Task 1 Literature Review

NCHRP Project 03-114

Planning and Evaluating Active Traffic Management Strategies

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CHAPTER 1 – DOCUMENT OBJECTIVE

The objective of the literature review task is to review existing literature on the planning, design, operations, maintenance, evaluation, and monitoring of Active Traffic Management (ATM) strategies as well as to conduct an assessment of current analysis tools that factor into the planning, evaluation, and implementation of ATM strategies, focusing for the most part on freeway applications. The team developed a conceptual framework utilizing a spreadsheet to organize the information collected during the literature review and to support the analysis of collected information in subsequent tasks. In addition, this task included consideration of key reference documents—such as the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book* (*1*), the *Manual on Uniform Traffic Control Devices* (*2*), and the AASHTO *Highway Safety Manual* (*3*) among numerous others—to identify how the developed guidelines will fit (and should fit) with respect to these key documents.

In the review of the literature, it was clear that the description and assessment of ATM strategies deployed both overseas and in the United States has been well documented by other researchers and transportation professionals. Rather than include this detailed information in this review, the research team presented that information as well as other findings within the context of the global view of ATM. The team focused on the overall approach and individual steps that an agency would need to undertake to successfully plan, design, and implement ATM and maintain deployed strategies into the future. Specifically, the team targeted the organizational and planning phases that are necessary to support ATM as well as highlighted other steps in the project development, deployment, implementation, and operational processes that can support ATM. Whenever appropriate, the team brought attention to existing documents, resources, policies, and procedures that easily lend themselves to ATM strategies, many of which are familiar to transportation professionals across the country.

Researchers structured the literature review according to the proposed outline for the guidance document and with panel input received from their review of the project proposal and the Amplified Research Plan. Particular emphasis was placed on the topic areas identified as potential gaps, but the framework will be flexible to accommodate gaps as they emerge. The initial information collected through the literature review supports the ATM strategy assessment in Task 2, the white paper on institutional issues in Task 3, and will continue to support the research activities in Task 7 as the framework is populated with information over the course of the work effort.

CHAPTER 2 – ATM OVERVIEW

2.1 Overview

Persistent congestion and safety concerns continue to challenge transportation professionals in the United States and around the world. Both recurring and non-recurring congestion continue to increase, leading to longer delays, higher fuel consumption, and more related crashes. Recognizing the inability to quickly and cost-effectively add capacity and enhance safety to their systems, agencies have relied on systems operations and maintenance strategies to mitigate their mobility and reliability impacts. Over the past two decades, there have been several success stories and advances in freeway management, arterial management and regional coordination. Today, most agencies have levels of detection and operational capability that would have been unimaginable two decades ago, which can be leveraged for a wide variety of approaches to improve mobility and safety. However, changing travel patterns, growing demand, traveler behavior changes and increasing expectations are all requiring agencies to ask the question of "what is the next generation of systems operations and management strategies that can address their new challenges?" ATM has emerged in the evolutionary advancement of systems management and operational strategies bringing together operational strategies and a management philosophy to manage highway network conditions to improve efficiency, safety, and reduce system congestion.

2.2 Operational Strategies

ATM is the ability to dynamically and proactively manage recurrent and non-recurrent congestion on an entire facility based on real-time or pre-planned traffic conditions. Focusing on trip reliability, ATM strategies maximize the effectiveness and efficiency of a facility while increasing throughput and enhancing safety. ATM strategies rely on the use of integrated systems with new technology, including comprehensive sensor systems, real-time data collection and analysis, and automated dynamic deployment to optimize system performance quickly and without the delay that occurs when operators must deploy operational strategies manually. When various ATM strategies are implemented in combination, they can work to fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. One of the benefits of these new systems is that they allow for the "dynamic" or real-time automated operation of traffic management strategies that more quickly respond to

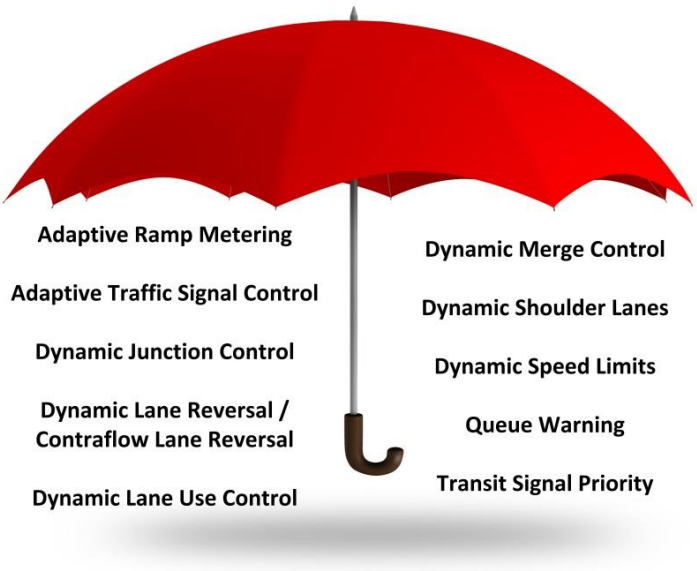

Figure 1. ATM Operational Strategies.

changing conditions as they occur. As shown in Figure 1, these strategies include but are not limited to adaptive ramp metering, adaptive traffic signal control, dynamic junction control, dynamic lane reversal / contraflow lane reversal, dynamic lane use control, dynamic merge control, dynamic shoulder lanes, dynamic speed limits, queue warning, and transit signal priority. Table 1 provides a brief definition of each ATM operational strategy assessed for the purposes of this project.

Table 1. Active Traffic Management Strategies (*4*).

ATM Operational Strategy	Description
Adaptive Ramp Metering	The deployment of traffic signal(s) on ramps to dynamically control the rate at which vehicles enter a freeway facility. Can utilize traffic responsive or adaptive algorithms, dynamic bottleneck identification, automated incident detection, and integration with adjacent arterial traffic signal operations.
Adaptive Traffic Signal Control	The continuous monitoring of arterial traffic conditions and queuing at intersections and the dynamic adjustment of signal timing to optimize one or more operational objectives (such as minimize overall delays).
Dynamic Junction Control	Dynamically allocating lane access on mainline and ramp lanes in interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day.
Dynamic Lane Reversal / Contraflow Lane Reversal	The reversal of lanes to dynamically allocate the capacity of congested roads, thereby allowing capacity to better match traffic demand throughout the day.
Dynamic Lane Use Control	Dynamically 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.
Dynamic Merge Control	Dynamically managing the entry of vehicles into merge areas with a series of advisory messages (e.g., displayed on a dynamic message sign [DMS] or lane control sign) approaching the merge point that prepare motorists for an upcoming merge and encouraging or directing a consistent merging behavior. This merge control is deployed on the main lanes, such as at a lane closure, rather than at a ramp or junction.
Dynamic Shoulder Lanes	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 non-peak periods.
Dynamic Speed Limits	The adjustment of speed limits based on real-time traffic, roadway, and/or weather conditions. Dynamic speed limits can either be enforceable (regulatory) speed limits or recommended speed advisories, and they can be applied to an entire roadway segment or individual lanes. These are also known as speed harmonization and variable speed limits.
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.
Transit Signal Priority	The management of traffic signals by using sensors or probe vehicle technology to detect when a bus nears a signal controlled intersection, turning the traffic signals to green sooner or extending the green phase, thereby allowing the bus to pass through more quickly.

It is important to note that high-occupancy vehicle (HOV) lanes, high-occupancy/toll (HOT) lanes, bus only lanes, and other managed lanes strategies are not typically included under the ATM umbrella of strategies. However, they do utilize similar technologies to improve travel time reliability and reduction congestion. These strategies are not specifically addressed in this document as a separate effort (NCHRP Project 15-59) is developing similar guidance specifically for managed lanes.

ATM focuses on active management of capacity and the direct interaction with drivers to encourage them to make tactical driving decisions (*5*). Agencies can move along an active management continuum (shown in Figure 2 with dynamic shoulder use as an example) from reacting to changing conditions to anticipating what will happen and actively managing the system accordingly. As highlighted by FHWA, this progress along the continuum represents a natural evolution in an agency's ability to provide and the public's acceptance of active management.

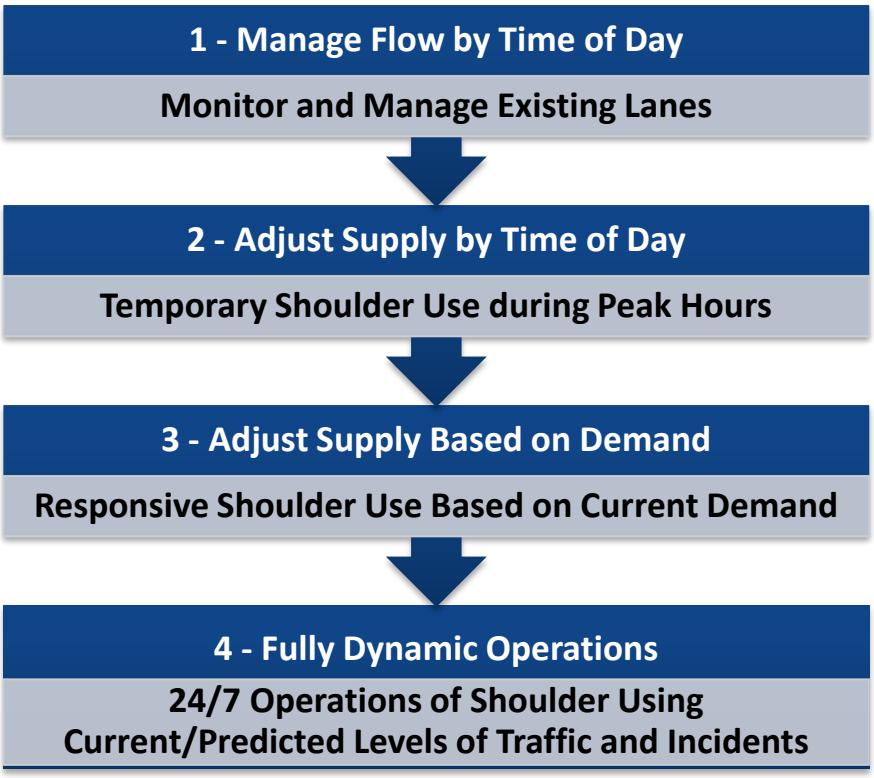

Figure 2. Dynamic Shoulder Use Active Management Continuum (*5*).

To reach the highest level of fully dynamic operations, an agency needs a combination of technologies, resources, policies, procedures, and public acceptance. A similar continuum can be mapped for each of the strategies under ATM to help chart an agencies progress.

2.3 Reported Impacts, Level of Use in the U.S.

The deployment of ATM projects in the United States has been limited to select locations and only a few applications. The projects currently in operation are provided in Table 2. Note that the level of operations across these projects varies across the active management continuum. While in most cases these are not just time-of-day, there are only a few examples of truly dynamic operations.

Table 2. Domestic Active Traffic Management Deployments (Battelle, *6, 7, 9*).

ATM Operational Strategy	Locations (States with Deployments)
Adaptive Ramp Metering	California, Minnesota, New York, Oregon, Washington
Adaptive Traffic Signal Control	Arizona, Arkansas, California, Delaware, Florida, Georgia, Michigan, Minnesota, North Carolina, Oregon, Texas, Utah, Virginia, Washington
Dynamic Junction Control	California, Washington
Dynamic Lane Reversal / Contraflow Lane Reversal	Arterial: California, Kentucky, Louisiana, Maryland, New Jersey, North Carolina, Washington, D.C.
Dynamic Lane Use Control	Delaware, Washington
Dynamic Merge Control	California
Dynamic Shoulder Lanes	Minnesota
Dynamic Speed Limits	Alabama, Arizona, Colorado, Delaware, Florida, Maine, Michigan, Missouri, Nevada, New Hampshire, New Jersey, New Mexico, Oregon, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, Wyoming
Queue Warning	Oregon
Transit Signal Priority	Arizona, California, Colorado, Delaware, Florida, Georgia, Illinois, Indiana, Kansas, Maryland, Minnesota, Missouri, Nevada, New Jersey, New York, North Carolina, Oregon, Pennsylvania, South Carolina, Texas, Utah, Virginia, Washington, Washington, D.C, West Virginia, Wisconsin

Overall, the more predominant ATM strategies deployed to date in the United States are adaptive ramp metering, adaptive traffic signal control, dynamic speed limits, and dynamic lane use control. Experience has been positive overall, and these strategies demonstrate that reduction in congestion and improvement in travel time reliability can be achieved. Additionally, some of these strategies are deployed in a work zone application to improve operations impacted by construction.

Domestically, adaptive ramp metering has shown both safety and mobility benefits when compared with no ramp metering, including drops in collisions in Portland, OR (43% - peak period), Seattle, WA (39% - collision rate), Minneapolis, MN (24% - peak period), and Long Island, NY (15% - collision rate) (*6*). Average travel speeds and travel times have also improved in these regions. Adaptive signal control has shown a reduction in stops at traffic signals (10-41%) and a reduction in delay (5-42%) across the country depending on the location and

application (*8*). Additionally, system operators have found that using adaptive traffic signal control delays the onset of oversaturation and reduce the duration of delay times (*9*).

Transit signal priority has shown benefits in various locations around the country. Examples include a reduction of signal delay (40%) in Tacoma, WA by deploying transit signal priority and signal optimization; an improvement in travel time (10%) and travel time reliability (19%) in Portland, OR; a reduction in bus travel times (25%) in Los Angeles, CA; and a reduction in average running time for transit vehicles (15%) in Chicago (*6*).

In Seattle, WA, the original concept of operations for the ATM deployment included specific user-oriented operational descriptions of each strategy identified for implementation (*10*). The plan also included an assessment of a variety of operational scenarios for ATM, including normal operations, incident situations, work zone/maintenance of traffic, queue spillback, and traveler information. Results of the variable speed limits and dynamic lane assignments deployed in Seattle along I-5 indicate that total crashes have decreased by 11% along the facility (*11*).

In Minneapolis, MN, intelligent lane control signals (ILCS) and a priced dynamic shoulder lane (PDSL) were implemented along with other regional strategies. Overall, use of the lanes increased after conversion from high-occupancy vehicle (HOV) lanes to high-occupancy/toll (HOT) lanes and opening a priced dynamic shoulder lane (PDSL) at a bottleneck location to ease congestion (*12*). It is important to note that the PDSL is only operational in one direction. The ILCS deployed with additional traffic control devices (TCDs) were successfully deployed and have enhanced operation of I-35W South. There were no negative impacts on safety from the projects. Law enforcement and first responders indicated that the intelligent lane control signals (ILCS) helped slow down traffic and move it out of blocked lanes when responding to an incident. Anecdotally, they feel that the signs help their ability to respond to crashes and maintain traffic flow during incidents (*12*).

2.4 International Applications and Relationship to U.S. Deployments

A 2006 International Scan Report first highlighted the potential for ATM to work to address congestion challenges in the U.S. (*13*). This review of European best practices identified commonalities between Europe and the U.S. in terms of challenges and issues facing the countries. These challenges included an increase in travel demand, a growth in congestion, a commitment to safety, and a shift in agency culture toward active management and system operation that focus on the customer, the willingness to use innovative strategies to address congestion, and the reality of limited resources to address all of these challenges (*13*).

Additionally, the scan team made the following observations related to the European approach to congestion management programs, policies, and experiences that resonate with transportation professionals in the U.S. and can guide future activities in this arena:

- Active management is essential to the European approach to congestion management, building on advancements in technology and traffic management experience to make the best use of existing capacity, and providing additional capacity during periods of congestion or incidents.

- The European mobility policy has the road user/customer as a focal point, and congestion management strategies center on the need to ensure travel time reliability for all trips, regardless of the time of day.
- Transportation and traffic management operations are priorities in the planning, programming, and funding processes and are seen as critical needs to realize the benefits of investment in the transportation infrastructure and deployed systems for congestion management.
- European 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. For example, The Netherlands utilizes a *Sustainable Traffic Management Handbook* (*14*), which is a guide for regional and local
- road authorities to determine how best to address accessibility problems, and the *Regional Traffic Management Explorer* ([15], which is a sketch planning and modeling tool that facilitates sustainable traffic management by quantifying benefits of traffic management strategies
- Innovative financing strategies, such as public-private partnerships are emerging overseas to solve the ever-growing funding shortfall.
- European agencies recognize that providing consistent messages to roadway users to reduce the impact of those travelers on congestion is essential.
- European agencies are considering tolling and pricing as potential long-term solutions to transportation finance shortfalls and congestion management (*13*).
- European agencies typically include automated enforcement tools when implementing ATM strategies, which is not commonly used in the U.S.

The realized benefits in the European application of ATM vary depending on location and strategies implemented. The following represent a highlight of benefits measured across the spectrum of deployments:

- Increase in average throughput for congested periods (3 to 7 percent);
- Increase in overall capacity (3 to 22 percent);
- Decrease in primary incidents (3 to 30 percent);
- Decrease in secondary incidents (40 to 50 percent);
- Overall harmonization of speeds during congested periods;
- Decreased headways and more uniform driver behavior;
- Increase in trip reliability; and
- The ability to delay the onset of freeway breakdown (*13*).

An Australian assessment of benefits of variable speed limits in European deployments identified a range of benefits, including safety, environmental, capacity, and traffic flow (*16*). The high level benefits are presented in Table 3.

Table 3. Benefits Reported for European VSL Deployments (Adapted from *16*).

Operational Criteria	Summary of VSL Benefits
Safety	Between 10% to 50% reduction in accidents.
Environmental	Between 2% to 10% emissions reduction together with fuel and noise reductions.
Capacity and Traffic Flow	• VSL can help stabilize traffic flow. • Increased flow is generally slight (typically up to 5%) and some studies are inconclusive. • Can reduce the potential for flow breakdown or delay flow breakdown. • Generally shifts the critical occupancy to higher values. The timing of VSL activation is critical. Activation too early can adversely affect efficiency (travel time). Desirably activate when critical occupancy is reached.

Overall, the international experience with ATM has provided direction for the development of ATM within the U.S. (*17*). Domestic agencies have seen similarities and commonalities in challenges and approaches that can be adapted to fit the needs of the American traveler. Table 4 highlights key influences of the European ATM approach and how the U.S. is adapting ATM to meet its needs and address its challenges.

Table 4. Influence of European ATM on U.S. Deployments (Adapted from *17*).

Influences from Europe	Adaptation to the U.S. Environment
Active management as a tactical philosophy.	U.S. agencies see the value of being more proactive and dynamic in overall operations.
Use of ATM strategies to manage motorways.	Several ATM strategies are of interest and have been tried in isolation or as part of pilots in the U.S.
Moving toward a performance- or risk-based approach to design for ATM.	U.S. agencies can adapt ATM strategies to address their challenges being faced in design, operations, maintenance, and enforcement.

