as-built plans.
- Understanding of systems integration and systems testing and access to systems integration and network specialist resources throughout the life of the project.
- Strong and ongoing relationship with software provider throughout life of project.
- Establishment of proactive risk management and risk mitigation program.
- Proactive engagement with third parties that may impact project critical path, such as resolution of utility conflicts and acquisition/coordination of power connections.
- Proactive coordination with other projects in study area and incorporation of those activities into project schedule and risk management plan.
- Proactive approach to permitting that mitigates schedule risks.
- Willingness to consider value engineering approaches when technology changes lead to potentially improved processes or other changed conditions lead to mutually beneficial modifications.
- Establishment of in-place standard operating procedures and the management structure to support the implementation of those SOPs effectively throughout the contractor team.
- Establishment of a well-defined, strong, documented, and enforced safety program.

The effectiveness of the contractor team will have a direct impact on the progress of the project implementation. All coordination efforts should be reflected within the overall project schedule and managed through a partnership between the owner agency project manager and the contractor. This coordination will be especially critical for elements such as software integration, training, and maintenance.



**Existing forums, processes, communication channels, committees, and coordination structures can be leveraged and modified to support implementation of ATM strategies on facilities in region with mature freeway management systems. If these efforts do not exist, their formation can help facilitate the effective implementation of ATM in a region.**

For agencies with mature freeway management systems and incident management programs, it is likely that there are forums, processes, and communication channels in place to facilitate stakeholder interaction—including regional incident management committees, ITS and technical reference manual committees, and regional ITS and transportation demand management committees. When available, these existing stakeholder coordination mechanisms should be leveraged and modified when necessary to support implementation of the ATM corridor. This may include additional coordination meetings, working sessions focused on the ATM corridor, and expanded membership to include partners not previously involved. In

locations where such forums or processes do not exist, it is suggested that one or more standing committees be established to maintain scheduled information sharing, information dissemination,

risk management, and issue resolution around the operations, maintenance, and outreach for ATM corridor construction.

## Schedule

Schedules are critical on any project, but ATM projects involve a complexity of coordination that increases the criticality of the schedule for an effective delivery. A traditional freeway-focused intelligent transportation systems (ITS) project can experience a delay with minimal or no impact to the day-to-day operations of the facility. A delay in delivery of the ITS solution would only extend the time frame at which the public begins to receive traveler information or when an agency can more effectively manage incidents. The benefits of the project are real and valuable to the public, but the direct impacts on the operation of the facility are not as easily felt.



**The complexity of ATM projects increases the need for coordination. ATM technology components must be integrated into existing operations, which be significantly impacted by schedule slippage on civil components. Schedule adherence and close risk monitoring can help facilitate on time ATM project delivery. It is also essential to maintain operations during construction, and ATM can reduce the impacts of construction if operational throughout.**

In a typical ATM deployment, the technology component is an integrated portion of the operation of the facility. Similar to a traffic signal for an arterial roadway, the ATM components—whether they are variable speed limit signs, lane control signals, or adaptive ramp meters—are an integrated part of the facility. In addition, ATM implementations often involve civil components such as shoulder lane improvements, ramp improvements, and gantry and sign structure installations. Delays associated with these civil components easily can impact the daily operation of the facility. Last, the culmination of all subsystems including the civil elements, field equipment, and central software must align to deliver a complete solution.

Thus, schedule adherence and schedule risk monitoring are critical to the success of an ATM project and require a coordinated schedule that addresses the field construction; central office construction and integration; operations and maintenance training and SOP development; formal partnership agreement codification; education and outreach campaign launch and continuation; and software integration into operations, which includes testing, debugging, and training.

Coordinating civil elements within the corridor is crucial to maintaining operations of the facility during construction<sup>(68)</sup> and includes a large structural engineering and foundation footprint that must be coordinated with existing structures and overhead signing. Roadbed construction must be phased to maintain traffic during tasks such as shoulder enhancements, ramp enhancements, and accident investigation. Last, the frequency of structures along the corridor must be coordinated to ensure signing consistency as new ATM dynamic and static signage is integrated with existing dynamic and static signage. It also is important that construction of these civil elements occur in coordination with other projects in the vicinity of the corridor.

Component-level subsystem and system testing and training are critical elements that should be integrated within the project schedule as well. Often, these soft elements are programmed for the

end of the project delivery life cycle and receive less emphasis than the more tangible elements. However, for a successful first day of operations, it is crucial that system testing be completed in a timely manner and that all operations, procedures, and protocols be aligned with the defined system and associated software.

Schedule is a critical component for any project, and most agencies and contractors use extensive tools and methods for monitoring schedule adherence. When compared to a traditional ITS project, ATM projects typically involve a larger civil component, the introduction of new subsystems and technologies to support traffic management, and a more intense software component to support the corridor. Managing these additional complexities warrants an enhanced risk management regime. In such a regime, all project risks are quantified and rated by probability of occurrence and impact of occurrence. Risks can be noted as either a threat or an opportunity for the project. Once identified and rated, a risk response plan should be developed, including the assignment of an appropriate mitigation response. Risk management, analysis, prioritization, and mitigation strategies should be ongoing parts of project management throughout the development and implementation of the project. The frequency of revisiting and updating the risk management plan should be commensurate with the size and pace of the project.

## 4.2 LEGAL ISSUES

ATM deployments may have legal implications. An agency should review laws, regulations, and policies at the local, State, and Federal levels that are relevant to ATM to determine whether the planned ATM strategies fit within the existing legal and policy framework for the local area if changes or additional policies are needed.<sup>(69,70)</sup> For example, dynamic speed limit (DSpL) and potential automated enforcement, use of shoulders as a travel lane, and ramp metering may all have legal implications. Thus, an agency should assess the legal authority to enforce ATM strategies as well as whether law enforcement and legislative parties are willing to support the enforcement of the ATM strategies.<sup>(70)</sup> In cases where supporting laws and policies are not in place, it may be necessary to gain the buy-in of higher-level agency stakeholders and elected officials before an ATM strategy can be deployed.



**ATM deployments may have legal implications that an agency should ensure are addressed prior to implementation. Strategies such as dynamic shoulder lanes and variable speed limits, along with enforcement approaches, can present operational challenges of legal authority or appropriate policies are not in place.**

Agencies have taken various approaches to address the legal aspects of ATM. For example, a number of States allow some form of dynamic shoulder use during congested periods, including bus-on-shoulder operations.<sup>(71,72)</sup> However, policies vary by State and facility regarding the vehicle types, allowable design exceptions, and other restrictions imposed on the use of shoulders as a travel lane.<sup>(71,72)</sup> In some areas, policies regarding a minimum posted speed limit may restrict the enforceable variable speed limits that can be posted.<sup>(73)</sup> In Missouri, the variable speed limit signs were blank when speeds were below 40 mph

(before the system was deactivated), while in Minnesota and Washington, the ATM signs may also post variable speeds of 35 or 30 mph.<sup>(73)</sup> Pennsylvania provides an example of policy that

supports variable speed limits to improve safety, with code 212.108 (Speed Limits) stating, “Speed limits may be changed as a function of traffic speeds or densities, weather or roadway conditions or other factors.”<sup>(70)</sup> The Pennsylvania code also states that “variable speed limit sign shall be placed ... at intervals not greater than 1/2 mile throughout the area with the speed limit.”<sup>(70)</sup>

Some ATM strategies may require operational changes within the agency that require modifying existing agency operating policies. While some ATM strategies may use automated systems, others may require operator verification or validation, particularly those related to ATM signage or dynamic shoulder use operations. Because it is very apparent to drivers when ATM signage is not accurate, agencies have an increased responsibility to ensure that appropriate, timely, and updated information is presented to retain motorist confidence.<sup>(61)</sup> To mitigate this concern, Washington State Department of Transportation (WSDOT) employed additional transportation management center (TMC) staff, and Minnesota Department of Transportation (MnDOT) cross-trained additional TMC staff to ensure 24/7 coverage.<sup>(61)</sup>

Agencies may need additional staffing and/or equipment to facilitate operational changes. For example, dynamic shoulder use operations might need additional freeway service patrols and law enforcement to ensure rapid incident response since the shoulder may not be available as a refuge area.<sup>(71,73)</sup> For truly dynamic shoulder use operations that allow 24/7 use of the shoulder during congested periods, an operator, enforcement, or freeway service patrol personnel will likely need to be available at all times to verify, either in person or using closed circuit television (CCTV) cameras, that the shoulder lane is cleared of debris and stalled vehicles prior to opening it to traffic. ATM deployments may also require additional staff for maintenance of the system.<sup>(73)</sup> Snow maintenance operations may be impacted by dynamic shoulder use operations due to the need to plow more pavement area and less area to place the snow.<sup>(73)</sup>

### **4.3 STAKEHOLDER ENGAGEMENT, PUBLIC OUTREACH, AND INVOLVEMENT**

Regional stakeholders are a critical contributor to the success of ATM strategies. Because ATM strategies will likely be new to most stakeholders and the public, an outreach program to provide information on the purposes, benefits, operation, and performance outcomes of ATM strategies will help build trust in the investments.<sup>(13)</sup> This engagement and outreach can take on many forms, and various aspects of this activity can help garner stakeholder and public support and thus ensure a successful ATM deployment.

#### **Identifying Stakeholders**

As an ATM project deployment moves forward, agencies need to reach out to various stakeholder groups to help ensure a successful deployment. These groups should be engaged early and often in the project planning process to ensure understanding, support, and successful deployment.<sup>(73)</sup> Stakeholders should include policy makers and staff from transportation agency divisions that will be responsible for deploying, operating, and maintaining the ATM system. Outside of the deploying agency, stakeholders include any agency or group that may be affected by the ATM deployment, including the public at large. Potential stakeholders may include but are not limited to:

- State, county, and city transportation agencies.
- Metropolitan planning organizations (MPOs).
- FHWA Division Office.
- Highway service patrol/contractors.
- State and local law enforcement.
- Fire departments and emergency medical services.
- Transit agencies and operators.
- Other incident management agencies.
- Elected and appointed officials.
- Media.
- Traveling public.

The role and level of involvement of individual stakeholder groups will certainly vary from project to project, but all may be able to offer valuable insight and help generate support for a project. Many stakeholder groups will have already been identified if the area has a regional intelligent transportation systems (ITS) architecture, which might be a good starting point for establishing a core team to further define the ATM strategy.<sup>(74)</sup>



**ATM project stakeholders can come from a variety of agencies and entities throughout a region. Project champions often emerge from these stakeholders, and can play a key role in advancing the dialogue associated with a project and contribute to a successful deployment.**

As an agency works to identify stakeholders, a project champion who can serve as a de facto spokesperson for the project and work to engage others to generate support within and beyond the deploying agency may emerge. The project champion might play various roles, including initiating a feasibility study, establishing a dialogue with other stakeholders, and helping establish support for the project across a broad range of audiences. Implementers of ATM strategies in California, Minnesota, and Washington have all

attributed their successes to a strong project champion who built working relationships and teamwork among various agencies to implement these strategies.<sup>(74)</sup>

### **Establishing a Stakeholder Team**

An agency may want to consider formally organizing an agency stakeholder team to establish collaborative support for a project. Initial efforts may include a peer exchange workshop or webinar with other agencies that have successfully deployed similar ATM strategies. Such events can be useful for an exchange of ideas, lessons learned, and best practices. The collaborative support of multiple agencies will be useful for gaining support of elected and appointed officials, media, and the public.

Smaller working groups may be developed and convened regularly to keep stakeholders informed about the progress of the deployment. These working groups can facilitate keeping agency stakeholders informed, creating opportunities for input and participation, providing feedback, creating an informed consensus, and identifying the need for system adjustments during deployment.<sup>(74)</sup>

## Engagement, Outreach, and Involvement

Buy-in from multiple levels of staff at stakeholder agencies can provide a basis for outreach to the public, media, and elected and appointed officials. Outreach to both the public and broader agency stakeholders is elemental to building the needed trust and gaining general acceptance of ATM strategies.<sup>(75)</sup> Gaining the support of agency decision makers and policy makers helps make the ATM project easier to move forward, particularly if there is a collaborative agency group willing to advocate for the ATM strategy with elected and appointed officials.<sup>(74)</sup> Outreach to elected and appointed public officials is important in various settings and helps these individuals understand the benefits of the ATM strategy. Their support will be needed to provide funding or to promote changes to legislation or new policies that will allow ATM strategies, such as dynamic shoulder use, variable speed limits, and nonstandard language for dynamic lane control signage.<sup>(74)</sup>

Various avenues of communication can facilitate this outreach and understanding, including one-on-one meetings, presentations, newsletters, and emails. Table 15 provides examples of outreach and engagement efforts that agencies across the country have undertaken to advance ATM projects in their region. The overall intent of all of these approaches is to ensure that all stakeholders have a common understanding of the purpose and objectives of a proposed ATM project prior to informing the public.



**Outreach videos for various projects are available online from WSDOT**  
<https://youtu.be/mIpPJrOeZyg>),  
**VDOT**  
[https://www.youtube.com/watch?v=zO\\_wNNkZOTg&feature=youtu.be](https://www.youtube.com/watch?v=zO_wNNkZOTg&feature=youtu.be)), Wyoming  
<https://www.youtube.com/watch?v=9ywrLjvEYyk>), and  
**Highways England**  
<https://www.youtube.com/watch?v=C5oDYA6hkY&feature=youtu.be>).

**Table 15. Engagement, outreach, and involvement examples.**

<b>Agency</b>	<b>Project(s)</b>	<b>Sample Outreach Approaches/Strategies</b>
Highways Agency (UK)	<ul style="list-style-type: none"> <li>• Various</li> </ul>	<ul style="list-style-type: none"> <li>• Special branding (Smart Motorway)</li> <li>• Dedicated website</li> <li>• Videos</li> <li>• Brochures</li> </ul>
MnDOT	<ul style="list-style-type: none"> <li>• I-35W</li> <li>• I-94</li> </ul>	<ul style="list-style-type: none"> <li>• Special branding (Smart Lanes)</li> <li>• Dedicated website</li> <li>• Media events</li> </ul>
Queensland Government (Australia)	<ul style="list-style-type: none"> <li>• Bruce Highway</li> </ul>	<ul style="list-style-type: none"> <li>• Special branding (Managed Motorway)</li> <li>• Dedicated website</li> <li>• Videos</li> <li>• Fact sheets</li> <li>• Frequently asked questions (FAQs)</li> </ul>
VDOT	<ul style="list-style-type: none"> <li>• I-495 Woodrow Wilson Bridge</li> <li>• I-66 ATM</li> </ul>	<ul style="list-style-type: none"> <li>• Public education campaign</li> <li>• Dedicated website</li> <li>• Videos</li> <li>• Presentations</li> <li>• Advertisements</li> </ul>
WSDOT	<ul style="list-style-type: none"> <li>• I-5</li> <li>• I-90</li> <li>• SR 520</li> </ul>	<ul style="list-style-type: none"> <li>• Special branding (Smart Lanes)</li> <li>• Public education campaign</li> <li>• Dedicated website</li> <li>• Videos</li> <li>• Presentation</li> <li>• Brochures</li> <li>• Press releases</li> <li>• Public forums/meetings</li> </ul>
WYDOT	<ul style="list-style-type: none"> <li>• VSL</li> </ul>	<ul style="list-style-type: none"> <li>• Press releases</li> <li>• FAQs</li> <li>• Video</li> </ul>

An example of the WSDOT ATDM website is shown in Figure 26, while the YouTube channel hosted by Virginia Department of Transportation (VDOT) for the I-66 visualization videos is shown in Figure 27. A brochure prepared by Highways England to educate the public on the use of the red X is depicted in Figure 28.

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**ATDM**

**Active Traffic and Demand Management**

I-5 Sign Locations

I-90 Sign Locations

SR 520 Sign Locations

Choosing Locations

How ATDM symbols work

Benefits of ATDM

## Active Traffic and Demand Management

Active Traffic and Demand Management (ATDM) is a strategy used by the Washington State Department of Transportation to reduce collisions associated with congestion and blocked lanes. About 25% of traffic congestion is due to events like collisions or disabled vehicles. WSDOT launched the system on August 10, 2010. The project to use ATDM on I-5, I-90 and SR 520 cost a total of \$65 million.