A 12-month evaluation of the ATM application of 4-lane variable mandatory speed limits on the M42 showed an improvement in capacity even as facility traffic growth kept pace with national traffic growth (*18*). In the first 12 months of operation, the application delivered the following:

- consistent, measurable benefits that are supported by user perception;
- reduces average trip times during recurrent congestion;
- reduction in trip variability;
- reduced occurrence of severe congestion;
- high compliance with speed limits;
- smoothed traffic operation and potential reduction in driver's workload;
- minor reduction in noise;
- reduction in vehicle emissions; and
- speeds consistent across all lanes.

A 3-year safety study of the same project indicated that the number of personal injury accidents (PIA) has decreased, and the number of people being fatally or seriously injured has seen a

notable reduction (*19*). It is important to note that one of the most important aspects of the European successes with speed-related strategies is the use of automated speed enforcement, which clearly impacts compliance and the overall improvement of operations.

2.5 Lessons Learned

The lessons learned by transportation agencies across the globe related to ATM applications are varied and cover a multitude of issues related to the operational approach. From the international perspective, a 2011 international scan identified the key lessons from which other agencies can learn, offered in Table 5 (*20*).

On the domestic front, agencies have identified numerous attributes that can help spell success for a project (*21*). For example, ATM requires that agencies focus on improving the driver or customer's experience in traffic. Effective engagement at every stage of project planning, development, and implementation is essential to implementing ATM on a broad basis. Transparent information about the project, its likely effects, its benefits, and consistent messages from all levels of the organization as the project is discussed with decision-makers, partners, and the public are essential to selling the concept, especially when they resonate with the greater population and target issues that are of global concern, such as health and safety (*21*). As a part of that focus, educating customers and policy makers about the benefits of ATM is needed to enlist support for these types of strategies being funded either as part of construction projects or as tailored ATM projects. The agency must also be willing to change project parameters in reaction to public comments.

Once the project is operating, real-time, accurate communications gives them actionable information that improves their ability to make better decisions about their travel routes and times of travel. Furthermore, technological capability is only one of the essential factors to ATM success; there are other important elements for managing the transportation system. ATM approaches may require changes in some policies and regulations; ATM often pushes the boundaries of operations, partnerships, and opportunities. Ensuring that laws are flexible enough to accommodate them and the myriad ways these strategies are planned, developed, financed, and implemented helps move the state of the practice forward (*21*).

Table 5. Lessons Learned from European ATM Deployments (Adapted from *20*).

Topic	Key Lessons Learned
Corridors in Progression	There is an evolutionary path in the appropriate design and operational strategies of individual freeway corridors. As traffic and congestion levels increase in the corridor, different approaches and management strategies should be considered to accommodate changing needs, risks, and appropriate tradeoffs.
Effective Use of Space	Several European countries dynamically manage the freeway space available. For example, they may use the paved shoulder space for traffic movement during peak travel periods and as a typical shoulder during off-peak travel times.
Importance of Collaborative Design Process	Actively and effectively managing roadways requires coordination across disciplines, and collaboration among planning, operations, and design is imperative. In England the Highways Agency uses the operational regimes to determine design criteria rather than adhere strictly to design standards.
Operating Costs	Stable, consistent, and ongoing funding for operations and maintenance is a critical component of the managed motorway concept.
Capital Costs	The M42 in England was designed conservatively on spacing of gantries, emergency refuge areas, and ancillary equipment. After monitoring operations and results, the English are making incremental changes based on data that demonstrate they can maintain or improve flow and safety while increasing the spacing between gantries and refuge areas and reducing lighting to lower costs.
Complementary Treatments	Many applications are complementary. For example, line control (or variable speed limits) and shoulder running installations result in complementary and synergistic operations and benefits.
Benefits	The countries visited report that managed motorways result in improved safety, reliability, and air quality benefits and can be provided at less cost than traditional capacity expansion.
Public Perception	The countries recognize that a proposed operational scheme will be successful only if the public perceives it to be successful (despite what data may say).
Procurement	Construction methods are evolving as a result of the high degree of technology required for managed motorway concepts. England has used innovative construction methods and offsite locations to assemble managed motorway gantries, signs, and ancillary equipment and realized efficiencies in buying equipment.
Sign Messages	England, Germany, and the Netherlands have found that it is important to test new sign messages with users before implementation.

CHAPTER 3 – ORGANIZING FOR ATM

3.1 Overview

The extent to which an agency is successful in implementing ATM strategies is contingent upon a variety of factors. In addition to legislative changes that may need to be implemented, institutional and organizational changes in policies, processes, structure, and resources should be examined to ensure success in adapting to a more active operations role for managing highway networks. Specifically, institutional capabilities and existing policy and laws must be examined, and considerations for outreach and public involvement need to be made.

3.2 Required Institutional Capability for ATM

ATM is a significantly more integrated approach to managing systems in real time and rests on a foundation of a robust systems management. A more formal, programmatic approach to operating facilities for improved travel time reliability and reductions in congestion is needed. This is a significant shift from the historic build and maintain mission of many organizations. Aggressively and proactively managing the systems is a new mission for many agencies. An agency with a very low level of capability in systems management and operations is probably not ready for ATM deployment, lacking the adequate business process, supporting technology, and the required workforce.

The notion of institutional Capability Maturity Model (CMM) has gained significant buy-in from the transportation community due to the results of the SHRP2 Reliability program (*22*) and subsequent efforts by AASHTO and FHWA. SHRP2 L01 (*23*) developed a guide to help transportation agency managers conduct self-assessments of an organization's development and guide its development of a more formal systems operations and management program that would include the adoption of ATM strategies. The assessment, development, and integration of key business processes to improve travel time reliability are components of the CMM tools and SHRP2 L06 (*24*) created some institutional architectures and a version of the CMM for highway operations. The CMM developed for SHRP2 was then refined and adopted as part of the AASHTO System Operations & Management (SO&M) Guidance (*25*).

Broadly, these tools aim to address the non-technological challenges towards creating a Transportation System Management and Operations (TSM&O) program. Moving transportation system management and operations activities and projects into the mainstream agency practice is a key 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 identified in the research move from level 1 (Performed) of having some programs, mostly information and champion-driven, to level 2 (Managed) with some developed processes, to level 3 (Integrated) where performance is measured and programs are formally budgeted, to level 4 (Optimized) where formal partnerships exist and performance-based improvements are the norm.

Six dimensions of institutional capability were identified as part of the SHRP2 and AASHTO efforts to help identify their current state of their operations programs and to provide guidance for improved levels of program effectiveness. These include – business processes, systems and

technology, performance measurement, culture, organization & workforce, and collaboration. These dimensions represent the key areas where an organization's capability will have a measurable impact on their ability to be operations-focused.

From an ATM perspective, these dimensions serve as a good organizing element for the organization. While assessment of the capability levels across the dimensions for an individual agency is relatively straightforward, defining these same levels for the entire nation is more challenging due to the many variations among the various levels of operating agencies. Thus, while the observations of this section are generally applicable, exceptions to the rule at an agency level are to be expected, with significant progress in some dimensions and less in others.

- **Business Process** – Business processes that drive the scoping, planning, evaluation, and budgeting processes are key elements to examine. Evidenced from the various statewide operations plans and ITS strategic plans, the role of operations strategies is increasingly becoming clear. With the emphasis on planning for operations, leading State DOTs are developing robust practices to include operations strategies in planning, programming and prioritization. The State Operations Survey conducted by ITS America for the Office of Operations (*26*), albeit inconclusive, provides some indication of the national capability in this dimension. Of the 24 states that responded to the survey, 77 percent (18 states) consider operational strategies during the development of the State Transportation Plan (STP) / Transportation Improvement Program (TIP), 62 percent consider operational strategies during the identification of alternative improvement strategies, and 38 percent consider operational strategies during visioning and goal setting. However, it is unclear on what operational strategies are considered by agencies and at what level of dynamism. This is particularly important given the broad range of operational strategies and the as-yet unproven nature of ATM strategies. The survey points to the need to address these business processes for greater consideration and adoption of ATM strategies. The survey reports that a variety of operational strategies implemented in most States include traffic signals operating on a closed loop or central system, travel time posting on DMS, Traffic Incident Management, and road weather information systems. About half of the States have adopted real-time traffic adaptive control signals, lane usage controls (HOV lanes), HOV lanes, and electronic tolling.
- **Systems and Technology** – Nationally, excellent understanding of the systems approach, the use of architectures and standardization at the operations agency personnel and management level exists, especially for ITS projects that are federally funded (where the use of systems engineering is required). Some strategies have become fairly standard and commonplace with available expertise, technology and systems such as traffic signal coordination, road weather information systems, the display of travel times on DMS, and traffic incident management. However, the on-going maintenance, management, and replacement/upgrading of systems is a challenge to most organizations. This dimension of assessment looks at how agencies are responding to the upgrading, replacement, and integration of systems in the world of rapidly changing technologies.
- **Performance Measurement** – How well an agency performs and the public support for the agency is related to the public's perception of the agency's performance. Federal legislation and directives are pointing towards an increased use of performance-based management. Level of Service continues to be used by a high percentage of agencies in

spite of research reports (*27*) and training that recommends the use of other measures. Although travel time and travel time reliability are of great interest to the public, their use is primarily limited to freeway facilities with reliability measures just starting to take on increased role due to the SHRP2 initiatives. However, efforts to standardize them are still in early stages. From an ATM standpoint, the use of performance measures is still at a low level of acceptance and use. While some measures may be reported, they are not widely utilized on an operational basis to improve agency performance, especially for near-term impacts of operational strategies. Importantly, types of performance of ATM strategies need to be better understood. More information is provided in other sections of this document.

- **Culture** – Most agencies derive their culture from their history as public works agencies, building and maintain highways, streets and roads. This 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. Several changes in culture of how an agency views its operations programs and activities have been the result of crises from weather events or major traffic crashes that call for new ways of delivering services. Currently, existing deployments are certainly supported by the respective agency decision-makers but constant engagement and communication is necessary to promote ATM as a core operating philosophy. Literature reviews on this dimension are scant with regard to transportation agencies.
- **Organization and Workforce** – The State of the Operations survey referenced earlier indicated average or above average rating of the quality of staff for operations, noting an expressed difficulty in attracting and retaining quality employees and their need for training on subjects such as lessons learned from other agencies for the deployment of operational strategies, costs/benefits of operational strategies, technology. Very little documentation exists on workforce issues for ATM (*11*, *12*, *13*).
- **Collaboration** – In recent years, this has been an area of emphasis and increasing capability in operations. 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. While agencies recognize the importance of collaboration, especially at an operational and implementation level, formal relationships are infrequent and hard to document. The popularity and potential of approaches like Integrated Corridor Management –ICM (*28*) are increasing the sophistication and formality of collaboration approaches.

3.3 Policy and Legislative Considerations

Laws, regulations, and policies on the local, state and Federal levels should be reviewed to determine if changes or additional policies are needed (*29*, *6*). This review needs to also consider whether the planned ATM strategies fit within the existing legal and policy framework for the local area (*29*). There is also a need to assess the feasibility of legal authority to enforce ATM strategies and whether there is support from law enforcement and legislative parties to enforce the ATM techniques (*6*). For example, issues could arise with the legality of variable speed limits and any associated requirements, automated enforcement, and the use of shoulders as a travel lane.

It should also be noted that ATM strategies are part of the broader metropolitan transportation planning process (*6*). The current federal surface transportation legislation (MAP-21) requires MPOs, with State and public transportation operators, to develop long-range transportation plans (MTP) and transportation improvement programs (TIP) through a performance-driven, outcome-based approach (*6*,*30*).

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" (*6*). 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" (*6*).

A number of states allow some form of dynamic shoulder use during congested periods (*31*,*32*). However, policies vary by state and facility regarding the vehicle types, allowable design exceptions, and other restrictions imposed on dynamic shoulder operations (*31*, *32*).

In some areas, policies regarding a minimum posted speed limit may restrict the enforceable variable speed limits that can be posted (*21*). In Missouri, the variable speed limit signs are blank when speeds are below 40 mph, while in Minnesota and Washington the ATM signs may also post variable speeds of 35 or 30 mph (*21*).

Additionally, ATM signage and procedures, particularly for dynamic lane assignment and possibly dynamic speed limits, as used in Europe and in the initial ATM implementations in the U.S. are not currently described in the MUTCD (*33*). A request to FHWA for experimental approval is necessary. Figure 3 shows signage displays developed and used by Minnesota and Washington that are not part of the MUTCD (*6*, *33*).

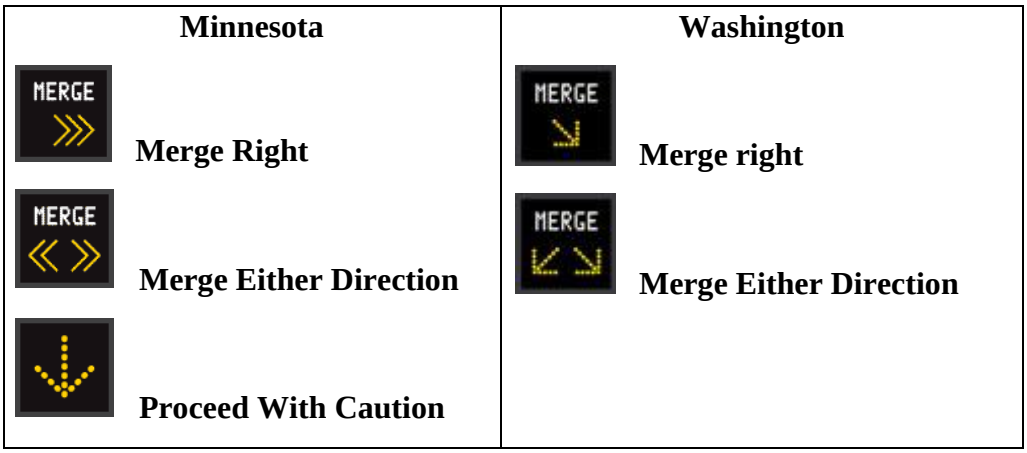

Figure 3. Experimental ATM Sign Displays.

3.3.1 Enforcement Approaches

A major enforcement challenge for ATM strategies is making sure that law officers know and understand the rationale of the strategy. The enforcement approaches from various ATM strategies may vary significantly. One example, often of primary concern for enforcement, is the

use of VSL as an ATM strategy. For VSL applications, the sign display or legal speed limit in real time, and when the last change to the speed display was made (i.e., officers generally will not issue a citation until the new speed limit has been in place for a number of minutes) (*6*). Also, there is a difference between fully automated speed enforcement of dynamic speed limits and the enforcement of dynamic speed limits, which requires law enforcement personnel patrolling the facility.

Given the variety of supporting policies that exist, ATM strategies may be deployed in alternate ways. Automated speed enforcement is deployed in conjunction with variable speed limits in Europe and Australia (*6*, *34*, *35*), but policies to support automated speed enforcement on freeways are lacking in the United States (*6*, *36*). As shown in Figure 4 and in Table 6, 140 communities in 15 states have automated speed enforcement as of September 2014, but in many instances this is limited to school zones, work zones, or residential areas and would not be compatible with ATM applications (*36*). Variable speed limit deployments in the United States have not used automated enforcement, but would have to consider privacy concerns. Without automated enforcement, an increased law enforcement presence may be warranted, as well as additional procedures for manual enforcement (*6*). Locations where law enforcement can be safely stationed to view compliance and where vehicles can be safely pulled over without adversely affecting traffic operations should be identified in these cases (and including any additional costs for these areas in the preliminary cost estimate (*6*, *31*).

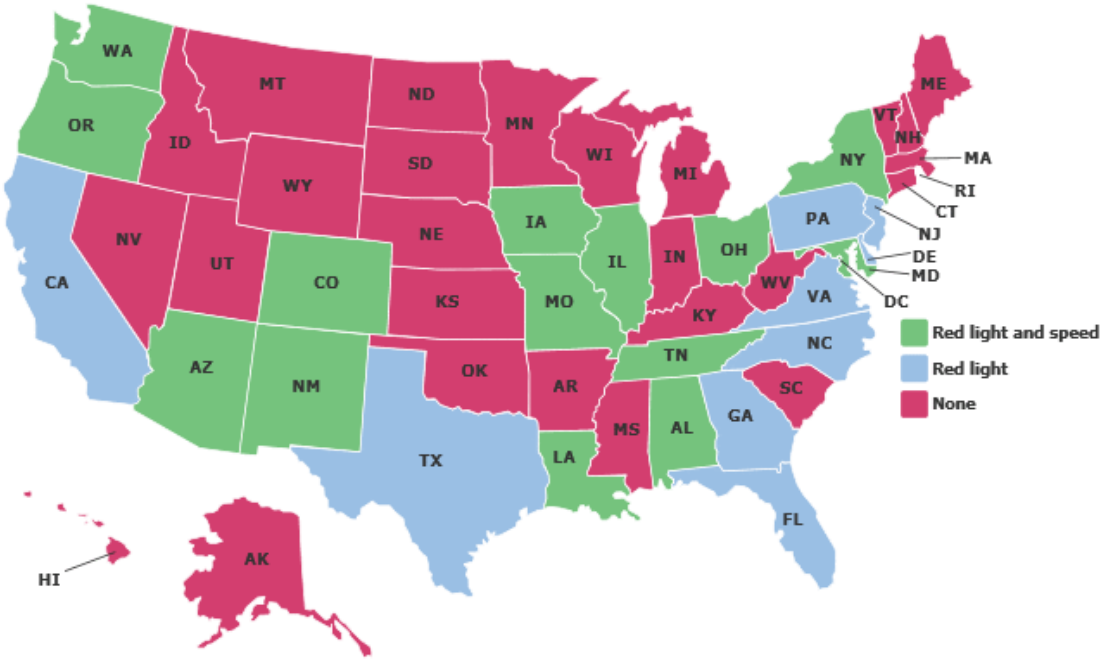

Figure 4. States with Automated Enforcement Policies (*36*).