**How does it work?**  
The system uses overhead lane signs to provide advance notice of traffic conditions:

- Variable speed limit signs direct drivers to incrementally reduce their speeds.
- Symbols direct drivers to change lanes when a lane is blocked.
- Overhead message signs warn drivers of slowdowns, backups and collisions ahead.

The system decreases last second avoidance maneuvers and panic braking, which are both primary factors that contribute to collisions.

**Current Active Traffic and Demand Management Corridors**

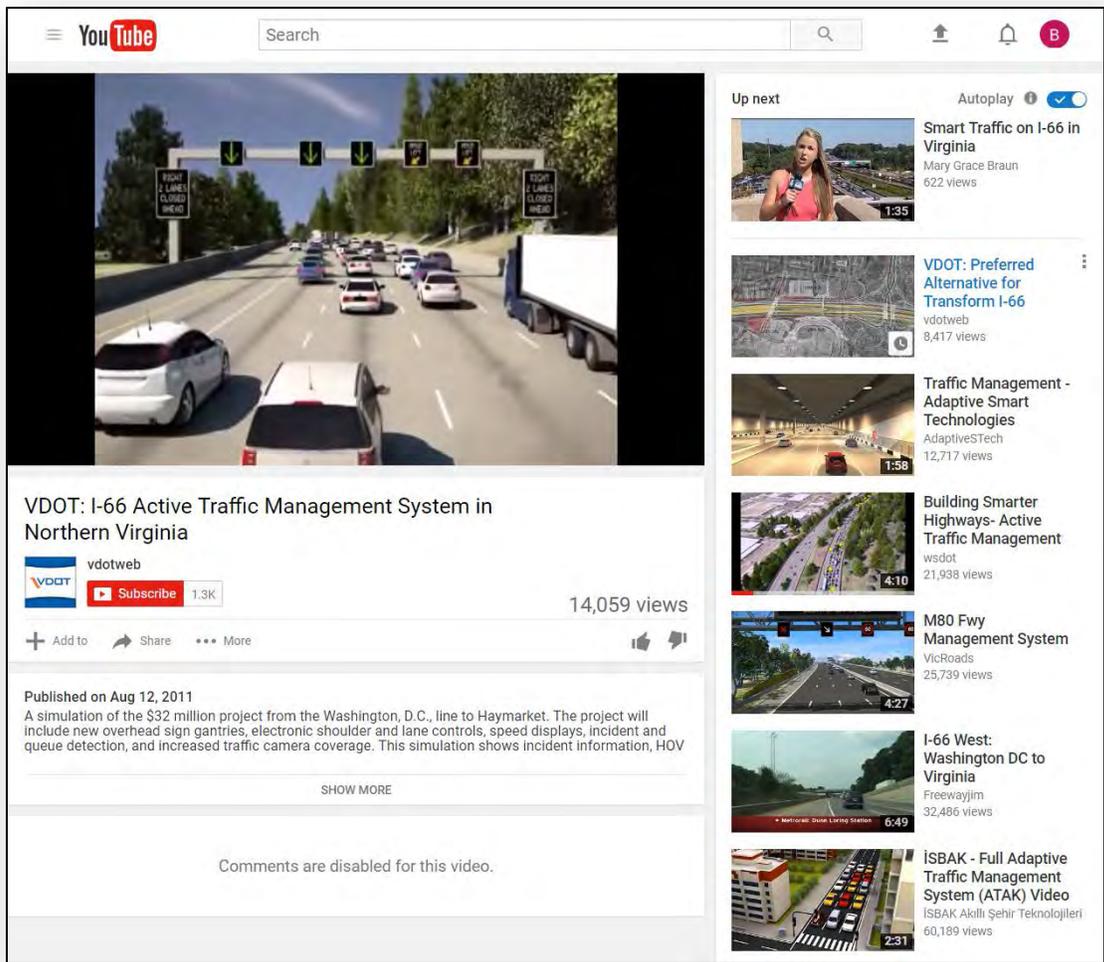
- Interstate 5
- Interstate 90 Seattle/Bellevue
- Interstate 90 Snoqualmie Pass
- State Route 520 Seattle/Bellevue

WSDOT is one of the first state transportation agencies to use this type of Active Traffic and Demand Management system in the United States. Considered a work in progress, analysis of existing traffic management corridors for safety and congestion relief could lead to additional locations like Joint Base Lewis McChord in Tacoma.

[Traffic & Cameras](#) | [Search](#) | [Contact Us](#) | [Site Index](#) | [Privacy Policy](#) | [Accessibility / Title VI](#)

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**Figure 26. Illustration. WSDOT ATDM website.<sup>(76)</sup>**



**Figure 27. Photo. VDOT YouTube channel with ATM visualization videos.<sup>(77)</sup>**



**Figure 28. Illustration. Highways England brochure for red X.<sup>(78)</sup>**

ATM strategies are likely to be new to most stakeholders and the public, which presents challenges when agencies want to communicate with stakeholders to gain support.<sup>(61)</sup> Implementing agencies need to educate stakeholders and the public so that they understand the potential benefits of an ATM system and do not make negative assumptions. To facilitate communication about an unfamiliar concept, many agencies create special branding for the new initiatives, which may involve hiring a communications specialist to work with the agency and community to develop appropriate messages and marketing materials to use for outreach, education, and public awareness.

A deploying agency must also determine the amount and type of public outreach to pursue to inform the public about ATM. The level of public outreach will depend on the scale, complexity, and potential level of controversy of the ATM deployment. For example, ATM deployments involving new and unfamiliar dynamic signage, such as dynamic lane use control (DLUC), dynamic shoulder lane (DShL), dynamic lane reversal (DLR), dynamic junction control (DJC), and variable speed limits, require a public education focus. Conversely, ATM strategies such as adaptive signal control, queue warning (QW), or adaptive ramp metering (ARM) will likely not require any public outreach because they are either transparent to the system user or easily understandable.

## Lessons Learned

In recent years, various agencies with experience implementing ATM have undertaken a variety of outreach efforts and have had varying experiences worth noting. In general, ATM public outreach efforts have two thrusts: to promote the ATM strategy that can offer benefits, and to educate travelers on proper usage of an ATM strategy. It is important for agencies to plan for public interaction in both the planning and deployment stages to keep the public informed and receive feedback. Agency outreach efforts should:

- Concentrate on providing information on whether a project is worthwhile.
- Consider travelers as allies and advocates for ATM and not just roadway users.
- Use a broad range of mechanisms and tools for information dissemination.
- Share the successes of completed ATM projects.
- Ensure effective communications via the delivery of consistent messages by all levels of the organization.
- Include policy- or legislative-related changes that might impact enforcement procedures.

WSDOT and MnDOT both used a wide variety of outreach approaches for their respective ATM projects—including workshops, forums, one-on-one meetings, group presentations, media advertising and outreach, newsletters, and emails—to provide information to the public, commuters, and policy makers about their new ATM strategies, in conjunction with new tolling initiatives.<sup>(79,80)</sup> WSDOT had a very positive experience with local media stations to broadcast coverage on why ATM signage technology is good but found it hard to maintain that message.<sup>(61)</sup> Additionally, WSDOT quickly realized that it was important to focus on safety benefits to be gained from ATM signage as opposed to other, less clear objectives such as speed harmonization.<sup>(61)</sup> WSDOT noted that while outreach advocates for specific projects, it can also lay the groundwork for future projects and concepts.<sup>(73)</sup>

Agencies deploying ATM strategies also emphasize the importance of maintaining consistent terminology and messaging, which should be determined early in the project planning stages.<sup>(73)</sup> For example, Missouri DOT (MoDOT) found success in outreach by targeting three key areas: expectations, enforcement, and media relations.<sup>(73)</sup> Ohio Department of Transportation (ODOT) found value in educating law enforcement and other emergency responders early in the planning process and then having them accompany agency staff when meeting with the media.<sup>(73)</sup>



**ATM Application:** VDOT developed a comprehensive outreach package to share information about the I-66 project in suburban Washington, DC. As part of this outreach campaign, VDOT prepared the following:

- A public information meeting presentation that was used at citizen information meetings and made available online, intended to describe the concept of ATM and how it would be used along the I-66 corridor ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_CIM\\_Presentation.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_CIM_Presentation.pdf)).
- A video used at citizen information meetings that described the project and included 4-d visualization of how the facility would operate (<https://www.youtube.com/watch?v=x-ZZKhaLRzI>).
- An ATM and I-66 project fact sheets ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_Fact\\_Sheet.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_Fact_Sheet.pdf)).
- A list of frequently asked questions associated with the project ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_FAQ.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_FAQ.pdf)).
- A list of treatment definitions used to describe the elements of the implementation ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_Treatment\\_Definitions.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_Treatment_Definitions.pdf)).
- A fact sheet illustrating the conceptual design of the project ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_Conceptual\\_Design.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_Conceptual_Design.pdf)).
- An illustration of the various gantry variations a traveler might see along the facility ([http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66\\_ATM\\_Gantry\\_Variations.pdf](http://www.virginiadot.org/projects/resources/NorthernVirginia/I-66_ATM_Gantry_Variations.pdf)).