Table 6. Communities with Automated Speed Enforcement (*36*).*

State	Communities
Alabama	Montgomery
Arizona	Chandler, El Mirage, Eloy, Globe, Mesa, Paradise Valley, Phoenix, Scottsdale, Show Low, Sierra Vista, Star Valley, Superior, Tempe, Tucson
Colorado	Boulder, Denver, Fort Collins
District of Columbia	District of Columbia
Illinois	Chicago, Statewide work zones
Iowa	Cedar Rapids, Davenport, Des Moines, Fort Dodge, Muscatine, Polk County, Sioux City, Windsor Heights
Louisiana	Baker, Gretna, Lafayette, New Orleans, Westwego, Zachary
Maryland	Annapolis, Baltimore, Baltimore County, Berwyn Heights, Bowie, Brentwood, Cambridge, Capitol Heights, Catonsville, Centreville, Charles County, Chesapeake Beach, Chestertown, Cheverly, Chevy Chase, College Park, Delmar, Denton, District Heights, Easton, Fairmount Heights, Forest Heights, Frederick, Fruitland, Gaithersburg, Glenarden, Greenbelt, Hagerstown, Hancock, Howard County, Hyattsville, Landover Hills, Laurel, Montgomery County, Morningside, Mount Ranier, New Carrollton, Prince George's County, Princess Anne, Rockville, Salisbury, Seat Pleasant, Silver Spring, Smithsburg, Snow Hill, Statewide work zones, Takoma Park, Wicomico County
Missouri	Berkeley, Calverton Park, Cool Valley, Country Club Hills, St. Ann, St. Louis County, State roads, Sugar Creek, Vinita Park
New Mexico	Las Cruces, Rio Rancho, Santa Fe
New York	Nassau County, New York City
Ohio	Akron, Ashtabula, Cleveland, Columbus, Dayton, East Cleveland, Hamilton, Newburgh Heights, Northwood, Parma, Toledo, Trotwood, Village of Lucas, West Carrollton
Oregon	Beaverton, Medford, Milwaukie, Portland, Statewide work zones
Tennessee	Bluff City, Bradford, Chattanooga, Graysville, Huntingdon, Jackson, Jonesborough, Madisonville, McKenzie, Mount Carmel, Red Bank, Selmer
Washington	Auburn, Burien, Federal Way, Issaquah, Kent, Lake Forest Park, Longview, Lynnwood, Renton, Seattle, Statewide work zones, Tacoma

* This table is current as of September 2014. The information listed is likely to change over time.

In Minnesota, ATM signage displays variable advisory speeds that are not enforceable because variable speed limits are not permitted (*37*, *33*). In Washington, even though the variable speed limits are enforceable, the speed limits are effectively advisory because law enforcement does not actively enforce an area with building congestion so that their presence does not contribute to the congestion (*33*). 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 issuing citations for driving at an unsafe speed, regardless of the posted or advisory speed.

3.3.2 Violations and Adjudication

While violations and adjudication procedures for ATM strategies can be similar for regular operations, in certain cases, they may need to be adjusted. For example, a variable speed limit system should archive the displayed speed limit by location and time of day for supporting evidence in the courts of the speeding violation (*6*). As noted above, in lieu of specific policy for variable speed limits, it may be possible for law enforcement to issue citations for driving at an unsafe speed, regardless of the posted or advisory speed. In Virginia, where hard shoulder running is permitted at certain times, local county courts are receptive to the enforcement efforts of law enforcement with respect to the illegal use of shoulders (*21*).

3.3.3 Operational Changes

Some ATM strategies may require operational changes within the agency. Because it is very apparent to drivers when ATM signage is not accurate, there is an increased responsibility on operators to ensure accuracy and retain motorist confidence (*33*). To mitigate this, WSDOT employed additional TMC staff, and Mn/DOT had to cross-train additional TMC staff to ensure 24/7 coverage (*33*). For dynamic shoulder deployments, additional freeway service patrol and law enforcement may be needed to ensure rapid incident response in lieu of the availability of the shoulder as a refuge area (*31*, *21*). ATM deployments may also require additional staff dedicated to maintenance of the ATM system (*21*). Dynamic shoulder use may also impact snow maintenance operations due to the need to plow more roadway, and less area to place the snow (*21*).

3.4 Public Involvement and Outreach

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 (*6*). This outreach should include elected and appointed public officials in various engagements and meetings for funding support or, as noted above, to help promote changes to legislation or new policies to support ATM strategies (e.g., hard shoulder running, variable speeds limits, and non-standard language for dynamic lane control) (*6*).

The *Active Transportation and Demand Management Program (ATDM): Lessons Learned* report contains valuable information regarding outreach (*21*), including the specific examples presented in Table 7.

Table 7. ATM Lessons Learned regarding Public Involvement and Outreach (*21*).

State	Public Involvement and Outreach Lessons Learned
Minnesota	It is important to be consistent with terminology and messaging and to determine that messaging early in the project. Obtaining buy-in from decision-makers makes these projects easier to move forward. Stakeholder support from lawmakers is important to ensure success.
Missouri	Missouri Department of Transportation (MoDOT) found success by focusing outreach on three key areas: expectations, enforcement, and media relations.
Oregon	It is important to take the time to educate law enforcement and other emergency responders, bring them into the conversation early, and have them accompany agency staff when meeting with the media.
Virginia	For implementing variable speed limits on the Woodrow Wilson Bridge reconstruction effort, Virginia Department of Transportation (VDOT) conducted targeted outreach to courts and judicial offices to obtain buy-in and enforcement support, though some judges were not comfortable enforcing some citations. Creating a good website with solid information, along with television, is effective to reach a wide audience. Ensuring a consistent and clear message is essential to gain support from elected officials.
Washington	It is essential to educate elected officials, the media, and the public on the project. This education should be early, often, and consistent in its message. This outreach can help advocate specific projects and lay the groundwork for future projects and concepts.

3.4.1 Common Messages and Public Education

Because ATM strategies are often new to most stakeholders, including the general public, many agencies create special branding for the new initiatives. Minnesota DOT (Mn/DOT) refers to their ATM corridor as “Smart Lanes”, Washington State DOT (WSDOT) uses the term “Smarter Highways”, and the United Kingdom now uses the term “Smart Motorways”, formerly “Managed Motorways”. These agencies all maintain a website with information, expected benefits, and videos for public education (*38*, *39*, *40*).

The Urban Partnership Agreement National Evaluation documented the outreach and public education activities in both Minnesota and Washington. Both sites used a wide variety of outreach approaches – including workshops, forums, one-on-one meetings, presentations to groups, media advertising and outreach, newsletters, and e-mails – to provide information to the public, commuters, and policy makers about their new ATM strategies, in conjunction with new tolling initiatives (*37*, *12*, *40*). 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 (*33*).

3.4.2 Project Champion

Projects including deployed ATM strategies in California, Minnesota, and Washington have all attributed their successes to strong project champion who built working relationships and teamwork among various agencies to implement these strategies (*21*). Minnesota also credits strong support from agency leaders (*21*).

3.4.3 Engaging Policy Makers

Many of the actions for engaging policy makers seem to be similar to those used to engage the public. Specifically, one-on-one meetings, presentations, newsletters, and emails may be used to provide information to policy makers (*37*, *40*, *41*).

3.4.4 Engaging the Media and General Public

ATM signage and the messages it conveys to system users is new for most regions. This unfamiliarity along with the overall goals and objectives of the ATM strategies is often difficult to communicate to political decision makers, policy makers, and the public to gain support (*33*). Engaging the public through outreach can be effective at gaining that support. For example, WSDOT found ATM signage to be very different from other projects, involving a much more resource intensive effort for outreach (*33*). WSDOT had a very positive experience with local stations to broadcast great coverage on why ATM signage technology is good, but found it hard to maintain that message (*33*).

3.4.5 Outreach and Marketing

Many of the ATM strategies are new to this country. Therefore, outreach to both the public and stakeholder organizations is the key to building the needed trust and gaining general acceptance (*34, 53*). An extensive public information campaign is necessary during the early stages of the ATM effort to educate motorists about the purpose, the operation, and the benefits of ATM strategies (*34*). Government officials must also be informed about the benefits of ATM systems so as to serve as advocates and provide continued support as needed; especially before including these techniques in funded programs and project budgets (*34*). Further, an outreach program is necessary to help promote legislation changes that will allow certain ATM strategies such as hard shoulder running, variable speeds limits, and dynamic lane control to be deployed (*6*).

Public understanding and acceptance of a project is not only important to implementing an ATM strategy, but also to upgrading or expanding a system. For example, a public opinion research conducted by the California Private Transportation Corporation (CPTC) indicated that prior to constructing the 91 Express lanes the public was accepting the pricing concept. However, due to the fact that the public did not have an understanding of the private development agreement between the state and CPTC, the end result was public's confusion and mistrust (*104*).

Agencies must concentrate on customers, who want to know whether a project is worthwhile and how it can assist them while driving, rather than focusing on how the agency benefits. Travelers must be considered as allies and advocates for ATM and not merely as roadway users. As part of this effort, it is important to describe completed ATM projects and demonstrate the success achieved. Effective communication with the public is essential to implementing ATM, especially when consistent messages are sent by all levels of an organization promoting the ATM concept (*21*).

However, prior to informing the public, practitioners, decision makers, planners, and politicians must have a common understanding on the purpose and the objectives of a proposed project. Polls and focus groups can help agencies understand the public's perspectives and identify appropriate marketing techniques and messages that resonate with the public (*21*, *104*). They also need to identify all possible local and regional issues that the public may encounter in the

future. This will allow marketing professionals to develop clear messages tailored to traveler's needs (*104*).

Several examples of education, outreach, and marketing efforts can be found in the literature. The Virginia Department of Transportation (VDOT) has developed a public education campaign for the VSL system at the I-495 Woodrow Wilson Bridge Project. The campaign includes advertisements and a website explaining the goal and operation of the system (*102*). Mn/DOT demonstrated through media events the travel time savings and benefits to using transit in a corridor with bus on shoulders (BOS) strategies. In these events, a local celebrity challenged a transit vehicle to a race on a congested corridor with BOS (*32*). The outreach efforts of the San Diego Association of Governments (SANDAG) to promote the I-15 Express Lanes project clearly identified the project objectives to the public, demonstrated how SANDAG would address them, and advertised the project benefits. The project also had strong political support (*104*).

In order to educate the public about ramp metering strategies, the Washington Department of Transportation (WSDOT) used various forms of media and outreach including press releases, printed brochures, and website information with frequently asked questions and answers. Professional editors and designers developed the brochures based on professional standards. Public forums were held at open houses, shopping malls, and community meetings. The in-house public relations personnel organized the public meetings with the assistance of other state employees. During these meetings, the public had an opportunity to review the plans and ask relevant questions about the new strategies. Another strategy used at a local shopping mall was to provide entertainment for children, while WSDOT staff could discuss with the parents. Additionally, a catchy phrase was created that the public could associate with the project (*75*). The Georgia Department of Transportation (GDOT) and the State Road and Tollway Authority (SRTA) contracted the Clean Air Campaign (CAC) to conduct public outreach to increase the number of 3-person carpools in the I-85 Express Lanes. CAC distributed over 600 targeted brochures to employers in meetings and events and targeted registered carpoolers using a database (*42*).

In addition to outreach and marketing activities, agencies must offer "in-reach" and training to their employees, who may not be familiar with the functionalities of new systems. For example, in order to train the bus operators on the newly introduced BOS system, Metro Transit has developed a training manual along with class time, route, and safety pamphlets. The manual includes topics on bus shoulder use, a training video and on-board training for the drivers (*32*). The Washington Department of Transportation (WSDOT) created a speaker bureau comprised of WSDOT employees from different groups within the organization, including those who worked on the ATM project. In this way, WSDOT was able to educate and engage more employees so that they all had a good understanding of the system regardless of whether they worked on the project or travelled along the project corridor. An additional benefit of this initiative was that each individual could then disseminate the benefits to the public (*75*).

Currently, there are no studies on evaluating outreach strategies in relation to ATM. Future research in this field, along with development of guidelines on selecting appropriate marketing techniques would prove beneficial for the transportation community, which has begun making significant steps towards ATM (*102*).

CHAPTER 4 – PLANNING CONSIDERATIONS

4.1 Overview

The modern transportation planning process works to improve the transportation system and investment decision-making associated with transportation projects. Based on concept of system preservation, critical issues related to transportation planning include:

- Linking transportation to the economic, mobility, and accessibility needs of the country;
- Emphasizing the participation of key stakeholders in the transportation planning process
- Recognizing the constraints limiting expansion;
- Protecting the human and natural environments while providing accessibility to transportation services; and
- Linking transportation planning to the air quality objectives in the Clean Air Act amendments and State air quality plans (*32*).

The transportation plan (also known as the long-range transportation plan, metropolitan transportation plan, regional transportation plan, etc.) is a statement of the way in which a region plans to invest in the transportation system (*43*). This 20-year document sets the stage for transportation investment in the region by mapping general strategies for improving the safe and efficient movement of people and goods throughout the area. Operational strategies, which might include temporary use of shoulders during peak periods or measures such as managed lanes, can be part of this plan.

The transportation improvement program (TIP) is a short-range document related to the transportation plan. Covering a minimum 3-year period of investment, this fiscally constrained document identifies the immediate high-priority projects and strategies as outlined in the transportation plan and advances them for implementation (*43*). In short, the Metropolitan Planning Organization (MPO) takes those projects in the transportation plan and lays out which of them can realistically be undertaken with the limited resources available over the next several years. The TIP is incorporated into the statewide transportation improvement program (STIP) and must conform to the state implementation plan (SIP) for improving air quality for projects to move forward to implementation.

The elements of the metropolitan transportation planning process include public involvement, planning factors, management systems input, corridor studies, MIS, the air quality conformity process, and the financial plan. Ways in which ATM operational strategies may impact these elements are as follows (*32*):

- Public involvement when planning ATM operational improvements helps ensure that all of the social, economic, and environmental consequences of investment decisions are considered and that the MPO has the broad support of the community.
- The goals and objectives of ATM operational strategies easily fit within the general planning factors in the transportation planning process.
- Congestion management systems might consider ATM operational strategies, whose goals and objectives work in concert with the system, to maximize the efficiency potential for the transportation network.

- Incorporating ATM operational strategies as potential solutions in the corridor study can help address the factors influencing project solutions while efficiently and effectively meeting the needs of the community.
- ATM strategies that involve pricing may present transportation agencies with an opportunity to capitalize on innovative techniques to balance financing with regional goals.

Incorporating ATM into the planning process fits within the overall context of planning for operations, which is set forth in guidance from FHWA (*44*). As highlighted in Figure 5, this iterative approach includes numerous actions to ensure management and operations (M&O) strategies are incorporated into the metropolitan transportation plan (MTP).

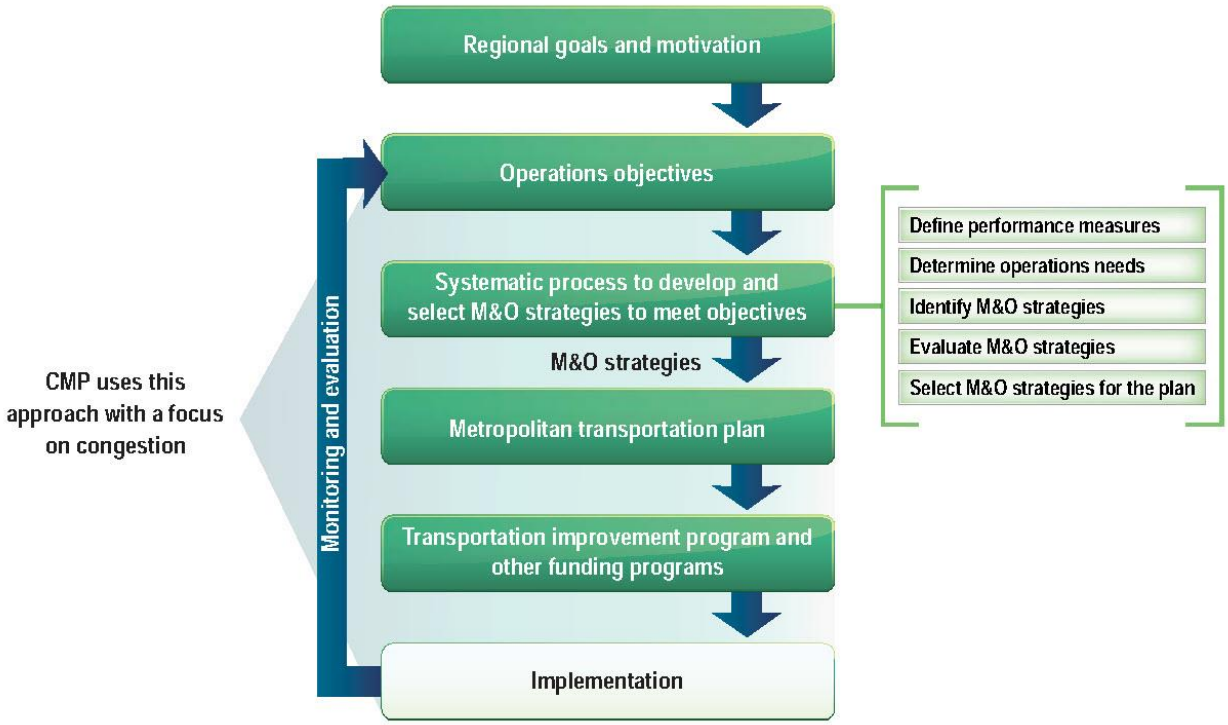

Figure 5. An Objectives-Driven, Performance-Based Approach to Planning for Operations (*44*).

Specifically, these steps include:

- The establishment of one or more goals within the MTP focusing on the efficient management and operation of the transportation system;
- The development of regional operations objectives for the MTP that are specific, measurable statements of performance that will lead to accomplishing the goal or goals;

- Use of a systematic process to develop performance measures, analyze transportation performance issues, and recommend M&O strategies;
- The selection of M&O strategies within fiscal constraints to meet operations objectives for inclusion in the MTP and TIP;
- The implementation of M&O strategies including program investments, collaborative activities, and projects; and
- The monitoring and evaluation of the effectiveness of implemented strategies and the tracking of progress toward meeting regional operations objectives (*44*).

Currently, those regions that consider ATM within the MTP and TIP do so on a selective basis with respect to operational strategies and typically with regards to specific corridors. For example, the Regional Transportation Commission of Southern Nevada includes advanced signal optimization in its regional transportation plan (*45*). Likewise, the Southern California Association of Governments includes advanced ramp metering in its regional plan (*46*), and the Metropolitan Council for the Minneapolis-St. Paul region includes ramp metering and variable speed control in its regional plan (*47*). Additionally, variable speed and queue warning are under consideration in the New York Metropolitan Transportation Commission in its Regional Transportation (*48*).

Designing for operations is also an integral part of the planning and project development process. Ensuring that M&O are considered in the design process helps improve the integration of operational considerations throughout the transportation project development lifecycle, resulting in better resource utilization, improved maintenance and asset management practices through enhanced collaboration, and effectively designed and deployed infrastructure improvements (*49*). Some advantages of incorporating operations into traditional design processes include:

- An increase in the benefits derived from a given infrastructure investment;
- The design of a safer facility for users, emergency responders, maintenance staff, and other system operators;
- Accommodating future work zones so that road users experience less interruption;
- The reduction of costs for future operational and ITS deployments; and
- The reduction of congestion and improvement of travel time reliability (*49*).

Related to planning for operations and designing for operations is the need to incorporate technology into operations for it serves as a key enabler in active strategies. A Systematic Technology Reconnaissance, Evaluation, and Adoption Method, or STREAM, was developed in 2013 to aid transportation agencies in assessing current and potential technologies that are directly relevant to agency missions and to the policy environment in which agencies operate; to incorporate technology assessments into existing agency functions, such as planning, system maintenance, and operation; and to better account for the uncertainties inherent with these technologies (*50)*. The major steps in the STREAM process, which directly connect to the consideration of ATM operational strategies, are shown in Figure 6.

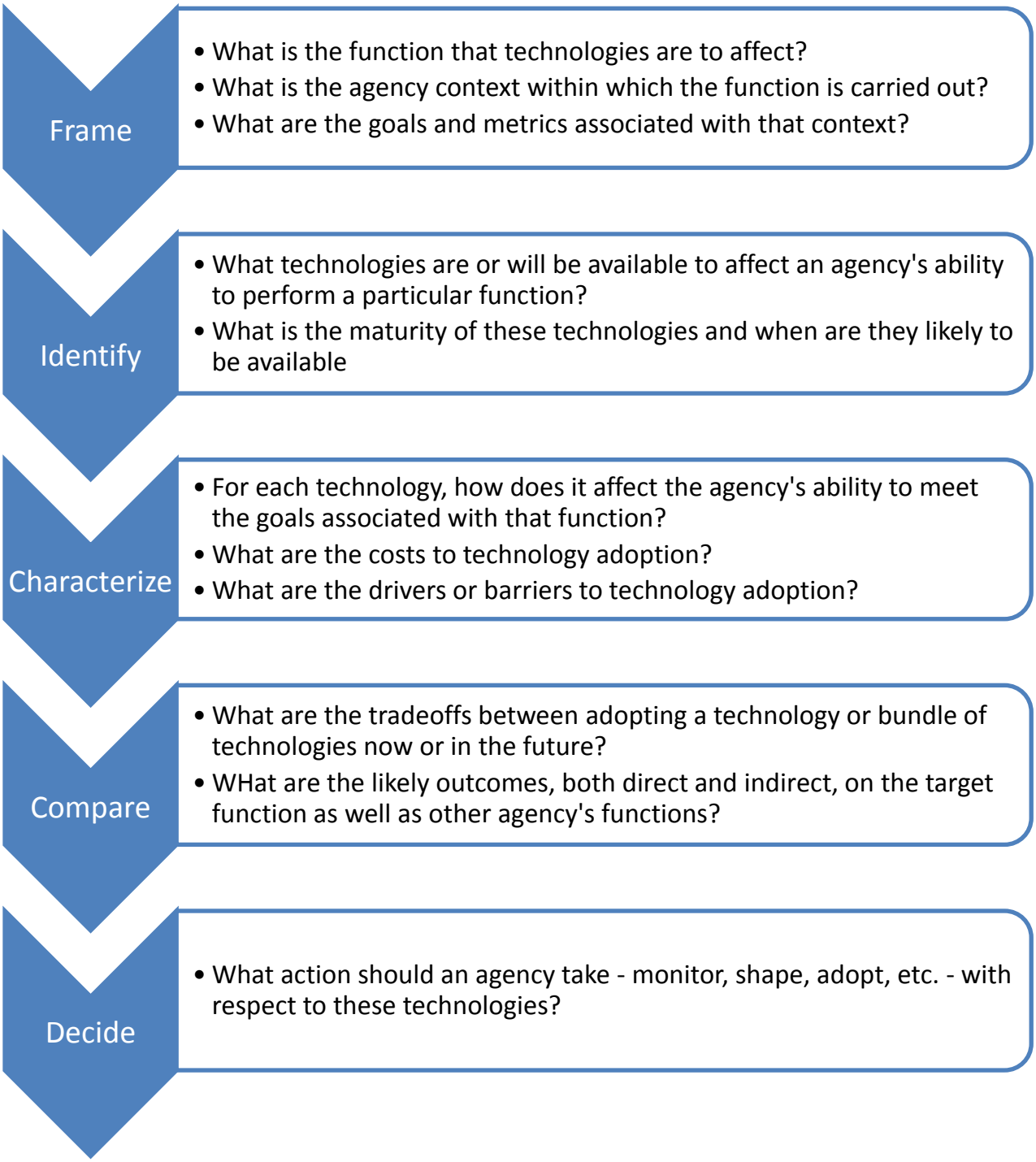

Figure 6. Major Steps in the STREAM Process (*50*).

4.2 Needs, Goals, and Objective Identification

The identification of regional goals and objectives is the first step in the planning process. Incorporating ATM operational approaches into this identification step is critical to ensuring that ATM becomes part of the conversation. *Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations* provides detailed guidance to help transportation planners and their partners develop a plan that includes operations goals, objectives, performance measures, and strategies that can easily support ATM operational strategies (*51*). The guidance document provides information on developing operations objectives, cross-references those operations objectives with specific performance measures, and offers model MTPs that reflect the objectives-driven approach. The target objectives that agencies can select for inclusion in their specific plan include:

- System efficiency,
- System reliability,
- System options,
- Arterial management,
- Emergency/incident management,
- Freeway management,
- Freight management,
- Special event management,
- Transit operations and management,
- Travel demand management,
- Travel weather management,
- Traveler information, and
- Work zone management (*51*).

For the ATM project deployed in Seattle, WSDOT identified the following as the relevant regional goals: a commitment to safety, balancing mobility and the environment, making the most of limited resources to address congestion, and optimizing performance of the facility through active management (*10*). These are all goals reflected in the 2007-2026 Highway System Plan for WSDOT (*52*). Furthermore, WSDOT identified critical operational goals for ATM projects that support the regional goals and which can be clearly measured. These goals are:

- Maximize safety and traffic flow;
- Optimize infrastructure during recurrent and non-recurrent congestion with minimum operator intervention;
- Use ATM as an interim strategy to maximize efficiency;
- Place operations as a priority in planning, programming, and funding processes;
- Focus on trip reliability and customer orientation;
- Add capacity when needed; and
- Optimize benefit-cost ratio in investment decisions (*10*).

At the feasibility study stage, WSDOT identified specific operational objectives to support a successful implementation. For example, to reduce potential tort liability issues, WSDOT

elected to operate the ATM system whenever the need arises, thereby requiring 24/7 monitoring and utilization (*53*). Other clear objectives included ensuring system compatibility with high-occupancy/toll facilities and/or managed lanes; addressing compliance and enforcement needs; maintaining appropriate operator workload; and planning for maintenance needs.

4.3 Linkage to Long-Range Transportation Plan

As discussed previously, it is critical to link operations and the consideration of operational approaches within the long-range transportation planning process. As shown in Figure 5, the objectives-driven, performance-based approach to planning involves five key steps within the systematic process to develop and select M&O strategies to meet regional objectives (*44*). The benefits of including ATM into this process include:

- The development of an MTP that includes specific, measurable, and agreed-upon operations objectives and links them to resource allocations;
- Increased accountability and communication with the public and stakeholders through the use of performance measurement;
- Engagement of key stakeholders (e.g., the operations community, law enforcement, freight, and the private sector) when setting objectives and measuring performance; and
- A focus on both short-range and long-range needs related to the operations (*44*).

Agencies across the U.S. are moving forward with incorporating ATM into the overall planning process or specific components thereof. Table 8 provides general information on how individual states have worked to implement operations into various aspects of the planning process (*54*).

Table 8. State Experience with Incorporating Operations into the Planning Process (Adapted from *54*).

Planning Process Theme	Implementing State
Operations initiatives are processes.	Colorado, Virginia
A regional concept of transportation operations can be used.	Arizona, Michigan, Virginia
The Congestion Management Process can be used.	New Jersey, Pennsylvania, New York, Washington
Performance measures may influence investment decisions.	Utah, Virginia
A few performance measures are better than none.	California, Oregon
A variety of performance measures are feasible.	Washington, D.C.

In terms of incorporating operations into the planning and project development processes, the following states have shown specific progress in this regard (*49*):

- The California Department of Transportation (Caltrans) and its local partners develop Corridor System Management Plans (CSMP) for heavily congested corridors, a practice which ensures that M&O strategies are routinely identified and included as improvements for the corridor. These were as were initiated by the California Transportation Commission as part of the Corridor Mobility Improvement Account and State Route 99 Bond Programs under the voter approved 2006 Proposition 1B (*55*).
- Partners in the Portland, Oregon region developed a regional concept of transportation operations that serves as regional guidance for collecting automated multimodal

performance measures on arterial roadways to support performance-based planning and investment decision-making.

- The Florida DOT's transportation systems management and operations (TSM&O) program formalizes designing for operations practices through stakeholder collaboration, relies on collaborative relationships between partners, and ensures that operational aspects of a facility are to be designed and built for easier long-term operations and maintenance. ATM is only nominally noted within the context as an initiative which this Florida is moving forward (*56*).
- Washington State Department of Transportation (WSDOT) has a System Operations and Management (SOM) committee that works to shape the design process to be more flexible for implementing creative operational solutions, ultimately focused on improving capacity and reliability without traditional levels of infrastructure investment.
- Pennsylvania DOT has incorporated operational considerations into its design manual and focuses on ITS elements and how they should be incorporated into the design process.

Overseas, agencies have gained much experience working to incorporate ATM into their respective planning and project development processes. Highlights related to planning for ATM are shared in Table 9.

Table 9. International Experience with Planning for ATM (*20*).

Planning Topic	Lessons Learned
Safety Concerns	Politicians, citizens, designers, and implementers in England, Germany, and the Netherlands had concerns about potential or perceived reductions or changes in safety because of the application of some management strategies. The Highways Agency in England developed a hazard index to systematically evaluate potential driver safety risks and aid in its decision to implement strategies and design choices on managed motorways. The agency uses a risk-based approach for transitioning the shoulder from an emergency lane to a travel lane. Its research has indicated that the risk of eliminating shoulders (at least for part-time use) is minimal.
Evaluation of Feasibility	Before managed motorway treatments were implemented, extensive studies were conducted to determine a technique or strategy appropriate to the problem and the roadway geometry.
Stakeholders	It is important to bring all stakeholders (enforcement, trucking, traveling public, agency, and government leadership) in at the early stages of the planning and design process. Emergency management was a key stakeholder group to educate and strategize on in several European countries.
Legislation and Policy	In England, Germany, and the Netherlands, national or state policy was a driving factor in implementation of managed motorway concepts. In 2003, the German state of Hessen initiated Congestion-Free Hessen 2015, which specifically identified future technologies, traffic management, and mobility services as tools to optimize traffic flow and increase safety. In England, longstanding public concern about the environmental cost of highway expansion drove the development of various reports and policy initiatives that emphasized sustainability in seeking solutions to roadway congestion.

Even with the advancements being made by agencies to incorporate operations into the planning process, barriers still exist that slow the full-scale integration of the concept into a long-range

vision and effective use of resources. Experience has shown that a lack of policies that support the integration of M&O considerations into planning and project development as a routine way of doing business creates challenges (*49*). Furthermore, the lack of involvement of internal and external facility operators during the project development process can pose problems and reduce the likelihood that all needs and considerations will be addressed in the final plan and project.

CHAPTER 5 – IDENTIFICATION OF PERFORMANCE MEASURES

After establishing goals and objectives for an ATM project, the accompanying step is to select appropriate performance measures, also known as measures of effectiveness (MOEs) to determine if the project meets those goals and objectives (*21*). The FHWA defines a performance measure as "the use of statistical evidence to determine progress toward specific defined organizational objectives," which includes both quantitative and qualitative measurement (*57*). The selection of performance measures determines the data that an agency must collect to calculate the MOEs, but must be considered within context of the individual needs and resources of each agency (*21*, *44*).

5.1 Overview of a PM Program

A performance measurement program manages data collection and analysis to effectively monitor the transportation system. The FHWA report *Operations Performance Measures: The Foundation for Performance-Based Management of Transportation Operations Programs* (*58*) contains a list of steps necessary to develop a formal performance management program, noting that doing so need not be difficult but does require commitment.

NCHRP Report 694 (*59*) and NCHRP Web-Only Document 174 (*60*) include sections on performance management programs for congestion pricing initiatives. NCHRP Report 660 offers an in-depth look at transportation performance management (61).

The FHWA maintains a site documenting a number of state and local performance management programs, including the Caltrans Freeway Performance Measurement System (PeMS) and dashboards and performance measures from Virginia DOT, Rhode Island DOT, Florida DOT, and Minnesota DOT (*57*).

The FHWA Operations Performance Management Capability Maturity Model (OPMCMM) describes four categories of a performance management program based on performance measures (content and form), performance management (agency culture), data, modes, facility and trip coverage, and traveler preferences and tradeoffs (*62*).

5.2 Overview of a Good PM

The FHWA (*57*) describes a good performance measure as one that:

- Is accepted by and meaningful to the customer;
- Tells how well goals and objectives are being met;
- Is simple, understandable, logical, and repeatable;
- Shows a trend;
- Is unambiguously defined;
- Allows for economical data collection;
- Is timely; and
- Is sensitive to project attributes and likely outcomes.

The development and selection of appropriate performance measures are well discussed in the literature (*29*, *59*, *60*, *61*, *62*, *63*, *64*, *65*, *66*). This includes multiple NCHRP reports on performance measures, including for freeway operations and congestion pricing (*59*, *60*, *65*, *66*).

In particular, the *Active Traffic Management Guidebook* (*29*) identifies multiple performance measures used in Europe for ATM deployments:

- Speed differential between lanes;
- Duration of speed less than x mph;
- Frequency of speed less than x mph;
- Flow/speed plots;
- Lane utilization;
- Headway distribution;
- Vehicle speed distribution; and
- Vehicle hour delay.

The *Highway Capacity Manual* contains a chapter on ATDM (*5*) that recommends four measures of effectiveness for evaluating ATDM-related objectives:

- Person Miles Traveled (PMT);
- Average delay per mile traveled;
- Average System Speed; and
- Planning Time Index (PTI).

In addition to these measures, the *Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies* (*63*) recommends:

- Vehicle-Miles Traveled (VMT)-Demand;
- VMT-Served;
- Vehicle-Hours Traveled;
- Vehicle-Hours Delay;
- Vehicle-Hours of Entry Delay;
- Vehicle-Hours Delay/Vehicle-Trip; and
- 80th Percentile Travel Time Index.

The average delay per mile traveled, VMT-Demand, VMT-Served, Vehicle-Hours Traveled, and Vehicle-Hours Delay are useful for measuring economic and environmental objectives (*63*). The other performance measures listed address key ATDM objectives of improving productivity (e.g., PMT), efficiency (e.g., average system speed), or reliability (e.g., planning time index) of the facility or system (*63, 64*).

While these performance measures focus only on mobility, the Urban Partnership Agreement National Evaluation in Minnesota and Washington (*37, 41*), both of which included ATM deployments, included performance measures for:

- Safety – changes in incident duration, incident response times, and incident frequencies;
- Customer satisfaction – impact of ATM in reducing congestion and improving safety, ease of understanding ATM messages, quality of ATM messages and information; and
- Mobility – travel times, vehicle throughput, travel time index.

5.3 Uses and Audiences for ATM Performance Metrics

Performance measures are used for a variety of reasons and seen by a number of audiences (*65*). The Active Transportation and Demand Management Program Lessons Learned report notes a need to have at least two layers of performance measures, one for the agency's operational purposes and the other to convey benefits to the public (*21*).

For the agency, performance measures must consider the needs of managers, planners, operators, and decision makers in order to provide sufficient information on progress toward meeting the objectives (*29*, *44*, *67*).

- Managers use performance measures to determine how well ATM services are being provided (*67*).
- Operators use performance measures to monitor the implemented ATM strategies, making changes as needed to the implemented strategies to improve operations (*29*).
- Decision makers use performance measures to determine whether or not to spend funding to expand coverage of ATM strategies, based on results that show the strategies work toward meeting regional transportation goals (*29*).
- Planners rely on performance measures to give insight into ATM strategies over time to determine what changes were beneficial and which were not and understand why (*29*).

As a part of gathering public support for ATM initiatives, these performance measures may be reported to the public to convey the system benefits (*57*).

Additionally, performance measures help to inform the Metropolitan Transportation Plan (MTP) to meet Federal transportation planning requirements for including "operational and management strategies to improve the performance of existing transportation facilities" and promote "efficient system management and operation." (*44*)

5.4 MAP-21 Requirements

The current transportation legislation, enacted in 2012 and called Moving Ahead for Progress in the 21st Century (MAP-21), establishes a performance-based transportation program. The legislation requires states, metropolitan planning organizations (MPOs), and other stakeholders to establish performance measures in seven areas, including those that are particularly relevant to ATM: highway performance, traffic congestion, fatalities and serious injuries, and emissions (*30*).

5.5 Setting Appropriate Performance Goals

While there is plentiful literature on various performance measures that may be applied for various situations, there is less guidance on setting targets for performance goals. NCHRP Report 551 includes a brief discussion on setting performance targets for transportation asset management (*66*). In general, setting performance targets varies considerably by agency based on the balance between financial, technical, policy, and economic considerations (*66*). Furthermore, some regional goals and performance targets may change depending on a specific location, such as a central business district vs. a suburb vs. a fringe area (*68*).

5.6 Setting Performance Goals by User Group

The literature includes extensive discussion on development and selection of a wide variety of performance measures for various user groups (*29, 59, 60, 61, 62, 63, 64, 65, 66*). However, information regarding appropriate goals for each user groups appears to be lacking.

5.7 Matching ATM Strategies to Performance Goals

Table 10, adapted from the New Jersey Statewide ITS Strategic Plan, is an example of how the relationship between goals and performance measures can be linked with individual ATM strategies. Note that some ATM strategies covered in this document are not included in the mapping.

Table 10. Example Mapping of ATM Strategies to Goals and Performance Measures (*7*).

Goal Area	MAP 21 Reference Example Performance Measures	ATM – Variable Speed / Dynamic Lane Assign.	ATM – Hard Shoulder Running / Junction Control	Adaptive Ramp Metering	Arterial Management (adaptive signal control)	TSP -Transit Management
Mobility	Congestion: Significantly reduce congestion on the NHS • Highway delay • Travel speed • Vehicle-hours of travel • Passenger travel times • Person throughput • Customer satisfaction	○	●	●	●	●
Reliability	Reliability: Improve efficiency for passengers and freight • Buffer index • Planning time index • Travel time index	●	●	●	●	●
Safety	Safety: Reduce fatalities and injuries on all public roads • Incident rate • Incident detection/response /clearance • Total fatalities and serious injuries • Excess travel time due to incidents • % vehicles exceeding speed limit by x%	●	○	●	●	○
Environment / Resiliency	Environmental sustainability: Enhance performance while protecting and enhancing the natural environment • Emissions (GHG, criteria pollutants) • Number of days exceeding air quality • Changes / trends in emissions at corridor / regional / state levels • System redundancy / resiliency (alternate routes / modes)	●	○	○	●	●

5.8 Performance of ATM Strategies under Special Conditions

Some evaluations of ATM strategies to date, such as those in Minnesota and Washington, have experienced challenges separating the effects of ATM from other complementary strategies or other changes that may have occurred around the same time (*12*).