## CHAPTER 5. OPERATIONS AND MAINTENANCE

This chapter provides guidance on operations and maintenance issues agencies will face once active traffic management (ATM) strategies go online. The chapter includes the following sections:

- **Activation Thresholds and Performance Monitoring.** This section discusses activation thresholds related to ATM operations and how agencies might use data and performance monitoring during ATM strategy activation. It also discusses performance monitoring of ATM strategies that can support daily activation and operations.
- **Performance Evaluation.** This section discusses the issues associated with evaluating the performance of an ATM deployment, including how an agency collects data and analyzes it to quantify or justify the deployment of an entire system or to demonstrate to what extent the deployment meets intended regional mobility goals and objectives.
- **Maintenance.** This section highlights the importance of maintenance of ATM strategies and the elements of maintenance that are needed on a periodic basis.
- **Incident Management.** This section provides information on the importance of incident management on facilities with ATM strategies along with strategies, agreements, and agency collaboration that can facilitate that management.
- **Enforcement.** This section presents the issues related to enforcement of ATM strategies and the options agencies can consider when establishing enforcement policy and procedures.
- **Costs.** This section discusses the overall costs associated with operations and maintenance of ATM systems and strategies for budgeting and programming those operational costs throughout the life of the project.

### 5.1 ACTIVATION THRESHOLDS AND PERFORMANCE MONITORING

ATM involves dynamically applying and adjusting traffic management strategies in response to current, measured travel conditions; therefore, performance monitoring is a critical element of ATM. Performance monitoring is an ongoing internal process where system conditions and performance are examined and evaluated through data collected through devices/equipment installed in the field. Performance monitoring provides the data needed in the decision-making



ATM projects are successful when they are actively managed. Ongoing monitoring of system conditions from devices and equipment provides data needed in the activation of strategies and the active management decision process.

process. With performance monitoring, detection and monitoring systems are generally used to indicate the current operating state of the system and to identify potential operational problems and situations that need to be addressed by operators (e.g., traffic incidents). The active management cycle shown in Figure 29 demonstrates the relationship between ATM performance monitoring and the ongoing active management of an ATM system.



**Figure 29. Diagram. The Active Management cycle.<sup>(28)</sup>**

Recent research related to implementation thresholds and performance monitoring shed light on the trends related to ATM operations. Recent National Cooperative Highway Research Program (NCHRP) 03-114 efforts revealed that deployment agencies use data and performance monitoring during ATM strategy activation, and activations typically fall into one of two types of processes that vary greatly in the thresholds used.<sup>(81)</sup> These systems are as follows:

- **Automated systems** are where data are automatically collected and applied to a set threshold to activate an ATM strategy. There are few fully automated systems to reference in determining appropriate thresholds for activation and deactivation. Speed and occupancy of mainline detection are typically the fundamental data sources for automated system alerting or decision making.
- **Manual systems** are where data are collected or visual confirmation is acquired and operators must manually make operational changes to their ATM applications. The processes are not automated other than potentially the data collection effort—analysis of the data is largely done manually. ATM strategies that have been deployed to support weather events and most shoulder use applications are manual systems that rely on an operator to verify activity prior to manually changing a sign display. The data most used by operators in manual ATM systems involve a combination of mainline detection of speeds and/or closed circuit television (CCTV) camera image monitoring.



ATM systems can either be fully automated in deployment and operation, manual in nature where operators activate the strategy, or a hybrid of the two processes. Agency processes, procedures, and data are needed for successful operations.

Agencies may implement a hybrid of these two processes in which the system automatically generates a recommended activation but requires an operator to accept or confirm activation. Additionally, agencies may start with ATM strategies that are manually deployed and move along the active management continuum as experience, technology, and regional needs evolve. This evolutionary approach allows agencies to gain

active management capability over time and gain experience with managing ATM strategies as part of their overall transportation systems management and operations (TSMO) approach. Table 16 shows that each ATM strategy can have a set of operational objectives and traffic parameters that deployment agencies can measure in real time to assess current operating conditions.

**Table 16. ATM strategies, data, and implementation processes.**<sup>(81)</sup>

ATM Strategy	Operational Objectives and Traffic Parameters	ATM Strategy—Threshold	Data Set Required (at minimum)	Implementation Process
Adaptive Ramp Metering (ARM)	Maintain smooth flow of mainline and increase throughput while not backing up to arterial cross streets and minimizing wait times to get onto freeway.	Thresholds are typically a combination of occupancy of the mainline, volume of the mainline, queue length of the ramp, and/or storage length of the ramp. For larger ramp meter systems with many along a single corridor, an adaptive system that interprets ramps upstream and downstream of the detected thresholds is effective. For smaller ramp meter systems with only a few along a single corridor, an adaptive system that interprets the local ramp traffic characteristics should suffice.	Occupancy; speed; vehicle count (volume)	Automated
Dynamic Junction Control / Dynamic Merge Control (DJC/DMC)	Maintain smooth flow of mainline, reducing incidents due to merges and aggressive driver behavior.	Late merge applications should activate when occupancy >15% of the time but deactivate when occupancy <15%. Early merge applications should activate when occupancy is less than 5%. Traditional merge should be between 5%–15%.	Occupancy and/or speed	Automated
Dynamic Lane Reversal (DLR)	Allow existing capacity to better match traffic demand throughout the day.	DLR to be considered in instances of lane closures due to incidents of 1 hour or greater, with the threshold equal to twice the time it takes for the reversal to be activated. For example, if the reversal takes 1 hour, the reversal threshold should be at least 2 hours of closure time.	Major incident occurrence	Manual
Dynamic Lane Use Control (DLUC)	Reduce crashes and improve safety.	Operator controlled based on visual confirmation of lane closure or system alert to close a lane.	Incident alert	Manual
Dynamic Shoulder Lane (DShL)	Reduce vehicle density per lane and increase service volume capacity.	Speed should be monitored along the mainline to warrant use of shoulder lane to ease congestion. Operator should verify no obstruction in the shoulder lane prior to opening. Where speed is not available, time-of-day applications of this ATM strategy are effective and have been evaluated to be safe through proper signage and public education.	Speed of mainline detection	Manual—alerted by speed data Automated—alerted by time of day
Dynamic Speed Limit (DSpL)	Increase speed, maximize throughput, decrease congestion, reduce secondary incidents, and reduce speed variation near an incident or weather event.	Threshold is mainline vehicle speed at 85th percentile average speed, with speeds dropping under 50 mph for at least 3 minutes during the day or 5 minutes at night. Speed at detector location compared to downstream speed.	Speed and potentially occupancy	Automated
Queue Warning (QW)	Reduce rear-end crashes and improve safety.	Detecting lowered speed should automatically populate upstream message signs to alert agency of queue forming ahead.	Speed and potentially occupancy	Automated

Performance reporting for ATM deployments includes three general types: (a) real-time reports, (b) time period reports, and (c) planning and design reports. According to recent NCHRP efforts, when considering time period reports, agencies often use a combination of short-term and long-term reports. The short-term time period reports collect data to adjust real-time parameters, often

daily or monthly. Long-term time period reports collect data to validate ATM strategies, usually on a quarterly or yearly basis.

Table 17 presents a summary of each ATM strategy and related performance reporting data, how frequently agencies might report those data, and in what forms. Additional information is provided to identify data requirements and recommended measures.

The prime focus of short-term performance monitoring is to evaluate the performance measures on a daily, weekly, or monthly basis and adjust the thresholds accordingly. This adjustment is based on the operational effect of the threshold in satisfying the ATM strategy objectives. In case of adverse effects, the threshold logic will be remodeled and implemented. This cycle will be continued until the desired outcome is achieved. In this instance, all the thresholds are determined by analyzing the historic trends of various traffic parameters.

The long-term performance monitoring particularly concentrates on evaluating the performance measures to ensure the accomplishment of operational objectives of the respective ATM strategy. This long-term monitoring is a foundational element of performance evaluation discussed in the following section. This evaluation considers multiple traffic parameters to depict network-level effect of the strategy.



**ATM performance monitoring and the data collected during these activities supports both daily operations, adaptive and dynamic changes, as well as longer-term performance evaluation.**

Necessary adjustments will be performed after thorough analysis of the data. It is important to note that the effectiveness of short-term and long-term performance monitoring depends on the quality of data collected. Therefore, detector health is a key factor for any evaluation or monitoring.

**Table 17. ATM strategy performance monitoring data requirements for threshold adjustments. <sup>(81)</sup>**

ATM Strategy	Operational Objectives	Sample Agencies	Performance Measures for Time Period Reports	Data Required	Typical Measures
Adaptive Ramp Metering (ARM)	Maintain smooth flow of mainline and increase throughput while not backing up to arterial cross streets and minimizing wait times to get onto freeway.	Washington State Department of Transportation (WSDOT), Caltrans District 7, Ohio DOT (ODOT), Minnesota DOT (MnDOT), Virginia DOT (VDOT), VicRoads	Throughput—vehicle	Vehicle counts	Short-term: review thresholds monthly based on daily throughput measures. Long-term: review thresholds quarterly or annually based on all measures to meet the operational objectives.
			Throughput—person	Vehicle counts by facility and/or lane type	
			Vehicle miles of travel (VMT)	Vehicle counts; length of road	
			Travel time index	Actual travel rate; ideal travel rate	
			Overall crash rate	Total crashes; VMT	
Dynamic Junction Control / Dynamic Merge Control (DJC/DMC)	Maintain smooth flow of mainline, reducing incidents due to merges and aggressive driver behavior.	WSDOT, Caltrans, MnDOT, Maryland State Highway Administration (SHA), Michigan DOT (MDOT)	Number of incidents by type and extent of blockage	Incident reports	Short-term: timely comparison of speed and delay trends to adjust thresholds. Long-term: comparative evaluation of VMT and crash reports on a quarterly and annual basis.
			Operating speed reliability	Speed data with respect to time	
			Congested travel	VMT; speed counts	
			Overall crash rate	Total crashes; VMT	
Dynamic Lane Reversal (DLR)	Allow existing capacity to better match traffic demand throughout the day.	No applications found in surveys	Congested travel	VMT; speed counts	Short-term: generally, no threshold changes in short period; adverse effect on congested time of travel might be an exception. Long-term: percentage change in VMT and volume analyzed to reassess the lanes and hours of operation.
			VMT	Vehicle counts; length of road	
			Throughput—vehicle	Vehicle counts	
Dynamic Lane Use Control (DLUC)	Reduce crashes and improve safety.	WSDOT, VDOT	Overall crash rate	Total crashes; VMT	Short-term: manual operation of signs based on incident reports and congested travel/delay. Long-term: crash reports, secondary incidents, and incident reaction time analyzed to adjust the design and execution.
			Secondary crashes	Crash reports	
			Lane-hours lost due to incidents	Time blocked; number of lane blocked (incident reports)	
Dynamic Shoulder Lane (DSHL)	Reduce vehicle density per lane and increase service volume capacity.	MnDOT, San Diego Association of Governments (SANDAG)/ Caltrans District 11, Illinois DOT (IDOT), Florida DOT (FDOT),	VMT	Vehicle counts; length of road	Short-term: weekly evaluation of vehicle throughput to adjust the time of activation and speed thresholds. Long-term: quarterly and annual evaluation of vehicle hours/miles traveled under and over predefined speeds to reassess the algorithm and manage the shoulder lane effectively.
			Throughput—vehicle	Vehicle counts	
Dynamic Speed Limit (DSpL)	Increase speed, maximize throughput, decrease congestion, reduce secondary incidents, and reduce speed variation near an incident or weather event.	WSDOT, ODOT, MnDOT, Wyoming DOT (WYDOT), Utah DOT (UDOT), Missouri DOT (MoDOT), VicRoads, UK, Netherlands	Operating speed reliability	Speed data with respect to time	Short-term: analysis of speed and throughput trends on a weekly and monthly basis to improve the threshold algorithm. Long-term: evaluation of incident reports and congested travel as key inputs to improve the adaptability to speed changes.
			Throughput—vehicle	Vehicle counts	
			Secondary crashes	Crash reports	
			Congested travel	VMT; speed counts	
			Percentage of hours influenced by weather	Weather reports; measurable precipitation	
Queue Warning (QW)	Reduce rear-end crashes and improve safety.	WSDOT, ODOT, IDOT	Overall crash rate	Total crashes; VMT	Short-term: no adjustments performed. Long-term: evaluation of crash reports to lead to adjustments in speed and occupancy thresholds.
			Secondary crashes	Crash reports	

## 5.2 PERFORMANCE EVALUATION

Performance evaluation is a process undertaken by an agency either post-hoc or on a project or regional level. In this process, an agency collects data and analyzes those data to quantify or

justify the deployment of an entire system. For example, after deploying an ATM system, an agency may collect performance data over an extended period of time to quantify the overall benefits of deploying the system to determine if it meets the intended goals and objectives. Performance evaluation is generally an aggregation of cumulative effects of multiple management events over an extended period. Many of the outputs and outcomes of the monitoring process can be used as input in the overall evaluation process.

As it reviews daily events, an agency can learn trends in ATM performance over time and fine-tune the deployment of these dynamic management strategies. Agencies should review what happened during the day as well as attempt to relate changes and modifications made by the deployed ATM strategies to observed performance. Agencies can then adjust deployment thresholds and fine-tune management strategies. Critical data that need to be collected by performance monitoring systems include timestamps associated with each change and/or



**The performance evaluation of ATM includes the aggregation of cumulative effects of management over an extended period of time. This evaluation can support the fine-tuning of the strategies and related algorithms as well as be used to incorporate into planning and justification for future ATM deployments.**

activation/deactivation of a management strategy; measured traffic and travel conditions at the time the management strategy was changed; and any external events and circumstances that led to a change in a management strategy, such as an incident on an adjacent or complementary facility.

Having access to quality data is an important element of ATM performance evaluation. In most major metropolitan areas, multiple sources of data are available for evaluating the performance of the freeway systems, and agencies are beginning to use data from multiple sources to evaluate the

performance of their freeway and arterial street systems and to make operational control decisions. Dashboards are a common tool used by some agencies to present travelers with information on the current conditions of travel in a region. These dashboards frequently compare the current conditions to expected or historical conditions for the same time of day. Figure 30 and Figure 31 provide examples of performance monitoring used by agencies in the United States.

State Route/ Interstate	Route Description	Distance (miles)	Average Travel Time	Current Travel Time	Via HOV (min.)
	<a href="#">Alderwood to Southcenter</a>	29.40	36	43	N/A
	<a href="#">Alderwood to Southcenter</a>	27.97	36	38	N/A
	<a href="#">Arlington to Everett</a>	13.32	13	13	N/A
	<a href="#">Auburn to Renton</a>	9.76	13	15	10
	<a href="#">Bellevue to Bothell</a>	9.61	10	10	10
	<a href="#">Bellevue to Everett</a>	26.04	28	27	26
	<a href="#">Bellevue to Federal Way</a>	24.56	25	26	25
	<a href="#">Bellevue to Issaquah</a>	9.55	10	11	11
	<a href="#">Bellevue to Lynnwood</a>	15.59	16	16	15
	<a href="#">Bellevue to Redmond</a>	6.62	8	7	8
	<a href="#">Bellevue to Renton</a>	11.12	11	12	11
	<a href="#">Bellevue to Seattle</a>	9.73	12	12	12

Figure 30. Illustration. Example of WSDOT travel time display for Seattle, Washington.<sup>(82)</sup>



Figure 31. Illustration. Example of speed performance monitoring at Houston TranStar.<sup>(83)</sup>

Most traffic management centers currently perform some type of data logging. System operations logs provide historical logging procedures (manual and automated) as determined by management within the capability of the specific system. Two logs that are important to keep with any ATM deployment are the following:

- **Device Activation Log**—this log provides a record of when devices were activated and deactivated and what message(s) were posted on each device throughout the duration of ATM activation.
- **Device Malfunction/Monitoring Report**—this log documents the operational status (e.g., online, offline, out of service, etc.) of every traffic management device in the system and documents the reason the device is not in service (communications failure, device failure, etc.).