5.8.1 Incidents

A primary goal of some ATM strategies is to reduce crashes and manage traffic during incidents. Specifically, Washington and Minnesota both expect to reduce secondary incidents in their ATM corridor by smoothing traffic flow, and have similar methods for incident management (*33*). Both sites have observed the ATM signage effectively clearing a blocked lane upstream of an incident using merge signs on the displays (*33*).

5.8.2 Special Events

ATM strategies have been used to manage traffic during special events; however a preliminary review of literature did not identify specific findings. Specific examples will be investigated and included in the guidebook as appropriate.

5.8.3 Evacuations

A preliminary review of literature has not identified the use of ATM strategies for evacuations.

5.8.4 Weather

ATM strategies can be used to mitigate weather issues, but can also present additional challenges. WSDOT noted that snow blocks views of individual lanes for operators, making it difficult to use ATM signage for incident management (*33*). Moreover, Washington noted that a snowstorm could cause so many incidents and visibility issues that it is difficult to effectively operate ATM signage when incidents are so closely spaced (*33*).

5.8.5 Data Collection Needs under Special Conditions

A preliminary review of literature has not identified any specific data collection needs for special conditions that differ from ordinary circumstances.

CHAPTER 6 – ASSESSMENT OF ATM SUITABILITY FOR A REGION

A key challenge for agencies considering ATM strategies for their region is determining the suitability of one or more particular approaches for a facility or corridor to address specific needs. Practical application results are only just emerging in the ATM arena through the limited number of deployments in the U.S. In general, agencies can look to documents that focus on planning for operations to identify operational strategies match specific regional goals and objectives. Though ATM may not specifically be referenced in some of these documents, it can be included in the assessment toolbox, particularly as the various approaches relate to operations objectives, performance measures, data needs and resources, partners, and the impacts of those strategies (*51*). The following sections highlight several approaches and processes to assessing ATM for a facility or corridor that available or on the horizon for agencies to consider.

6.1 Identification of Good Corridors/Locations for ATM

Various corridor factors and conditions can serve as identifiers that may indicate the suitability of ATM for the facility. FHWA provides a list of these identifiers as a first step in assessing ATM for a region. They include:

- High traffic volumes;
- Changes in prevailing conditions;
- A high prevalence of crashes;
- Capacity bottlenecks;
- Adverse weather;
- Adverse environmental impacts;
- Variability in trip reliability;
- Construction impacts;
- Financial constraints and priorities; and,
- Limitation in capacity expansion (*69*).

General guidance on ATM feasibility also identifies both essential and preferable facility elements that can help agencies determine whether a specific ATM operational strategy might work for a particular location and mobility challenges (*70*). A summary of these elements for select ATM strategies is provided in Table 11. Note that some ATM strategies covered in this document are not included in this reference.

Table 11. Essential and Preferable Elements for ATM Strategies (*70*).

ATM Strategy	Essential Elements	Preferable Elements
Dynamic Shoulder Use for All Vehicles	• LOS E or F for at least 2 hr per day • facility segment under consideration at 3 mi in length • no expected bottleneck downstream of the shoulder use segment • low volumes entering and exiting the facility, especially if going through interchanges • minimum shoulder width of 10 ft • available right-of-way for emergency refuge areas and acceleration/deceleration tapers • sufficient pavement strength on the shoulder to bear the traffic	• active incident management • connection to a TMC that serves as the focal point for the system • existing sensors and ITS • presence of speed harmonization on the facility
Dynamic Shoulder Use for Transit	• predictable congestion delays, LOS D for 2 hr per day • minimum 10-ft shoulder width available • sufficient pavement strength to sustain bus load • minimum service of 50 buses/hr (freeway) or 25 buses/hr (arterial)	• travel time variability higher than 1 min per 2 mi • few conflict points at interchanges • portion shared with multiple bus routes • acceptable changes for on-street operation (arterial)
Dynamic Speed Limits	• LOS E or F for 3 hr during the peak hour and 5 hr per day • right-of-way available for overhead gantries and DMSs at regular intervals • at least one location where queues regularly form and warning is warranted • at least five incidents related to queuing merging/diverging per week	• willingness to automate the deployment of the strategy • existing ITS and connections to the TMC
Queue Warning	• LOS E/F for at least 2 hr per peak period • presence of queues in predictable locations • sight distance restricted by vertical grades, horizontal curves, or inadequate illumination • right-of-way for overhead gantries and DMSs • at least five incidents related to queuing merging/diverging per week	• large mix of high-profile vehicles or inability to control speeds • willingness to automate the deployment of strategy • existing ITS and connections to TMC
Dynamic Merge Control	• significant merging volumes (>900 vph) • available capacity on general purpose lanes upstream of the interchange that can be borrowed with no worse than LOS E after implementation • non-simultaneous peak traffic upstream on the general purpose lanes and merging lanes	• active incident management in the corridor • existing ITS and connections to the TMC • combination with shoulder use

6.2 The Potential Impacts of ATM Strategies

When considering ATM strategies for a region, agencies should consider the potential impacts of those strategies in both near- and long-term scenarios. Typical assessments of potential benefits of many of these strategies are provided in Table 12. Note that some ATM strategies covered in this document are not included in this reference.

Table 12. Some Potential Benefits of ATM Strategies (Adapted from *13*).

	Potential Benefits												
ATM Strategy	**Increased throughput**	**Increased capacity**	**Decrease in primary incidents**	**Decrease in secondary incidents**	**Decrease in incident severity**	**More uniform speeds**	**Decreased headways**	**More uniform driver behavior**	**Increased trip reliability**	**Delay onset of freeway breakdown**	**Reduction in traffic noise**	**Reduction in emissions**	**Reduction in fuel**
Dynamic Junction Control	X	X	X			X		X	X	X	X	X	X
Dynamic Lane Use Control	X	X	X			X			X				
Dynamic Merge Control	X	X	X			X		X	X	X	X	X	X
Dynamic Shoulder Lanes	X	X							X				
Dynamic Speed Limits	X		X		X	X	X	X	X	X	X	X	X
Queue Warning			X	X	X	X	X	X	X		X	X	X

Research has shown that rarely are ATM strategies implemented in isolation. A number of them are complementary and form a logical relationship within the context of operations. Table 13 indicates typical complementary and/or supporting strategies for several ATM strategies (*34*). It is important to note that these strategies do not have to be implemented together. Rather, they work towards similar operational objectives and can capitalize on the same data requirements and ITS infrastructure needed for functionality. Note that some ATM strategies covered in this document are not included in this reference.

Table 13. Compatibility of ATM Strategies (Adapted from *34*).

ATM Strategy	Complementary and/or Supporting Techniques	Dynamic Speed Limits	Queue Warning	Dynamic Shoulder Lanes	Dynamic Lane Use Control	Dynamic Junction Control	Dynamic Merge Control	Adaptive Ramp Metering
	Dynamic Speed Limits		X	X	X	X	X	X
	Queue Warning	X			X			
	Dynamic Shoulder Lanes	X			X	X	X	X
	Dynamic Lane Use Control	X	X	X		X	X	X
	Dynamic Junction Control	X		X	X		X	
	Dynamic Merge Control	X		X	X	X		
	Adaptive Ramp Metering	X		X	X			

6.3 Sketch Planning Tools

An ongoing effort funded by FHWA is developing an *ATM Feasibility Guide* that will be intended to enable agencies to make informed investment decisions in this regard (*6*). As part of that guidebook development, the project team has proposed an ATM screening process shown in Figure 7.

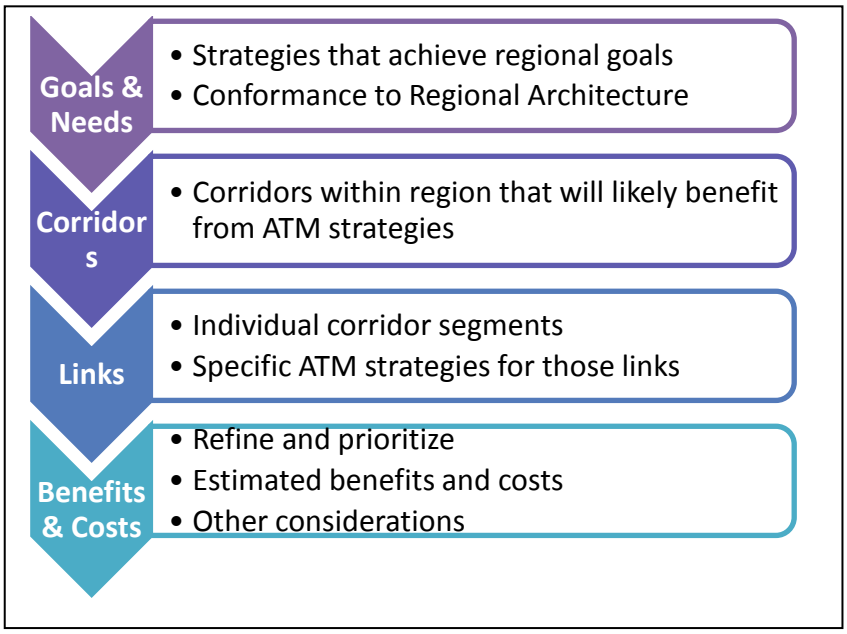

Figure 7. Proposed ATM Screening Process (*6*).

This effort has also identified a draft list of desired data elements agencies might need for ATM screening. Robust and appropriate data elements support the assessment of strategies as well as the measure of their performance and success after implementation. They also help link the strategies to regional goals and objectives, thereby linking ATM to the planning process. These data needs are provided in Table 14.

The *Operations Benefit/Cost Analysis Desk Reference* and its companion tool are designed to assist practitioners in conducting benefit/cost (B/C) analysis for various TSM&O strategies (*71*). Specifically, this reference document provides users the following:

- The ability to investigate the expected range of impacts associated with previous deployments and analyses of many TSM&O strategies;
- A screening mechanism to help identify appropriate tools and methodologies for conducting a B/C analysis based on their analysis needs;
- A framework and default cost data to estimate the life-cycle costs of various TSM&O strategies, including capital, replacement, and continuing operations and maintenance (O&M) costs; and
- A framework and suggested impact values for conducting simple B/C analysis for selected TSM&O strategies (71).

Table 14. Desired Data for Preliminary ATM Screening (Adapted from *6*).

Data Type	Desired Data
Crash Data – 3 years or more of most recent information	• Time and date of crash • Location of crash and direction of travel (e.g., vicinity of ramp) • Type of crash (rear end, side swipe, head on, fixed object etc.) • Severity of crash (damage only, slight injury, serious injury, death) • Classifications of vehicles involved • Weather conditions at time of crash • Primary vs. Secondary crash
Volume and Congestion Data – Preferable by roadway segment (between ramps)	• Volume data and/or V/C ratios (an indication of recurrent congestion that may be helped by hard shoulder running) • Ramp (on and off) and mainline data at major interchanges (for determining the feasibility of junction / merge control) • Average link speed information / speed profiles by time of day (15-minute intervals) and for special events. Speed profiles not only identify congested segments, but also those segments with significant variability in speeds – scenarios that may be improved by ATM (variable speed limits / advisories). It is desirable for the speed profiles to cover one calendar year, all days, and all hours. This allows the flexibility to isolate certain days and operational scenarios such as peak periods, major incident conditions, special events, holidays, etc. • Spot speed data on mainline and ramps at major interchanges • LOS for signalized intersections and locations with recurring congestion (saturated flow)
Air Quality Data	• As available on a county basis.
Recurring and Potentially Hazard Weather Conditions and Issues	• Frequency and locations • Impacts
Transit Information	• Bus routes and service frequency (headways / number of buses per hour) • Type of bus service (local, express, BRT) • Schedule reliability / variability • Number of passengers
On-going and planned major roadway improvements	• As appropriate
Existing ITS Assets	• Communications, power, detectors, CCTV, DMS, signal control, controller types, etc. • This information will be used during the initial costing exercise
Roadway Mapping and Geometry	• As appropriate

Those ATM strategies included in the desk reference document are speed harmonization, hard shoulder running, and ramp metering. The reference includes a summary of B/C assessment tools appropriate for specific strategies, a mapping of analysis methods/tools to appropriate geographic scope, and measures of effectiveness for specific strategies.

CHAPTER 7 – ANALYSIS, MODELING, & SIMULATION

Traffic analysts increasingly rely on a growing toolbox of software, analytical tools, and methodologies to evaluate current and future performance of transportation facilities. The most common objectives for using traffic analysis tools include: improve the decision-making process; evaluate and prioritize planning and operational alternatives; improve design and evaluation time and costs; reduce disruptions to traffic; present and market strategies to the public or stakeholders; operate and manage existing roadway capacity; and monitor roadway or network performance (*72*). For a set of complex strategies included in ATM, the ability to model and analyze the facility operations with and without-ATM is critical to agencies. However, agencies have no definitive guidance or analysis methodology to allow them to estimate the impacts of ATM strategies. The 2010 HCM Chapter 35 (ATM) does not currently contain such a quantitative analysis methodology either (*64*). However, the update currently being completed for the HCM will include ATDM at a high level as well as reliability methodologies.

The implementation of ATM strategies requires a careful analysis to justify the project costs. The most straightforward approach to conducting such analysis is through a pilot study where the strategies under consideration are implemented. However, due to budgetary constraints and resource limitations, this is not always feasible. A less expensive way to perform such analysis is by using traffic analysis tools that can be generally grouped into the following categories (*72*):

- **Sketch-planning tools**: are appropriate for high-level analysis that can be used to evaluate alternatives or projects without performing a detailed traffic analysis.
- **Travel demand models**: are mathematical models that predict future travel demand based on existing conditions and projections of socioeconomic characteristics.
- **Analytical/deterministic HCM-based tools**: are based on Highway Capacity Manual methodologies and procedures, and are used to evaluate the performance of isolated or small-scale facilities.
- **Traffic signal optimization tools**: are used to develop optimal signal phasing and timing plans for isolated signal intersections, arterial streets, and signal networks.
- **Microscopic simulation tools**: rely on car-following and lane-changing theories and simulate the movement of individual vehicles.
- **Mesoscopic simulation tools**: combine capabilities of both microscopic and macroscopic simulation models considering the individual vehicle as the traffic flow unit, whose movement is governed by the average speed on a link.
- **Macroscopic simulation tools**: are based on deterministic relationships of traffic network parameters (speed, flow, density) and simulate traffic on a section-by-section basis (*73*).

The available simulation analysis tools are theoretically capable of modeling the impacts of ATM strategies, but their accuracy relies heavily on driver behavior models and compliance with ATM traffic control devices and messages, which at this point are not sufficiently calibrated or understood in the U.S. Further, the variety of these tools present challenges to the operating agencies as to which methodology or technique is appropriate for ATM strategies. The purpose, the application area, the development cost/time, the required level of knowledge, hardware/software requirements, input parameters, and the expected output are some of the basic

components that complicate the process of selecting the appropriate tool. Each category of tools has specific characteristics, methodology, applicability, and limitations.

For example, HCM is the most widely used traffic analysis tool in the United States. The HCM procedures are appropriate and reliable for predicting whether or not a facility will be operating above or below capacity. The HCM procedures are static, macroscopic, and deterministic, but have limited capabilities in evaluating system-wide effects and dynamic traffic conditions. Most of the HCM methods assume that the operation of a facility is not affected by traffic conditions on adjacent roadways. The HCM procedures are of limited value in analyzing queues as they may extend upstream and affect other locations violating the previous assumption (*73*).

There are also several gaps in the HCM procedures as far as simulating ATM strategies is concerned. Some of these gaps include special lanes, such as HOV lanes; ramp metering; posted speed limits and the extent of police enforcement; presence of ITS features; segments near a toll plaza; lane additions leading up to or lane drops leading away from intersections; interactions among passing and climbing lanes on two-lane highways; and effects of lane drops and additions at the beginning or ending of multilane highway segments (*73*).

As opposed to HCM procedures, simulation models are effective in capturing the dynamic evolution of traffic, but require significant amount of input data and manipulation of calibration parameters. Microsimulation typically requires significant computational time, but tends to be accurate in modeling driver behavior. Mesoscopic simulation, on the other hand, is less computationally intensive, at the expense of a less detailed modeling of driver behavior (*74*).

In addition to the analysis tools, the users must take into account other factors such as performance measures, availability of data, and available evaluation resources, which typically depend on the identification of the appropriate study area and vice versa. All these factors are considered when determining the study area and, in some cases, the study area may be the driving force for selecting possible performance measures, the appropriate analysis tools, and the evaluation resources required. With that said, ATM strategies can be modeled and analyzed at different spatial levels such as corridor or regional. Literature reveals that it is common for transportation agencies to use multiple study area definitions within the same project (*75*).

The *Ramp Management and Control Handbook* includes a matrix (Table 15.) that shows the applicability of traffic analysis tools per study area and facility under examination. The matrix considers three study areas: localized, corridor, and regional. The differentiation between localized and corridor-level analyses is not based on firmly established criteria. The localized analysis has similar characteristics with the corridor analysis, but focuses on a specific part of a corridor. The majority of the studies found in the literature attempt to evaluate impacts of ATM strategies at corridor- and/or regional-level. Further, all the traffic analysis tools that can be used for a localized analysis can also apply to a corridor-level analysis. Therefore, the localized analysis can be considered as a smaller-scale corridor analysis.

The remaining part of this Chapter includes two sections. The first section deals with corridor-level analysis, while the second section is dedicated to regional-level analysis of ATM strategies. Both sections include a review of the most commonly used methods and tools, as well as previous studies that analyzed individual and integrated ATM strategies under various traffic conditions.

Table 15. Mapping of Analysis Needs to Common Traffic Analysis Tools (*75*).

		Traffic Analysis Tool Category							
Study Area	**Problem Area (Operational Impact)**	**Direct Measurement**	**Sketch-Planning Tools**	**Travel Demand Models**	**Analytical/Deterministic (HCM-Based)**	**Macroscopic Simulation**	**Mesoscopic Simulation**	**Microscopic Simulation**	**Signal Optimization Tools**
Localized	Merge/Weave	✓	✓		✓	✓	✓	✓	
	Ramp Operations	✓	✓		✓	✓	✓	✓	
	Freeway Operations	✓	✓		✓	✓	✓	✓	
	Arterial Operations	✓	✓		✓	✓	✓	✓	✓
Corridor	Merge/Weave	✓	✓		✓	✓	✓	✓	
	Ramp Operations	✓	✓		✓	✓	✓	✓	
	Freeway Operations	✓	✓	✓	✓	✓	✓	✓	
	Arterial Operations	✓	✓	✓	✓	✓	✓	✓	✓
Regional	Merge/Weave	Not typically performed for a regional study							
	Ramp Operations	✓	✓	✓					
	Freeway Operations	✓	✓	✓		✓			
	Arterial Operations	✓	✓	✓		✓			

7.1 Corridor Level Analysis of ATM Strategies

The analysis at the corridor-level aims to evaluate potential impacts of one or more ATM strategies that are anticipated to affect performance measures and operational characteristics along a corridor. The length of a corridor is typically based on local street patterns and knowledge of local travel demand. These factors are necessary to determine other roadway facilities to be included in the analysis.

In some cases, the analysis can be performed at a smaller scale focusing on the facility, which is in the close vicinity and directly affected by the ATM strategy under consideration. The localized analysis is suitable for individual and limited-scale ATM strategies, or for evaluating performance measures at a particular segment that is part of a system-wide deployment. For example, evaluating potential safety impacts of a ramp meter on its downstream merge lane might limit the study area to this narrowly defined extent (*75*). However, as explained at the beginning of this Chapter, the localized analysis can be perceived as a smaller-scale corridor analysis.

Microscopic and mesoscopic simulation models are the most commonly used tools for this level of analysis. Microscopic simulation models account for vehicle-specific lane changing and driving behavior, detailed signalization and gap acceptance theories. They simulate at short time intervals and adopt car following and lane changing models that incorporate human behavioral components through the use of parameters calibrated by the user. The parameters are sensitive and if not selected, calibrated and validated carefully, can yield misleading results; especially in the case of network analysis which typically requires a large amount of data. One downside of these models is the extensive computation time needed to generate results of high detail. As a result, microscopic simulation models are often used to analyze small-scale deployments and may lead to boundary effects (*76*).

Mesoscopic models aim to describe an individual route–departure time choice adjustment and to relate such changes to the network-level performance through simulation. Typical applications of mesoscopic models are evaluations of traveler information systems. These models apply iterative procedures to adjust the traveler route assignment in order for travelers departing at different times to select the respective minimal experienced travel time route (*77*, 78, *79*, *80*, *81*). As opposed to microsimulators, many simulation-based Dynamic Traffic Assignment (DTA) models are more computationally efficient and are able to simulate traffic flow at a larger geographical area (e.g., regional level) and over a longer time period. Mesoscopic models have several common characteristics with microscopic models. They represent individual vehicles and simulate vehicle dynamic states through simplified car-following or traffic flow theories without relying on lane changing or gap acceptance theories.

Some of the most popular microsimulation packages include, but are not limited to, CORSIM (*82*), VISSIM (*83*), and Paramics (*84*). Software packages appropriate for mesoscopic simulation analysis include DynaMIT (*85*), VISTA (*86*), and DYNASMART (*87*). A more extensive list of traffic analysis tools commercially available is provided in the Traffic Analysis *Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools* (*73*).

As opposed to the previous models, macroscopic models do not simulate individual vehicles, but take into consideration cumulative traffic stream characteristics (speed, flow, and density) and their relationships to each other. They are typically used to predict the extent of congestion caused by traffic demand or incidents in a network. Macroscopic models do not have high software/hardware requirements and cannot provide detailed simulation results.

In addition to microscopic, mesoscopic, and macroscopic simulation models, several studies have developed multiresolution/multiscenario approaches. The multiresolution methods are typically used to evaluate a limited number of alternatives for which accurate and detailed results are needed. These methods combine the modeling capabilities of multiple analysis tools such as

travel demand and traffic simulation models. Travel demand models are appropriate for assessing long-term impacts of travel demand and analyzing recurring traffic conditions. In contract, simulation models are suitable for dynamically assessing operational performance during small time intervals and during varying nonrecurring traffic conditions. Integrating the two types of models provides the ability to assess both the immediate impacts of an ATM strategy, as well as the longer-term impacts due to travel demand changes over longer periods of time. Multiresolution models are appropriate when examining dynamic traffic management strategies such as speed harmonization and peak-period shoulder use (*74*).

Likewise, multiscenario methods can be used to assess ATM strategies under a variety of conditions such as incident versus no-incident, and good weather versus adverse weather conditions. In order to simulate all the examined conditions, the models need to be run multiple times. The multiresolution and multiscenario methods can capture the multifaceted impacts of many strategies for both operations and planning purposes to a high degree of realism. The main downsides of these methods are: significant amount of time and effort required to develop them; potential compatibility issues among the various analysis tools and methods needed to be integrated; and confinements on the study area or the number of alternatives to be analyzed due to the substantial amount of resources required for the development and calibration of a model (*74*, *71*). A typical example of a multiple resolution and multiple scenario approach is FHWA's Integrated Corridor Management (ICM) methodology that links regional travel demand models with refined simulation models. The ICM analysis process was completed for multiple iterations to determine performance variations under various operating scenarios (*88*).

Several studies have determined performance measures and evaluated potential impacts of various ATM strategies on traffic parameters and safety under varied traffic conditions. For example, the *Ramp Management and Control Handbook* includes several case studies that describe how different agencies have successfully evaluated and deployed ramp management strategies. One of them is the deployment of ramp metering along the Highway 12 corridor in Madison, Wisconsin. The evaluation effort included both corridor and regional analysis. Different groups of analysts used before and after field data, microscopic traffic simulation analysis, stakeholder interviews, public surveys, a regional travel demand model, and the U.S. DOT's ITS Deployment Analysis System (IDAS) software tool to determine the impacts and benefits of the ATM strategy. Both assessments showed that the ramp metering implementation yielded significant benefits (*75*).

In 2002, Caltrans developed a Transportation Management System (TMS) Master Plan that included several strategies such as ramp metering, incident management, arterial signal management, traveler information systems, and the associated support elements. Initially, Caltrans analyzed potential impacts of these strategies on two corridors under varied operational conditions. Different scenarios were then examined reflecting different deployments and travel conditions. Pre-timed, traffic responsive, and system-wide ramp metering strategies were used in the analysis. Each strategy was separately tested with aggressive, moderate, and no queue control. In order to identify potential benefits of the examined systems as well as which operating conditions were best improved by different strategies, the analysts tested each strategy alone and in combination with others. The need to identify the impacts of numerous scenarios prevented the use of real world "before" and "after" impact studies of existing strategies. The analysts developed, instead, a microscopic traffic simulation model that allowed them to better

control the varying traffic conditions (*75*). The study found that ramp metering should be deployed in urban and suburban locations where projected volumes are greater than 1,800 vehicles per hour and at locations experiencing merging problems.

A project conducted by the Center for Transportation Research (2009) implemented various strategies of variable speed limits and shoulder use. Using a combination of micro- and mesoscopic traffic modeling techniques, the analysts developed a VISTA/VISSIM hybrid traffic multi-resolution model to assess the impact of the examined strategies on traffic operations and safety. The concept behind the development of the multiresolution model is that speed harmonization and peak-period shoulder use are typically implemented at specific roadway segments, yet they can potentially affect traffic conditions in larger regions. The study results showed that the strategies were found to homogenize traffic and create safer driving conditions, but did not increase the throughput of the system (*74*).

A study conducted by the University Transportation Center of Alabama (2009) developed a CORSIM microscopic simulation model to quantify the impacts of temporary shoulder lane use on traffic operations of a subsection of I-65 in Birmingham, Alabama. The model was calibrated and validated to simulate complex geometric conditions and capture recurring and nonrecurring congestion. The simulation results showed that the use of temporary shoulder lanes had positive effect on traffic operations along I-65 under both recurrent and non-recurrent congestion (*89*).

In 2007, the Washington State Department of Transportation (WSDOT) conducted a feasibility study to assess six ATM strategies including speed harmonization; queue warning; junction control; hard shoulder running; dynamic re-routing; and traveler information. The feasibility study was conducted in two phases. In the first phase, three major corridors were evaluated to determine the most appropriate one that would be used to test the strategies. In the second phase, the ATM techniques were assessed along a segment on I-405 corridor and VISSIM microsimulation models were developed to estimate the benefits of three strategies: speed harmonization, queue warning, and junction control. Dynamic rerouting, traveler information, and hard shoulder running could not be modeled. Several incidents were modeled to estimate the reduction in traffic delay as a result of the various ATM strategies and as a result of collision avoidance (*53*). In the case of speed harmonization, the researchers estimated a potential cost savings of $13.6 million per year due to the reduction in collisions and reduced delay. The costs associated with queue warning could be recovered in approximately three years. Lastly, potential deployment of junction control would require between six and eleven years to recover the system costs.

In 2010, the Minnesota Department of Transportation (Mn/DOT) conducted a study of the I-94 corridor to identify potential improvements to the physical facilities, traffic operations, and transit services. A number of build concepts including general-purpose lanes, Dynamic Shoulder Lanes (DSL) and High-Occupancy-Toll (HOT) lanes were initially considered. Based on a high-level travel demand analysis for the corridor and recommendations from project committees, two alternatives and a no build option were selected for CORSIM microsimulation analysis. The preliminary CORSIM models revealed that capacity constraints at the beginning and end of the examined corridor had negative effect on traffic operations. Based on these findings, the build concepts were evaluated under both constrained and unconstrained conditions. A series of CORSIM modeling alternatives and scenarios were developed to test different geometric

variations at several locations. The preferred alternatives were then modeled using existing traffic volumes (*90*). The analysts concluded that the ATM strategies analyzed could improve both safety and traffic operations on the examined corridor.

In general, analysts must address a series of issues prior to developing simulation models. First, they need to define the size and scope of the network to be analyzed. They need to ensure that the selected network contains all the ATM strategies under consideration along with extended highway segments, side streets, and ramps that can be affected by the deployment. Some software packages cannot model queues of vehicles extending outside the examined network or bottlenecks occurring outside the network, yet affecting its operations (*54*).

Additionally, analysts must define the scenarios to be examined in relation to the time of the day or day of the week analyzed. In addition to peak hours, in some cases is important to capture situations where the onset/offset of congestion is delayed. Therefore, taking into consideration the shoulders of the peak periods should not be neglected. Another consideration is the availability of historic crash and incident data that can be used to evaluate the ability of an ATM strategy to mitigate non-recurring congestion. The analysts must also account for the concept of operations of an ATM strategy, as it can dictate the traffic analysis tool to be used. Moreover, the analysis requires assumptions about how drivers will react to the proposed ATM strategy (e.g., speed distribution and routing decision changes).

Another consideration is that the selected simulation tool must have the capability to model the ATM technique under consideration. Several software packages such as Synchro and CORSIM have limited capability to simulate some strategies such as VSL systems or dynamic hard shoulders that change dynamically based on traffic conditions. Conversely, packages such as VISSIM or PARAMICS provide greater flexibility by allowing user adjustments and preferences to be incorporated to a model. Furthermore, the limited experience in modeling ATM strategies in the United States makes the modeling activity more challenging. In order to overcome these challenges, the analysts make a series of assumptions that can affect the model results creating additional uncertainty. In addition to the aforementioned considerations, modeling can be a time-demanding task; therefore, it must be conducted after preliminary analyses have indicated potential benefits for the ATM strategies considered (*54*).

7.2 Regional Level Analysis of ATM Strategies

Regional-level analysis is appropriate when a comprehensive assessment of possible impacts is required, when the deployments are scattered across a large area or when they are concentrated in a small area or corridor, but may have region-wide effects. Regional analyses can be considerably expensive, due to the significant development effort, time, and large amount of data required. Many agencies use large-scale traffic analysis tools such as regional travel demand models (*75*). These models predict travel demands over large geographic areas at the expense of accuracy and precision that can be achieved otherwise by modeling traffic operations of individual segments or facilities. When the goal of employing regional demand models is to determine demand effects of operational or capacity improvements, the models are frequently integrated with traffic operations models, which provide higher precision. In order to ensure consistency of data inputs, the two models must be equilibrated. This process is typically

resource-intensive, thus some agencies use instead other tools (e.g., sketch-planning tools) making appropriate assumptions (*63*).

As part of regional-level analyses, agencies often compare traffic conditions "before" and "after" a strategy is deployed. The observed before and after data can be obtained from previous impact studies conducted to assess similar strategies that were deployed in the same or in a different region (*75*, *63*). In some cases, the deployed strategy is deactivated for a certain period of time to account for the before-deployment effects. The strategy is then put back into operation to determine the after-deployment impacts. For example, a ramp metering system in the Twin Cities (2000) was shut down for six weeks to allow the identification of conditions without ramp meters. After this period, the system was fully functioning again. In this study, a corridor-level analysis was initially performed on four corridors to determine potential impacts of ramp metering strategies on freeway, ramp, and parallel arterial facilities. Using spreadsheet-based analysis tools, the project team extrapolated the findings from the corridor-level analysis to develop travel demand forecasts and estimate regional impacts (*75*). The regional model included 7 core counties and several ring counties surrounding the core. The main inputs to the model included socioeconomic and traffic network data. For each forecast year, the model was run in a full feedback mode that included trip generation, distribution, mode choice, and morning/midday highway assignment. Then the model was calibrated and validated appropriately (*90*).

In June 2013, FHWA published a Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies (*63*). The guide provides a conceptual analysis framework, recommended measures of effectiveness, and an initial recommended methodology for assessing the impacts of ATDM strategies on traffic demand, capacity, and performance for two conditions: before and after implementing ATDM strategies. The before conditions are mainly used to calibrate the analysis models, whilst the after conditions predict how facility throughput, mean travel time, and travel time reliability will vary after the ATDM strategy is implemented. The framework considers two types of "after" conditions: a) "opening day" conditions that represent what happens immediately after implementation; and b) equilibrium conditions that reflect the conditions 3 to 6 months after implementing the strategy. Depending on the traffic analysis tool selected by an agency to perform the evaluation, the ATDM Analysis Methodology can be employed to analyze an individual facility or a system of highways.

The "before" analysis involves the following steps: defining the analysis scope, purpose and study area as well as collecting data; generating scenarios that will be used for evaluation and comparison purposes; applying a traffic analysis tool to evaluate each scenario; and estimating measures of effectiveness. The "after" analysis involves: selecting and designing the ATDM strategy to be tested; translating the strategy into input parameters required by the analysis tool; applying the tool to analyze "opening day" conditions; and computing measures of effectiveness. The equilibrium effects aim at capturing demand changes due to possible operations and travel time reliability improvements (introduced by the new strategy) that are likely to attract more travelers from adjacent networks. Taking into consideration the equilibrium effects of ATDM can enhance the accuracy of the evaluation results, but is not critical for every analysis (*63*).

CHAPTER 8 – PROGRAMMING & BUDGETING

To promote the deployment of ATM approaches on a broad basis, agencies should include them in their long-range planning process and consider specific implementations as they move forward with management and operations of their networks. Specific issues related to future deployments and planning for ATM include but are not limited to anticipating future ATM deployments and operational approaches, incorporating ATM in a region's congestion management process, and considering features in future facilities that might accommodate ATM.

8.1 The Funding Process

Once agencies have decided that ATM operational strategies fit within the overall goals and objectives of their region, it is imperative to ensure those projects are programmed so that funds will be available when needed for implementation. As discussed previously, the metropolitan planning process (shown in Chapter 4 as Figure 5) goes beyond just the development of the transportation plan. Once the plan is established, the identification of resources and specific programming for projects begins. While only one step, the inclusion of projects in the transportation improvement plan and other funding programs is essential to success (*44*).

A formal program and budget can be important tools for supporting the implementation of ATM strategies. Similar to TSM&O, agencies can develop programs and budgets that support ATM strategies and are strengthened by organizational processes and institutional arrangements. For example, the Maryland State Highway Administration (SHA) Coordinated Highways Action Response Team (CHART) program is a formal, multiyear budgeted ITS and operations program with an advisory board that provides oversight and strategic direction for efforts under the program (*91*). Similarly, the Virginia DOT organizational structure includes a Deputy Director for Operations and Maintenance within its senior management to bring focus and equal weight systems operations and management activities along with maintenance resources (*91*). This arrangement helps ensure that system operations, including ATM, has a seat at the table when planning and budgeting efforts take place. Currently, U.S. DOT is looking to make changes to how specific projects are funded (i.e., capital and operations and maintenance funding) to support ATM.

Programming and budgeting for ATM strategies also has a place within the designing for operations approach. Scoping and financing of projects is an early stage in the project development process. Specifically, the project delivery method is a consideration at this stage and agencies can determine if alternative delivery methods, collaboration with operational partners, or other financial and development arrangements are going to be part of the project (*49*). This likelihood becomes more relevant within the current climate of limited resources.

8.2 Lessons Learned

Funding for ATM, as with all other transportation projects, can be a challenge. Experience has shown that agencies are successful at securing funding for ATM when it is part of a larger, more comprehensive project that may already be in the planning stages. Leveraging resources with partnering agencies has also proved fruitful.

The Minnesota ATM and PDSL projects were part of the larger UPA project funded by the USDOT. The significant amount of Federal funding available through the UPA was a key mechanism for bringing the agencies and partners together, and the mix of funding and the flexibility in applying the funds were also important factors in the deployment process (*21*). The I-5 ATM project in Seattle was funded as part of a larger project, the SR-99 Alaskan Way Viaduct Replacement project. Funding for that project originated from a variety of sources, including gas taxes, State transportation funds, traditional Federal funds, local funds, toll revenues, and the Port of Seattle. Federal grant funding was secured for the UPA program. This included $43.7 million for the technology (ATM) portion of the program (*21*). Furthermore, WSDOT intentionally works to combine ATM deployments or infrastructure work to support future ATM deployments other projects whenever possible to maximize the effort construction projects. Planning for operations in the future can save time and resources in the overall scheme of project development and deployment.

The deployment of the Los Angeles junction control project had a safety focus, which allowed Caltrans to secure safety funding for the implementation. The crash rate was six to eight times what would be expected on a typical connector. Thus, Caltrans requested funds from the State Highway Operation and Protection Program for the project, demonstrating that the agency was using technology to solve a safety problem (*21*).

8.3 Examples of Improvements for Future Deployments

ATM was recently included in the Mn/DOT Metro District Highway Investment Plan 2011–2030 (*92*). Specifically, the plan outlines a new investment strategy that recognizes that while congestion will not be eliminated within current fiscal constraints, its impacts can and must be mitigated to the fullest extent possible in order to preserve mobility levels essential to the region's economic vitality and quality of life. To that end, the plan recommends that ATM applications be implemented system wide to smooth the effects of congestion and reduce the number of incidents. Specific ATM approaches noted in the plan include traveler information systems, incident response programs, dynamic signing and rerouting, dynamic shoulder lanes, hard shoulder running, speed harmonization, and queue warning (*21*). The plan notes that comprehensive ATM implementation can be more effective when combined with other corridor-wide improvements, such as the construction of a new managed lane. However, it recognizes that more limited ATM strategies can be implemented in an effective manner, on a case-by-case basis, to improve freeway and non-freeway highways.