With some ATM deployments, such as DSpL, an agency needs to capture and retain the status and content of information displayed on each device. Retention of this information is needed to support enforcement activities in the corridor. With many systems, automatic logging features are most often incorporated into system software applications.

### 5.3 MAINTENANCE

Most ATM deployments are part of an agency’s overall transportation management system (TMS), which is a complex, integrated amalgamation of hardware, technologies, and processes designed specifically to perform an array of functions. Disruptions or failures in the performance of any one of these functions, including ATM, can impact traffic safety and reduce system capacity, and possibly lead to the traveling public losing faith in the transportation network. The complex interdependencies of these systems further complicates maintenance such that a single malfunction can critically impact the ability of the overall systems to perform their intended functions.

System maintenance includes replacing worn components, installing updated hardware and software, tuning the systems, and anticipating and correcting potential problems and deficiencies. Maintenance includes the development and implementation of action plans for responding quickly, efficiently, and orderly to systemic failures, as well as having infrastructure and procedures for measuring and monitoring maintenance activities. The number of components in a system can impact maintenance costs. For example, the way in which DSpL is displayed (i.e., overhead gantry with lane-by-lane signage vs. single shoulder-mounted sign) can make a significant difference in maintenance costs.<sup>(27)</sup> The design of an installation can also impact maintenance. For example, MnDOT sign gantries incorporated a catwalk so that maintenance personnel could access the back of the dynamic message signs (DMSs) on the gantry without closing lanes. The WSDOT installation



**The ITS Joint Program Office maintains a comprehensive costs database for ITS deployments that provides information on system costs—including capital, operating, and maintenance costs—for a variety of applications, many of which are comparable to ATM deployments in terms of the operational elements. The database is available online on the USDOT website (<http://www.itscosts.its.dot.gov/>).**

required a full lane closure for maintenance. Agencies need to consider regional policies regarding maintenance activities and lane closures when designing the system so that regular maintenance costs are reasonable and efficient.

An agency's maintenance strategy can dictate system design and must be considered in the planning phase to ensure that it will have the personnel or financial resources to adequately maintain the ATM system. Key maintenance decisions that need to be made during the planning portion of a project include the location of maintenance resources, institutional responsibilities, staffing levels and requirements, and use of contract services to maintain agency assets. Table 18 provides an overview of maintenance needs for ATM strategies, while Table 19 includes maintenance considerations that may be unique to ATM strategies and that an agency needs to examine prior to implementation. In all cases, the frequency of maintenance should be per manufacturer recommendations, as technology evolves, as new ITS elements are deployed, and/or as a result of damage or failure.

**Table 18. Maintenance needs for ATM strategies.**

<b>ATM Strategy</b>	<b>Maintenance Elements</b>	<b>Relative Cost Range</b>
Adaptive Ramp Metering (ARM)	Signal heads; controllers; detectors; signage; ramp metering software; controller upgrades	Low to Moderate
Adaptive Traffic Signal Control (ATSC)	Signal controllers; control software; hardware platform; detection; controller upgrades; communication	High
Dynamic Junction Control (DJC)	Control software; detection; signage; communication; overhead gantry; lane control signals	Moderate
Dynamic Lane Reversal (DLR)	Control software; detection; signage; communication; overhead gantry; lane control signals; access control system; overhead beacons	Moderate
Dynamic Lane Use Control (DLUC)	Control software; detection; signage; communication; overhead gantry; lane control signals	Moderate
Dynamic Shoulder Lane (DShL)	Control software; detection; signage; communication; overhead gantry; lane control signals; noise barrier; pavement markings	Moderate to High
Queue Warning (QW)	Control software; detection; signage; communication; overhead gantry; overhead beacons; DMSs	Low
Dynamic Speed Limits (DSpL)	Control software; detection; signage; communication; overhead gantry; lane control signals; RWIS	High
Dynamic Merge Control (DMC)	Control software; detection; signage; communication; overhead gantry; lane control signals	Moderate

**Table 19. Maintenance considerations (adapted<sup>7</sup>).**

<b>ATM Strategy</b>	<b>Maintenance Consideration</b>
Adaptive Ramp Metering (ARM)	Maintenance similar to that for regular traffic signal systems; pole-mounted signal heads may be prone to knockdown by vehicles, requiring additional repair; construction can affect detection systems.
Adaptive Traffic Signal Control (ATSC)	Construction and other utility work can impact detection; communications and hardware/software maintenance also have to be accounted for.
Dynamic Junction Control (DJC)	No significant maintenance challenges beyond other lane control issues unless in-pavement lighting is used to support merge applications.
Dynamic Lane Reversal (DLR)	Maintenance of pylons and lane separators is always a challenge when they are used to separate reversible lanes; maintenance of core elements; maintenance of any ITS equipment and electronic signage and/or software can be significant.
Dynamic Lane Use Control (DLUC)	The health of signs needs to be consistently monitored because of their importance; replacement signs need to be available and need to be swapped as efficiently as possible.
Dynamic Shoulder Lane (DShL)	Highway appurtenances are closer to traffic and more subject to damage; additional personnel and equipment might be needed to close lanes and provide adequate work-area protection during maintenance; most incidents may require some action by personnel that involves shoulders, which in turn requires shoulders to remain closed until the incident is cleared, items are removed, or other action is completed; emergency vehicles' use of shoulders to access scenes of accidents and delays in arriving on the scene may have consequent increases in periods of congestion, secondary accidents, and clearance time.
Queue Warning (QW)	When implemented with speed harmonization, QW pictograms and/or flashing lights need to be visible to all vehicles; during normal operation, all the signs are blank; the signage should also be consistent and uniform to clearly indicate congestion ahead.
Dynamic Speed Limit (DSpL)	Strategy greatly increases the amount of field equipment to be maintained at a higher level than before; maintenance considerations for overhead signs have to be factored into the design stage.
Dynamic Merge Control (DMC)	No significant maintenance challenges beyond other lane control issues unless in-pavement lighting is used to support merge applications.

## **5.4 INCIDENT MANAGEMENT**

One major challenge associated with ATM is incident management, particularly if an operational strategy has eliminated the ability for vehicles to seek emergency refuge, such as with DShL. Opening the shoulder to traffic during peak periods means the loss of that shoulder as an emergency refuge area in the event of an incident. Those agencies that have deployed DShL have taken a variety of approaches to addressing the incident management issue in a practical manner. The following sections provide a discussion on the more popular incident management approaches.

### **Incident Management Activities**

The most prevalent approach to incident management on facilities with DShL is an increased use of motorist service patrols on the facility. Those agencies that already have a dedicated service patrol to quickly respond to freeway incidents frequently increase coverage in the impacted area when shoulder use is operational to ensure incident response times are minimized. When combined with a typical unified response approach and significant involvement of a traffic management center, patrols can help minimize the negative impact of the shoulder being open to traffic.



Incident management is particularly important when DShL is in operation. In addition to technologies, agencies can mitigate the loss of the shoulder with such techniques as increased motorist service patrols, staged tow trucks, emergency refuge areas, and closing the shoulder to facilitate access to an incident by emergency response.

Another strategy is to station tow trucks strategically throughout the facility to clear a lane or the shoulder should an incident occur. Furthermore, motorists are encouraged to do everything possible to exit the freeway should they experience vehicle trouble or be involved in a minor crash. Some States even have laws requiring motorists to do so. The installation of accident investigation sites may help encourage this behavior on heavily traveled roadways.