WSDOT assessed the feasibility of ATM strategies in the Seattle region in 2008. The agency used the results to incorporate ATM into the regional ITS architecture and develop a concept of operations, which helped move the concept into implementation. WSDOT has adopted a policy, titled *Moving Washington*, which emphasizes the investment of resources in an integrated manner to operate the network more efficiently, to manage demand, and to strategically add capacity (*93*). ATM has become part of that dialogue and is being considered in other corridors that are in need of attention. Moving forward, WSDOT has identified specific issues that can be considered to facilitate implementation (*21*). First, it is important to coordinate early with FHWA on sign messages, given that there are few accepted standards for MUTCD messaging.

ATM messaging is the key mechanism for communicating with the traveling public, and working with FHWA is a key to success in that arena. Second, projects can benefit from the development of standard operating procedures. Partner agencies should spend time thinking beyond the normal situations to ensure that plans are in place when an unusual event occurs. They should also plan ahead to work through testing procedures prior to deployment to ensure that issues are addressed. Finally, education is essential—early, often, and continual. Agencies should take advantage of all media platforms to ensure that their messages are delivered to the right audience throughout the life of the project.

CHAPTER 9 – AVAILABLE TOOLS & RESOURCES

This chapter presents a plethora of recently published resources including reports, guidelines, manuals, primers, and tools, which can be used by transportation agencies to support ATM functions. The resources presented herein cover a wide spectrum of areas involving organizing, planning, analyzing, modeling, programming, and budgeting for ATM strategies. The resources are presented in ascending chronological order and based on the type of the sponsoring agency, are categorized into three sections as follows:

- SHRP 2 and NCHRP
- FHWA and FTA
- State and Local Projects

9.1 SHRP2, NCHRP, and TRB

2010 NCHRP Synthesis 403: Adaptive Traffic Signal Control Systems - Domestic and Foreign State of Practice

This synthesis study summarized the state of practice in deploying ATCSs in North America and described ATCS deployments worldwide. This study uses an ATCS definition that includes all traffic-responsive and traffic-adaptive control systems under the third generation of traffic signal control systems. The objectives of the study involved describing operational characteristics of major ATCS deployments; identifying and describing widely deployed ATCSs, including a description of their working principles and operational requirements; identifying operational advantages and disadvantages of deploying ATCSs, along with implementations issues and lessons learned; identifying institutional problems at agencies that deploy ATCSs, along with documenting their experiences; and investigating implementation costs and benefits perceived by ATCS users (*9*).

2010 Highway Capacity Manual

Chapter 35 of the Highway Capacity Manual (HCM) describes six ATM strategies (roadway metering, congestion pricing, traveler information systems, managed lanes, traffic signal control, and speed harmonization), discusses the mechanisms by which demand, capacity and system performance are affected, and offers guidance on possible evaluation methods for ATM strategies. Note that the 2010 edition of the HCM does not currently provide specific methodologies for evaluating the effects of ATM strategies. This topic is addressed in more detail by previous, ongoing, and future research studies conducted at the federal and state level (*64*). The update currently being completed for the HCM will include ATDM at a high level as well as reliability methodologies.

2011 SHRP 2 L01: Integrating Business Processes to Improve Travel Time Reliability

This report and an accompanying guide are intended to help transportation agencies to reengineer their day-to-day business practices to improve traffic operations, address nonrecurring traffic congestion, and improve travel time reliability on highway networks. The report includes several case studies from the United States and one case study from the United Kingdom. The case studies show how business processes were successfully implemented in operational areas

such as traffic incident management (TIM), work zone management, planned special-event management, road weather management, and traffic control system management. Students of traffic operations will recognize these subject areas as corresponding to five of the seven causes of nonrecurring traffic congestion. The research report and the accompanying guide also introduce one of the tools used in business process reengineering: business process mapping. Business Process Modeling Notation (BPMN), developed by the IBM Corporation, is used in this report and the guide. This approach proved highly adaptable to business processes related to traffic operations. BPMN uses a straightforward, graphical approach to business processes, illustrating them with objects, flows, swim pools, and swim lanes (*23*).

2011 SHRP 2 L06: Institutional Architectures to Improve Systems Operations and Management

The objective of this research was to undertake a comprehensive and systematic examination of the way agencies should be organized to successfully execute operations programs that improve travel time reliability. Some of the questions addressed by the research included the following:

- How do operations fit into a transportation agency's overall program?
- What changes can be made in agency culture and training to promote operations?
- Which local and regional public agencies and private-sector organizations are essential to the various aspects of operations?
- Are there emerging technologies, systems, or organizational structures that can be used to advance intra-agency and interagency communications and therefore operations?

The research investigated the potential to use a Capability Maturity Model that is used extensively in the information technology field for organizational self-assessment purposes. Elements defining different maturity levels include culture/leadership, organization and staffing, resource allocation, and partnerships.

The outcome of the study was a research report and a guide that were refined through workshops with operations managers, executives, and others. After this guide was submitted for publication, the SHRP 2 Reliability Project L06 research was converted into a web-based tool that would be user friendly, easy to access, and updatable. This work was carried out under the Transportation Research Board's NCHRP Project 03-94, Transportation Systems Operations and Management Guide. The web tool, Systems Operations and Management Guidance, is available on the AASHTO website at www.aashtosomguidance.org (*24*).

2013 NCHRP Synthesis 447: Active Traffic Management for Arterials

This synthesis documents the state of the practice associated with designing, implementing, and operating ATM strategies on arterials. The study has focused on strategies used to actively manage traffic and congestion on arterials; situations and operating conditions in which ATM strategies have been successfully and unsuccessfully deployed on arterials; and system and technology requirements associated with implementing the strategies. In addition to the above, the report provides some information pertaining to institutional issues associated with implementing ATM for arterials; operations and maintenance requirements associated with implementing these strategies; and the benefits and costs associated with implementing these strategies (*94*).

2014 SHRP 2 L07: Evaluation of the Costs and Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion

The objective of this ongoing effort (SHRP 2-L07) is to identify the full range of possible roadway design features used by transportation agencies on freeways and major arterials to improve travel time reliability, assess their costs, operational effectiveness, and safety, and provide recommendations for their use. The research products of this project include a report, a design guide, and an Excel-based tool. The guide consists of a compendium of design treatments likely to affect non-recurring congestion. It also includes quantitative and qualitative safety and operational benefits of the treatments, and assistance on how to evaluate and select design treatments. The Excel-based tool can be used by design engineers to evaluate the effects of such treatments on delay, safety, travel time reliability, and lifecycle benefits and costs (*95*).

9.2 FHWA and FTA

2006 FHWA: Ramp Management and Control Handbook

The ramp management and control handbook provides guidance and recommendations on managing and controlling freeway traffic on ramps. The goal of the guidance is to improve the use and effectiveness of ramp management and control strategies. The handbook also provides detailed information concerning the issues and concepts specific to ramp management and control that were provided in Chapter 7 of the Freeway Management and Operations Handbook (*75*).

2006 FHWA: Freeway Management and Operations Handbook

The Freeway Management and Operations Handbook provides an overview of various institutional and technical issues and includes information and guidance that will help the user to better understand the wide variety of potential strategies, tools, and technologies that may be used to support management and operation of the freeway network. Some of the topics covered in this handbook include: freeway management programs; performance monitoring and evaluation; roadway and operational improvements; ramp management and control; managed lanes; high occupancy vehicle treatments; traffic incident and special event management; management during emergencies and operations; information dissemination; transportation management centers; detection and surveillance; regional integration; and communications (*96*).

2007 FHWA, AASHTO, NCHRP: Active Traffic Management: The Next Step in Congestion Management

The purpose of this scanning study was to examine the congestion management programs, policies, and experiences of European countries (Denmark, England, Germany, and the Netherlands) that have extensively used ATM strategies including speed harmonization, temporary shoulder use, and dynamic signing and rerouting. This scan provides information on how agencies dealt with highway congestion, actively managed and operated freeways, and planned for and designed managed lanes at the facility, project, corridor, or system levels. The scan focused on managed lanes that were used to provide additional roadway capacity and operating strategies to respond to variable traffic conditions. Furthermore, the scan examined how agencies integrate managed lane strategies into their congestion management program,

network, and corridor planning and how managed lanes are considered in the context of developing highway improvement projects (*13*).

2008 FHWA: Managed Lanes – A Primer

The purpose of this primer is to provide information on managed lanes as a mobility strategy, and to assist practitioners in exploring managed lanes strategies in their own region. The primer is written for community leaders, key policy makers, and transportation agency managers. Topics covered in the primer include: defining managed lanes; managed lane success stories; issues and challenges unique to managed lanes projects; and the future of managed lanes (*97*).

2009 FHWA: Traffic Signal Operations and Maintenance Staffing Guidelines

This guidebook describes how to estimate staffing and resource needs necessary to effectively operate and maintain traffic signal systems. The project revealed that high levels of signal system performance are achieved under various conditions such as geography, agency size, system complexity, and traffic conditions. Additionally, the guidelines include a set of performance-based criteria that are focused on defining operations objectives and performance measures (*98*).

2010 FHWA: Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach - A Guidebook

This guidebook describes an approach that can be used to integrate management and operations (M&O) strategies into the metropolitan transportation planning process with the aim to maximize the transportation network performance. The recommended approach can be used to meet Federal transportation planning requirements for promoting efficient system management and operations and implementing a congestion management process (CMP). The approach is based on quantifiable operations objectives, performance measures, and M&O strategies that affect the projects selected for the transportation improvement program (TIP) (*44*).

2010 FHWA: Efficient Use of Highway Capacity Summary - Report to Congress

The purpose of this report is to provide an overview of implementation efforts aiming to increase roadway capacity by using shoulder lanes as temporary or interim travel lanes. The report includes information related to the impact of that shoulder usage on highway safety and/or accidents during operations. It also provides critical information that can be used by FHWA to formulate guidance for transportation agencies on using shoulder lanes as travel lanes. In addition to the above, the report addresses several deployment-related issues that need to be taken into consideration by transportation agencies. Some of these issues pertain to traffic control devices, design, performance measures, potential safety benefits, maintenance, enforcement roles and processes, incident response, personnel training, costs, liability, and public outreach and education (*32*).

2010 FHWA: Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations

The intent of this report is to assist transportation planners and their partners to develop a transportation plan that is based on operations objectives, performance measures, and strategies that are relevant to their region addressing community's needs and constraints and improving mobility and safety. The report contains excerpts from a model metropolitan transportation plan,

presenting the results of an objectives-driven, performance-based approach to planning for operations (*51*).

2010 FHWA: Synthesis of Active Traffic Management Experiences in Europe and the United States

This synthesis report describes both US and European techniques in Active Traffic Management (ATM). The primary focus of this synthesis is on European experience, which in some cases dates back a number of years. This report provides a compilation of lessons learned, experiences, operational results, and benefits associated with active traffic management applications. The applications included for discussion are primarily those that include variable speed management (also called speed harmonization or lane control in Europe), shoulder or line management, junction control, and directional routing. The report concludes with a discussion of the potential benefits and challenges of a system-wide application of techniques to actively manage traffic and a listing of initial implementations of European strategies in the US (*34*).

2011 FHWA, AASHTO, NCHRP: Freeway Geometric Design for Active Traffic Management in Europe

The purpose of this scanning study was to examine innovative design practices and techniques used in England, Germany, the Netherlands, and Spain to improve the operational performance of congested freeway facilities. This effort builds upon other scans that focused on congestion management and managed lane programs and aims to help transportation agencies to implement world' best practices in the United States. The report contains information about managed motorways that involve active or dynamically managed operational regimes, specific designs of infrastructure, and technology solutions. Shoulder running, variable mandatory speed limits, lane control signals, and driver information using variable message signs are some of the examples of such strategies (*20*).

2011 FHWA: Integrating Active Traffic and Travel Demand Management: A Holistic Approach to Congestion Management

The purposes of this primer are to present ATM and TDM concepts and strategies and to show the need for and benefits of using them to mitigate traffic congestion. The primer describes a conceptual framework, introduced by the Dutch Ministry of Transport, and makes a distinction between traffic management and travel demand management (*99*).

2012 FHWA: Guidelines for the Use of Variable Speed Limit Systems in Wet Weather

This report provides guidance on the use of variable speed limit (VSL) systems in wet weather at locations where the operating speed exceeds the design speed and the stopping distance exceeds the available sight distance. The guidebook includes recommendations pertaining to the design, installation, operation, maintenance, and enforcement of wet weather VSL systems. The guidelines presented in this report are intended for a broad range of audiences, from the transportation policy professionals who are considering whether or not their agency should use VSL systems, to engineers who are designing VSL systems for their jurisdictions. The information within this guidebook should be useful to anyone considering the implementation or development of a VSL system. The guidebook also includes examples of VSL implementation issues that agencies have encountered in the past (*100*).

2012 FHWA: Creating an Effective Program to Advance Transportation System Management and Operations - A Primer

The purpose of this document is to raise awareness of the opportunities for improving the effectiveness of State and local Transportation System Management and Operations (TSM&O) activities. The primer provides high-level guidance focused on key program, process, and organizational capabilities necessary for the development of more effective TSM&O strategies. It is intended for program and activity-level managers who are responsible for TSM&O functions in State, county, and local transportation agencies (*91*).

2012 FHWA: Operations Benefit/Cost Analysis Desk Reference

This Desk Reference is intended for a wide range of practitioners who are interested in conducting benefit/cost analysis of operations strategies. The guidance provided in the Desk Reference includes basic information as well as more complex analytical concepts and latest research in order to support the needs of both beginners and more advanced analysts. Some of the more advanced topics include capturing the impacts of travel time reliability; assessing the synergistic effects of combining different strategies; and capturing the benefits and costs of supporting infrastructure, such as traffic surveillance and communications. The Desk Reference is supported by an Operations B/C decision support tool, called the Tool for Operations Benefit/Cost (TOPS-BC), which is designed to assist practitioners in performing benefit/cost analysis (*71*).

2013 FHWA: Operations Benefit/Cost Analysis TOPS-BC Users' Manual

This manual provides guidance on the installation and setup of the Tool for Operations Benefit/Cost (TOPS-BC), which was developed to support key decision capabilities including: the ability for users to investigate the expected range of impacts associated with previous deployments and analyses of many TSM&O strategies; a screening mechanism to help users identify appropriate tools and methodologies for conducting a benefit/cost (B/C) analysis based on their needs; a framework and default cost data to estimate the life-cycle costs of various TSM&O strategies, including capital, replacement, and continuing operations and maintenance (O&M) costs; and a framework and suggested impact values for conducting simple sketch planning level B/C analysis for selected TSM&O strategies. The TOPS-BC tool was developed to complement the Desk Reference developed as part of the FHWA Operations Benefit/Cost Desk Reference project (*101*).

2013 FHWA: Designing for Transportation Management and Operations

This primer deals with the collaborative and systematic consideration of management and operations during transportation project design and development. It introduces the concept for designing for operations and describes tools or institutional approaches to assist transportation agencies in considering operations in their design procedures. The primer also addresses specific design considerations for various operations strategies (*49*).

2013 FHWA: The Active Transportation and Demand Management Program (ATDM): Lessons Learned

This report documents the lessons learned and critical issues related to the deployment of ATDM nationwide. Some of the topics discussed in this report include agency approaches to

incorporating ATDM in the planning process, regulatory and institutional obstacles that may need to be overcome prior to implementation, the importance of developing strong partnerships with stakeholders, the importance of outreach, addressing design exceptions created by ATDM applications, appropriate signage to adequately convey operational strategies to travelers, and operations and maintenance approaches and responsibilities (*21*).

2013 FHWA: Guide for Highway Capacity and Operations Analysis of ATDM Strategies

This guidebook includes a conceptual analysis framework, recommended measures of effectiveness, and a methodology for evaluating the impacts of ATDM strategies on system demand, capacity, and performance. The guide presents methods to analyze the varying demand and capacity conditions that facilities operate under and to apply a transportation management action to respond to those conditions. The methodology captures the effects of ATDM at a macroscopic level suitable for planning and investment decision-making but not real-time operations. This guide is designed to be used in conjunction with the Transportation Research Board's Highway Capacity Manual (HCM) for the planning, programming, and design of ATDM measures (*63*).

2013 FHWA: Minnesota Urban Partnership Agreement: National Evaluation Report

This document presents the final report on the national evaluation of the Minnesota Urban Partnership Agreement (UPA) under the United States Department of Transportation (U.S. DOT) UPA Program. The Minnesota UPA projects focus on mitigating congestion by employing combinations of strategies including tolling, transit, telecommuting/TDM, and technology, also known as the 4 Ts. The Minnesota UPA projects include high-occupancy toll (HOT) lanes, a priced dynamic shoulder lane (PDSL), active traffic management (ATM) strategies, new and expanded park-and-ride lots, new buses, a drive assist system (DAS) for shoulder-running buses, dual bus lanes in downtown Minneapolis, real-time traffic and transit information, and telework programs. This report provides information on the use of the new Minnesota UPA projects documenting changes in travel speeds, travel times, trip-time reliability, park-and-ride lot use, and transit ridership. It also presents results of surveys, workshops and interviews with various stakeholders such as Minnesota State Patrol officers, bus operators, and service patrol personnel (*12*).

2013 FHWA: Traffic Analysis Tools

The Traffic Analysis Tools Program was created by FHWA aiming to strike a balance between efforts to develop new, improved tools in support of traffic operations analysis and efforts to facilitate the deployment and use of existing tools. As part of this program, FHWA has established two tracks: the deployment track and the development track. The former focuses on the needs and concerns of the traffic analysis stakeholder community. A series of guidebooks has been published under this track covering a wide range of traffic analysis topics including:

- Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies
- Guide on The Consistent Application of Traffic Analysis Tools and Methods
- Volume I - Traffic Analysis Tools Primer
- Volume II - Decision Support Methodology for Selecting Traffic Analysis Tools
- Volume III - Guidelines for Applying Traffic Microsimulation Modeling Software

- Volume IV - Guidelines for Applying CORSIM Microsimulation Modeling Software
- Volume IX - Work Zone Modeling and Simulation - A Guide for Analysts
- Volume V - Traffic Analysis Toolbox Case Studies - Benefits and Applications
- Volume VI - Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness
- Volume VII - Predicting Performance with Traffic Analysis Tools
- Volume VIII - Work Zone Modeling and Simulation - A Guide for Decision-Makers
- Volume X - Localized Bottleneck Congestion Analysis
- Volume XI - Weather and Traffic Analysis, Modeling and Simulation
- Volume XII - Work Zone Traffic Analysis – Applications and Decision Framework
- Volume XIII - Integrated Corridor Management Analysis, Modeling, and Simulation Guide
- Volume XIV - Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling

The development track concentrates on enhancing and developing models that are easier to use, more robust in their application, and more reliable in their results. More information and tools about the Traffic Analysis Tools Program can be found at FHWA's website at http://ops.fhwa.dot.gov/trafficanalysistools/.