Often, agencies will treat an incident on a shoulder that is operational as a typical lane blocking and handle the incident appropriately. Utilizing DMSs,

dynamic lane control signs, and other techniques, the agency moves traffic out of the shoulder and responds to the incident accordingly. In this case, an emergency response vehicle may access the facility downstream of the incident and travel upstream on the cleared shoulder to reach the blocked shoulder.

One strategy to supplement the incident management activities is to install automatic vehicle detection, CCTV coverage, and/or emergency call boxes in the emergency refuge area to decrease the notification time for an incident.

### **Emergency Refuge Areas**

As noted previously, the primary concern with opening a shoulder to traffic is the lack of an emergency refuge for disabled vehicles. To overcome this problem, an agency may install a small emergency refuge area beside the shoulder. These areas, often spaced at 0.5-mi intervals, provide motorists a place to pull out of the shoulder traffic in the event of an incident.

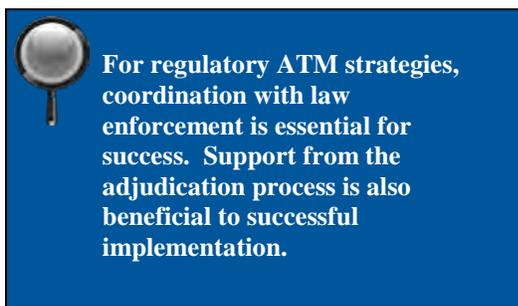
## **5.5 ENFORCEMENT**

It is essential that law enforcement officers know and understand the rationale of the ATM strategy. Enforcement approaches for various ATM strategies may vary significantly, given the variety of supporting policies that exist, and can play a critical role in the success of a deployment.

Engaging law enforcement early in the implementation can help an agency gain understanding, feedback, and buy-in from law enforcement regarding both the ATM strategy and that an acceptable enforcement strategy is important. Ongoing discussions with law enforcement are important during the planning and design phases in order to inform personnel about the purpose and expected operations of the ATM strategy. These discussions can help to address the concerns of law enforcement personnel about how the ATM deployment could impact their job duties, and to accommodate their suggestions and needs into the design where possible. If a new ATM strategy is implemented with supporting new policies or laws, a period of issuing only warnings may be beneficial while the public gains an understanding of the new system.

Enforcement considerations are perhaps of greatest concern with the use of variable speed limits as an ATM strategy. Fully automated enforcement of variable speed limits removes the need for law enforcement personnel to patrol the facility, but public support and the policies needed to support automated speed enforcement on freeways are lacking in the United States.<sup>(84)</sup> Thus, reliance on law enforcement may be a more realistic option, and an increased law enforcement presence and additional procedures for manual enforcement that are more customized for the new ATM strategy may be needed.<sup>(70)</sup>

If an agency does not want to create new enforcement policies for variable speed limits or other ATM strategies, it can take a different approach. In Minnesota, for example, ATM signage displays variable advisory speeds that are not enforceable because variable speed limits are not permitted.<sup>(61,79)</sup> In Washington, even though the variable speed limits are enforceable



**For regulatory ATM strategies, coordination with law enforcement is essential for success. Support from the adjudication process is also beneficial to successful implementation.**

(regulatory), the speed limits are effectively advisory because law enforcement does not actively enforce roadways during building congestion to avoid contributing to the congestion.<sup>(61)</sup> These two cases demonstrate that supporting policy is not always needed to accomplish a similar end, which is to prepare traffic for slower downstream speeds and issue citations for driving at an unsafe speed, regardless of whether the posted speed is regulatory or advisory.

Law enforcement may also choose to adapt and apply existing procedures to reduce confusion and level of effort for education and outreach. For instance, instead of establishing a specific variable speed limit policy, law enforcement could issue citations based on basic speed law, which requires drivers to travel at a reasonable and prudent speed for current conditions regardless of the posted or advisory speed. In other cases, it may be preferable for violations and adjudication procedures to be adjusted. A variable speed limit system should archive the displayed speed limit by location and time of day for supporting evidence in court of the speeding violation.<sup>(70)</sup>

## **5.6 COSTS**

Agencies need to carefully consider costs associated with ATM long before implementation. Costs include the capital investment in not only the infrastructure and technology but also the longer-term operations, maintenance, and upgrade of the system over time. Often, federal funding is available to help pay for ATM strategies and projects, not only for initial construction but also for ongoing costs. Understanding the categories of federal funding in which ATM strategies and projects are undertaken is a first step in matching eligible projects with funding. A variety of federal programs provide opportunities for financing ATM strategies, either alone or in combination with other activities or projects. Other revenue sources at State and local levels may also be available. Program managers should work closely with the agency's programming and financial offices to best understand funding availability and eligibility requirements.

Current federal funding program categories that can provide resources to agencies for ATM are included in Table 20. Included is information on the purpose of the funds and examples of

eligible activities related to a wide variety of TSMO functions and activities that would encompass ATM strategies.

**Table 20. Description of Federal funding programs that may support TSMO activities.<sup>(85)</sup>**

Federal Funding Program	Purpose	Sample of Eligible Activities Related to TSMO
Congestion Mitigation and Air Quality (CMAQ)	To provide a flexible funding source to State and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act. Funding is available to reduce congestion and improve air quality for areas that do not meet the National Ambient Air Quality Standards for ozone, carbon monoxide, or particulate matter (nonattainment areas), as well as former nonattainment areas that are now in compliance (maintenance areas). Construction and operations activities are eligible.	<ul style="list-style-type: none"> <li>Projects that improve traffic flow, including projects to improve signalization; construct HOV lanes; improve intersections; add turning lanes; improve TSMO strategies that mitigate congestion and improve air quality; and implement ITSs and other CMAQ-eligible projects, including projects to improve incident and emergency response or improve mobility, such as real-time traffic, transit, and multimodal traveler information.</li> </ul>
Highway Safety Improvement Program (HSIP)	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads, including non-State-owned public roads and roads on tribal lands. A highway safety improvement project is any strategy, activity, or project on a public road that is consistent with the data-driven Strategic Highway Safety Plan and corrects or improves a hazardous road location or feature or addresses a highway safety problem. Construction and operations activities are eligible.	<ul style="list-style-type: none"> <li>Installation of a priority control system for emergency vehicles at signalized intersections.</li> <li>Collection, analysis, and improvement of safety data.</li> <li>Planning of integrated, interoperable emergency communications equipment, operational activities, or traffic enforcement activities (including police assistance) relating to work zone safety.</li> </ul>
National Highway Performance Program (HSPP)	To support the condition and performance of the National Highway System (NHS), to construct new facilities on the NHS, and to ensure that investments of Federal-aid funds in highway construction are directed to support progress toward the achievement of performance targets established in an asset management plan of a State for the NHS. Construction, maintenance, and operations activities are eligible.	<ul style="list-style-type: none"> <li>Operational improvements of NHS segments, which include capital improvements for installation of traffic surveillance and control equipment; computerized signal systems; motorist information systems; integrated traffic control systems; incident management programs; and transportation demand management facilities, strategies, and programs.</li> <li>Capital and operating costs for traffic and traveler information, monitoring, management, and control facilities and programs.</li> <li>Infrastructure-based ITS capital improvements.</li> </ul>
Statewide Transportation Plan (STP)	To provide flexible funding that may be used by States and localities for projects to preserve and improve the conditions and performance on any Federal-aid highway, bridge, and tunnel project on any public road, pedestrian and bicycle infrastructure, and transit capital projects, including intercity bus terminals. MPOs are given full project selection authority over portions of STP funding (called urban allocation). Construction, maintenance, and operations activities are eligible.	<ul style="list-style-type: none"> <li>Operational improvements for highways.</li> <li>Capital and operating costs for traffic monitoring, management, and control facilities and programs, including advanced truck stop electrification.</li> <li>Infrastructure-based ITS capital improvements.</li> </ul>
Statewide and Metropolitan Planning Funds; State Planning and Research	To establish a cooperative, continuous, and comprehensive framework for making transportation investment decisions in metropolitan areas and on a statewide basis. Planning and research activities only. Establishes funds to be used for a wide variety of State transportation research activities. Only planning and research activities are eligible for funding.	<ul style="list-style-type: none"> <li>State planning funds are used to support federally required long-range and short-range planning functions as well as research carried out at the State level. Metropolitan planning funds may provide for MPO staff support for regional transportation operations coordination, regional operations guideline development, minor studies, and other staff activities to support regional TSMO programs.</li> <li>Research funds can be used to research ATM strategies, deployments, cost-benefit of ATM, etc.</li> </ul>

Federal funding of ATM strategies or projects, as shown in Table 20, can come from a wide range of categories. All of the ATM strategies that are covered in this Guide are eligible for funding since they are directly related to improving travel time reliability, congestion reduction, and safety. To further illustrate the types of projects that could be funded, listed below are some of the types of installations and integrations of intelligent transportation systems (ITS) infrastructure that qualify for Federal funds:

- Regional management and operations program planning.
- Traffic signal control systems.
- Freeway management systems.
- Incident management systems.
- Multimodal traveler information systems.
- Transit management systems.
- Electronic toll collection systems.
- Electronic fare payment systems.
- Railroad grade crossing systems.
- Emergency services.
- National ITS Architecture implementation for metropolitan and rural areas.
- Regional ITS architecture development.

Examples of typical Federal-aid, capital improvement projects that may include eligible operating costs are:

- System integration.
- Telecommunications.
- Reconstruction of buildings or structures that house system components.
- Control/management center (construction) and system hardware and software for the projects.
- Infrastructure-based intelligent transportation system capital improvements to link systems to improve transportation and public safety services.
- Dynamic/variable message signs.
- Traffic signals.

Examples of typical eligible operating cost and expenses for traffic monitoring, management, and control include:

- Labor costs.
- Administrative costs.
- Utility and rent costs.
- Other costs associated with the continuous operation of the above-mentioned facilities and systems.
- System maintenance (activities to assure peak performance).
- Replacement of defective or damaged computer components and other traffic management system hardware (including street-side hardware).<sup>(86)</sup>

As discussed previously, ATM involves hardware, software, and software integration. As such, agencies need to consider the long-term support of that software, including the need to perform periodic upgrades and modifications to control operational scenarios.

Different areas of staff education and training must also be considered, which impacts costs. ATM strategies generally require more complex ITS that may be unfamiliar to agency planners, designers, construction personnel, and transportation management center (TMC) operators. The following are specific training efforts that an agency can consider:

- Peer-to-peer exchanges with other transportation agencies that operate similar ATM deployments, to include document sharing, teleconferences, webinars, or site visits for key agency personnel.
- Structured mentoring and training between experienced operators and junior operators to formally provide junior operators additional learned knowledge regarding complex operations, automated features, and decision support system responses.
- Cross-training to ensure sufficient operations staff are available to facilitate 24/7 operations and to cover in the event of staff absences or departures.
- Safety training for personnel in the field, including maintenance staff, law enforcement, incident response teams, emergency management, and transit drivers, especially if ATM in any way impacts how they conduct their job duties.



***ATM Application:*** WSDOT determined costs of operations and maintenance associated with ATM deployments along I-5, SR 520, and I-90. The estimated budget for maintenance was approximately \$317,000 per year. Maintenance activities involve repairs to malfunctioning signs, maintaining communications networks, and electricity costs. The estimated operations budget was approximately \$184,000. Operations activities include monitoring and controlling ATM devices, reviewing and analyzing system operations to identify and implement refinements, developing and testing software modifications, training operators, planning special events, and coordinating operations with local agencies.

*Active Traffic Management Report, Washington State Department of Transportation, 2013,*  
[https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=ATM%20Report%20January%202013\\_4e6795ed-fd51-41f6-9e9a-9a674cfd61c5.pdf](https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=ATM%20Report%20January%202013_4e6795ed-fd51-41f6-9e9a-9a674cfd61c5.pdf).

MnDOT's Smart Lanes costs are comparable to those for WSDOT. The cost to install the ATM elements including intelligent lane control signals and gantries, speed harmonization, and incident management, was \$22.6 million. Annual operating expenses are \$300,000.

*ITS JPO Costs Database,*  
<http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/E7E3DC47A960631085257CE8005589F2?OpenDocument&Query=CApp>.



## CHAPTER 6. FINAL REMARKS

As discussed throughout this Guide, active traffic management (ATM) encompasses a broad array of nontraditional solutions that agencies can deploy to increase the efficiency of their transportation facilities. By moving from static approaches to more actively and dynamically managed traffic operations, which work to match fluctuating demand and varying conditions, agencies improve efficiency of their infrastructure. As transportation agencies grapple with growing congestion and fewer available funds to add capacity, temporary and permanent ATM strategies have been increasingly deployed in the United States within the last decade. This final chapter discusses the potential impact that connected and automated vehicles may have on the implementation and operation of ATM strategies, and how this Guide might be used by transportation agencies to advance ATM and benefit the traveling public.

### 6.1 THE IMPACT OF CONNECTED AND AUTOMATED VEHICLES ON ATM

Currently, ATM strategies rely on traditional detection and similar field-generated data to run the algorithms that determine when and where they need to be deployed to optimize performance. As the implementation of connected vehicles and automated vehicles increases within the transportation system, the data from connected and automated vehicles may have an impact on these strategies in terms of how, when, where, and which operational strategies are used in a region. Early research indicates that ATM can function within the connected vehicle (CV) environment and that the technology can enhance the delivery of ATM-related messages to travelers.

A demonstration project sponsored by FHWA in 2015 deployed the intelligent network flow optimization (INFLO) prototype system to demonstrate its functionality and performance in an operational traffic environment.<sup>(87)</sup> The intent was to demonstrate the ability to deliver queue warning (QW) and speed harmonization messages to drivers directly into the vehicle using both cellular communications and dedicated short-range communications. The results of the demonstration confirmed that the INFLO system could process data and accommodate the communications bandwidth to support ATM functionality in a CV environment. Furthermore, simulation research assessed the potential impacts of dynamic speed harmonization (i.e., dynamic speed limit [DSpL]) and QW.<sup>(88)</sup> Results of the research found that the INFLO prototype and its application to these ATM strategies had a positive impact on system operations, including the reduction in the magnitudes of shockwaves related to speed changes, which would benefit overall operations and safety.



**Connected and automated vehicles may provide valuable data to be used in ATM system algorithms. Agencies will need to explore how they might interact with these vehicles to convey dynamic roadway information and influence driver behavior.**

With respect to the future of CVs and automated vehicles (AVs) and ATM strategies, transportation professionals will need to assess issues such as how the format and nature of data may impact algorithms, which data can be used to implement strategies, and which computing capabilities may be needed within transportation management centers (TMCs) to support online analysis and prediction capabilities for implementation. Agencies will also need to explore how they might interact directly

with connected and automated vehicles, particularly with respect to influencing ATM strategy use and driver compliance, as well as methods for providing in-vehicle information regarding operational ATM strategies and how those methods impact TMC operations and infrastructure needs. These specific topics are beyond the scope of this guidebook, but agencies need to be aware that these issues are on the horizon.

## **6.2 USE OF GUIDE BY TRANSPORTATION AGENCIES**

This Guide provides an overview of ATM strategies along with information related to their characteristics and when they might be appropriate to address regional goals and objectives. It describes the stepwise approach to accomplishing the implementation and operation of ATM strategies through the application of the systems engineering process; comprehensive planning; and organizational considerations, capabilities, and design considerations.

Agencies interested in implementing ATM in their region, as well as those that have implemented ATM and are interested in guidance on operating their ATM systems and strategies more effectively, can both benefit from this Guide. Agencies following the Guide can ensure that ATM projects deployed and operated in their jurisdictions help meet the regional goals and objectives related to safety and mobility. Additionally, they can incorporate ATM into their overall TSMO program to help optimize the performance of their system in a cost-effective and efficient manner. System users can benefit from ATM in numerous ways when strategies are properly implemented and operated by agencies. In general, travelers can expect such benefits as improved travel times, reduced travel delay, improved travel time reliability, reduced crashes and crash severity, and improved personal mobility and safety. Through communication, outreach, and efficient operations, agencies can ensure that travelers gain an understanding of the travel options available in a corridor and the potential ATM has for the entire region.

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