9.3 State and Local Projects

2013 UTCA: Implementing Active Traffic Management Strategies in the U.S.

This report presents opportunities and challenges associated with the implementation and deployment of ATM strategies in the U.S. The study objectives are to assess the state of the practice for ATM strategies, such as speed harmonization, temporary shoulder lane use, and junction control and to analyze potential operational benefits from implementing temporary shoulder lane use strategies on a segment of I-65 in the Birmingham, AL region. The report describes how microscopic simulation modeling was used to quantify the impacts of temporary shoulder lane use on traffic operations. It also documents how a detailed cost-benefit analysis was carried out to analyze the economic feasibility and potential gains from deploying such strategies (*102*).

2007 WSDOT: Active Traffic Management (ATM) Feasibility Study

This report discusses findings on ATM from the European experience and assesses several ATM techniques including speed harmonization, queue warning, junction control, hard shoulder running, dynamic rerouting, and traveler information. The report provides background information; the concept level design; signing and operation plans; the estimated capital, operating and maintenance costs; and the anticipated benefits for each ATM technique as it applies to the selected study area (Puget Sound region). Additionally, an assessment of the potential operational and policy level implementation issues is provided for each ATM strategy examined (*53*).

2008 WSDOT: Active Traffic Management Concept of Operations (WSDOT)

This document is the Concept of Operations Report (Con Ops) for the Washington State Department of Transportation (WSDOT) Active Traffic Management (ATM) Program. The

document provides a description of ATM along with its goals, vision, and high-level concepts. This report is intended for readers of all levels and provides information on the project justification, stakeholder and operational needs, system overview, operations and maintenance budgeting, and an overall concept of operations for the ATM program (*10*).

2010 Mn/DOT: I-94 Managed Lanes Study

The purpose of this study was to identify potential improvements to the physical facilities and traffic operations that existed prior to the I-35W bridge collapse (August 2007), while considering potential improvements in the I-94 corridor. The study examined options that would fit in the existing corridor envelope including a no build alternative, added general-purpose lanes, and managed lanes. Four basic alternatives including High Occupancy Toll (HOT) lanes, Priced Dynamic Shoulder Lanes (PDSL), DSL and bus shoulders, along with hybrid scenarios were examined. The alternatives included three-lane and four-lane segments, and right and left entering/exiting ramps. The report describes the benefits of Active Traffic Management (ATM) in addressing safety issues in the I-94 corridor and evaluates the most promising cost effective options (*90*).

2011 UTCM: Best Practices and Outreach for Active Traffic Management

This report provides a summary of the research conducted during a project sponsored by the University Transportation Center for Mobility related to best practices for deployment and operation of ATM strategies. This document includes a literature review related to ATM, an inventory of ATM deployments both overseas and in the United States, a summary of best practices and general guidelines for the deployment of ATM, information on the development of an ATM website and a webinar that can be used to disseminate the project findings to the transportation community (*70*).

2012 UTCM: Enhancement and Outreach for the Active Management Screening Tool

This report presents an Active Management Screening Tool (AMST) that agencies can use to better assess the potential of active management strategies for their region. The screening tool is structured to provide useful information and guidance related to active management strategies in all areas and levels of transportation planning. Active management strategies included in the tool include: HOV lanes, HOT lanes; express toll lanes; non-tolled express lanes; exclusive/dedicated truck lanes; exclusive transitways; temporary shoulder use; speed harmonization; queue warning; dynamic rerouting and traveler information; ramp metering; dynamic merge control; and automated enforcement. The AMST was improved through this project by considering recent and emerging research and domestic experiences. The project also enhanced the website developed in the previous UTCM project (2011) to incorporate changes in the newly formed Active Transportation and Demand Management program within the Federal Highway Administration (*103*).

2008 NYSDOT: State of the Practice for Managed Use Lane Projects

This report documents the existing body of knowledge regarding managed use lane (MUL) facilities. The intent of the report is to better inform decisions in the New York City region. The report covers topics such as key elements and objectives of managed use lanes; types of managed use lanes focusing on efficiency-, transit-, and pricing -centric MULs; development of MUL projects, including project conceptualization and planning, strategy selection, corridor

management, performance measurement, technology options, public participation, and policy refinement; and case studies of implemented managed use lanes in North America and Europe (*104*).

2012 VTRC: Planning for ATM in Virginia: International Best Practices and Implementation Strategies (VTRC)

This report provides four sets of guidelines on how to incorporate Active Traffic Management (ATM) applications into the planning process. The first set of guidelines identifies required infrastructure and operational conditions, such as sensor placement and queuing behavior, to apply a particular ATM technique at a particular roadway segment. The second set documents sketch planning analysis methods that can be used to estimate operational and safety benefits stemming from a particular ATM. The third set describes more detailed simulation analyses, while the fourth set deals with continued monitoring of an ATM deployment at a given site. The report also presents a framework for incorporating ATM strategies into regional planning functions (*54*).

2013 FDOT: Statewide Active Arterial Management Needs Plan

This report addresses the need to apply operational strategies of the (ITS) technology in conjunction with Advanced Traffic Management Systems (ATMS) for the arterial roadways in order to reduce unnecessary delays and improve the overall reliability of the arterial system. The report provides information and recommendations concerning the implementation of an Active Arterial Management (AAM) program within FDOT that will enhance the maintenance and operations of the network with the overall goal of reducing congestion in the short-term (*105*).

CHAPTER 10 – DESIGN CONSIDERATIONS

10.1 Overview

Most ATM strategies are compatible with existing facility designs because they are operational in nature and may not necessarily conflict with existing standards or guidelines. Past experience with ATM strategies across the United States has offered insight into how agencies are currently addressing any design challenges that may arise across the various ATM strategies and can provide guidance for future projects. For example, key design lessons learned for ATM systems identified through workshops for FHWA, are included in Table 16 (*21*).

Table 16. Key Design Lessons Learned from ATM Applications in the U.S. (21)

Agency	Design Lesson(s) Learned
FHWA	**Currently, agencies interested in proceeding with dynamic lane use control will need to get a design exception to use the shoulder as a travel lane, which can be coordinated through the FHWA Division Office.** A request for experimental treatments is required if signing will be used that is not currently in the Manual on Uniform Traffic Control Devices (MUTCD). The decision to deploy dynamic lane use control on the right or left side of the facility is case dependent and requires specific analysis. At entrance and exit ramps, an agency can either make the shoulder lane an exit-only lane or allow vehicles to travel through the interchange on the shoulder. Drainage issues need to be assessed when considering dynamic lane use control involving the shoulder.
Minnesota	**The sign structures that support the intelligent lane control signals (ILCSs) were designed with maintenance of the system in mind. The structures are a catwalk design allowing crews access to the equipment mounted over the roadway, including the hinged ILCS.** Design considerations for emergency pull-offs included a goal to locate them every half mile and make them 14 ft wide and a minimum of 200 ft long.
Oregon	Oregon Department of Transportation (ODOT) **utilizes a battery backup to help offset power and telecommunications issues in a rural location.**
Virginia	The spacing of emergency refuge areas is not necessarily consistent, but the agency installed them wherever feasible. **A different color pavement is used to differentiate the shoulder from the general purpose lanes.**
Washington	**The agency has tried to limit the usage of static signs and is keeping to MUTCD guidance for DMS spacing where possible.** Washington State Department of Transportation (WSDOT) uses a three-gantry rule whereby successive speed changes are not more than 15 mph. Gantry spacing is half a mile. Initially, speeds were held constant across all lanes, but now the system allows for speed differentials to allow higher speeds in the adjacent HOV lane, up to a 15 mph speed differential. **Camera coverage is essential to successful operations.**

Specifically, agencies have identified ways to address design issues related to dynamic shoulder use, which is one of the more prevalent ATM strategies to be deployed in the U.S. and has the

highest likelihood of impacting design features that may be in conflict with existing standards or policies. A recent survey of state agencies with experience deploying dynamic shoulder use offered the following practices, contained in Table 17 (*31*).

Table 17. Design Experience with Dynamic Shoulder Use in the U.S. (Adapted from *31*).

Design Consideration	General Experience and Practice
Minimum Shoulder Width	Acceptable shoulder width varies considerably and is most likely related to existing pavement width prior to implementation. Clear guidance needed.
Operations at Interchange	Traveling through the interchange on the shoulder is the most common method for accommodating DSU traffic at interchanges. Assessment is needed to identify treatment that remediates driver expectancy violations.
Drainage Treatment	Providing proper drainage includes moving inlets, retrofitting inlets, and/or reinforcing existing inlets or adding new ones. Need to assess ability of inlet to drain storm water adequately.
Rumble Strips	Remediation involves either moving existing rumble strips so that they are not the wheel path of the shoulder or complete removal. Guidance is needed regarding treatment and appropriate design and placement.
Fixed Objects	Treatment includes installation of new guardrails, relocation of fixed objects, and modification of existing guardrails
Bridge Clearances	If clearance is an issue, trucks may be restricted from using the shoulder.
Emergency Refuge Areas	Typical treatment is to install emergency refuge areas at regular or irregular intervals where possible. Risks and benefits need to be assessed as well as recommended spacing for optimal placement.
Changes to Pavement	Resurfacing or reconstruction is often necessary to correct for cross-slope issues and rumble strips. Guidance needed to strike a balance between costs and needs for improvement.
Shoulders on Bridges	States rarely have issues with lack of shoulders on bridges, though they are required for successful implementation if bridges present on the facility.
ITS Treatments	Typical treatments include cameras and loop detectors along with dynamic message signs. Other equipment may include sensors, ramp meters, and variable speed limit signs if appropriate. Minimal requirements need to be determined. Equipment impacts ability to be fully dynamic.
Changes in Design Standards	States typically did not develop new design standards. Greater flexibility in standards is appropriate for bus-only applications or left-side shoulder applications.

10.2 General Geometric Design Considerations

AASHTO Green Book (*1)* does not specifically identify ATM as operational approaches impacting design, but numerous design aspects of freeways are within the purview of ATM and may be essential to successful development of projects. These include the following, many of which are in need of specific guidance or standards related to their impact on ATM operational strategies (*31*):

- Edge of traveled way / roadside features;
- Design / allowed vehicle(s);
- Beginning and ending of ATM segments;
- Design speed;
- Access control, design, and spacing;
- Vertical clearance;

- Lateral clearance;
- Sight distance;
- Acceleration and deceleration distance;
- Entrance ramp and exit ramp tapers;
- Weaving area provisions;
- Shoulder width;
- Lane width;
- Should pavement;
- Fixed objects;
- Drainage treatment;
- Signing and pavement markings;
- Driver information;
- Drainage; and
- Design flexibility for future needs.

The United States can learn from the experiences with ATM in Europe given their long-standing deployment of various strategies. Specific design-related observations (*20*) include the following:

- The need for the outside shoulder to serve for disabled vehicle storage has decreased over time with improved vehicle mechanical reliability. Thus, the risk level for not providing full shoulder widths may have also decreased.
- When shoulders are used as travel lanes, typically the overall speed limit for the segment is reduced, especially if the reallocation of the shoulder reduces the overall lane widths for all travel lanes.
- When a facility cross section is reallocated to add a lane, existing lane widths may be narrowed. In some instances, no-passing restrictions are also implemented for heavy trucks.
- Typically, shoulder running is continued through interchanges to help increase capacity a key bottlenecks.
- Gantry and detector spacing for ATM applications varies depending on the information being conveyed to travelers. Overall, agencies stress the importance of having a continuum of information across successive gantries for the driver.
- Spacing of emergency refuge areas varies across facilities and countries.
- The best balance between static and variable message signs continues to be a highly debated topic.
- Some countries have implemented a performance-based design approach that is an outcome-based, operationally focused design approach that considered the goals and objectives for the facility (Germany), while others have implemented a risk-based approach to innovative design practices, providing additional flexibility to design for safe operations (England).
- Many European countries continue to evaluate cost-saving approaches to design, including the assessment of tradeoffs of increasing the spacing between gantries, detectors, and emergency refuge areas. (*20*)

In Australia, VicRoads has published documents that contain specific information related to the design of all components of lane use management, including integrated speed and lane management signs and their display; gantry arrangement, location, and spacing between and near interchanges; design, location, and spacing of emergency stopping bays; and the design, location, and spacing of variable speed limit signs (*16*).

Within the United States, FHWA does not currently have specific guidance related to ATM strategies where the design deviates from typical design practices and standards. Until such time that guidance is developed, agencies should request design exceptions ATM projects that may violate traditional design standards and policies for roadway facilities. Information is expected to be included in the pending

10.3 System Integration Considerations

As noted throughout this document, ATM operational approaches do not operate in a vacuum. They must operate within the existing infrastructure and be integrated with other strategies either in operation or planned for specific facilities or regions. Key factors identified by domestic agencies that have implemented ATM strategies, which are the key to facilitating the successful deployment of ATM, are provided in Table 18.

From the international perspective, integration is a key hallmark for successful deployment of ATM. In terms of integration, European agencies ensure that all ATM-related systems are integrated into respective traffic management centers (TMCs) for operations and maintenance. These TMCs play an integral role in such strategies as dynamic shoulder use, junction control, queue warning, dynamic ramp metering, and speed harmonization. Furthermore, agencies have learned that these strategies can easily be applied in both temporary (work zone) and permanent situations, and these agencies also emphasize a desire for consistency across borders because of the establishment of the European Union (*13*). Note that some ATM strategies covered in this document are not included in this reference.

Table 18. Key Factors to Consider to Facilitate Successful ATM Deployment (*70*).

ATM Strategy	Essential Elements
Dynamic Shoulder Use	• Temporary shoulder use is typically implemented in conjunction with dynamic speed limits. • When implemented with speed harmonization, speed limit signs and lane control signals need to be visible to all vehicles; therefore, the signs should be placed on gantries over every lane of traffic. During normal operation, i.e., when the use of the shoulder is prohibited, all the signs—including the sign over the shoulder—are blank. • Either the left or right shoulder can be used for the application, depending on the facility conditions. It is not recommended to apply shoulder use on both left and right shoulders of a facility at the same time. • To ensure the safety on the shoulder, video cameras should be placed regularly to allow operators to check for obstacles before opening the shoulder to traffic and monitor operations while shoulder use is permitted. To avoid having stranded vehicles on a used shoulder, emergency refuge areas should be located at regular intervals along the shoulder with proper signing. • Overhead guide signs should adapt to the current used width of the roadway. In other words, when the shoulder is open to traffic, guide signs should provide information to the shoulder lane as if it were a permanent travel lane. This can be accomplished with DMSs. • When acceleration and deceleration tapers are needed, additional tapers should be placed on the right side of the shoulder since the original tapers are usually on the shoulder. The additional tapers are meant to be used only while traffic circulates on the shoulder.
Dynamic Speed Limits	• The success of speed harmonization is closely linked to the extent to which drivers comply with the signing, so it is important that agencies communicate with the public and inform motorists of new measures and regulations as they are put in place. • Speed harmonization needs to be implemented in response to an actual situation. If users do not believe the system is legitimate, compliance rates will be low. Therefore, if the reason for the new speed limit is not apparent, it should be explained through appropriate signing. • Speed limit signs have to be visible to all vehicles; therefore, the signs should be placed on gantries over every lane of traffic. DMSs should be placed regularly to either give explanation for the lower speed limits or warn about extraordinary events.
Queue Warning	• Queue warning can be more effective when deployed in conjunction with speed harmonization. • When implemented with speed harmonization, the queue warning 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. • An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is optimal.
Dynamic Merge Control	• Effective dynamic merge control uses lane control signals on the main lanes and merging lanes of a freeway to dynamically adapt to varying demand. It is important that these signs be installed on gantries that are sufficient enough to ensure advance warning to roadway users. • An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is optimal. • To handle emergencies, a bypass lane for emergency vehicles, transit, or other identified exempt users is optimal. • Dynamic merge control can be implemented in conjunction with temporary shoulder use as long as the overhead gantries with appropriate signing and lane control signals are part of the implementation.

10.4 Operational Impacts on Design

In addition to the specific design and integration issues discussed previously, the design of a facility can have impacts on ATM operations. Integrating operations into design – specifically as it relates to ATM strategies – can have the following benefits:

- Increasing the benefits derived from a given infrastructure investment;
- Designing a safer facility for users, emergency responders, maintenance staff, and other operators;
- Designing for future work zones so that road users experience less interruption;
- Reducing the costs for future operational and ITS deployments; and
- Reducing congestion and improving travel time reliability (*49*).

To accommodate designing for operations, it is important to include traffic operations staff into project discussions early in the process and in all phases of design so that they can have input on key decisions that may impact overall design, operations, and long-term ease of maintenance. Furthermore, having a one stop manual for engineering and other technical information for use during project development, including a list of design considerations, can enhance opportunities and the ultimate deployment and successful operation of various ATM strategies (*49*).

10.5 Traffic Control Devices

As discussed previously, ATM operational strategies encompass a group of traffic operations strategies to increase efficiency and throughput on congested facilities using real-time, dynamic traffic management techniques. The primary method of conveying the operational approaches to travelers is through traffic control devices. One ATM strategy in particular, dynamic lane use control, uses overhead advisory signs to warn motorists of closed lanes and slow conditions ahead so that lane merges can be made in an orderly manner. These signs may also be used to display speed limits. For dynamic lane use control to work, motorists must understand whether they are allowed in a lane or not, the proper placement of their vehicle laterally within a lane, and whether the status of the lane is in flux. Thus, agencies rely on traffic control devices to communicate these dynamic operations (*33*).

Because ATM strategies are so new in the U.S., the MUTCD (*2*) contains limited material specific to dynamic lane use control. Agencies currently have had to use engineering judgment to apply the principles of the MUTCD and its existing language on lane control signals and dynamic message signs (DMSs) in an experimental manner. Important questions remain to be answered before standardization of signs and signals can be completed.

Recent research results that are pending involved human-factors testing of multiple symbols used for dynamic lane use control to assess traveler comprehension of the signs and the appropriate actions they convey to drivers. This research recommends the inclusion of additional alternatives to the MUTCD to enhance their use with ATM operational strategies (*33*).

WSDOT requested experimental permission from FHWA to vary from MUTCD for their use of overhead lane control signals in its ATM deployment. They also deployed full-matrix DMS on overhead sign bridges (spaced at ½ mil intervals) to provide appropriate traveler information and offer flexibility of use (*53*). For junction control – though not currently operational in Seattle – WSDOT developed a hybrid static sign with a DMS panel showing the down arrow and "EXIT ONLY" (shown in Figure 8) to convey to travelers that the exit configuration has changed (*10*). This design also allows for the flexible and dynamic use of the junction control concept.

The Florida Department of Transportation has also identified best practices in the use of hybrid static-dynamic signs for a variety of uses and offers the flexibility needed for ATM applications.

Their guidance includes 10 applications for the use of these signs, as shown in Table 19, all of which could be suitable on both freeways and arterials as appropriate (*106*).

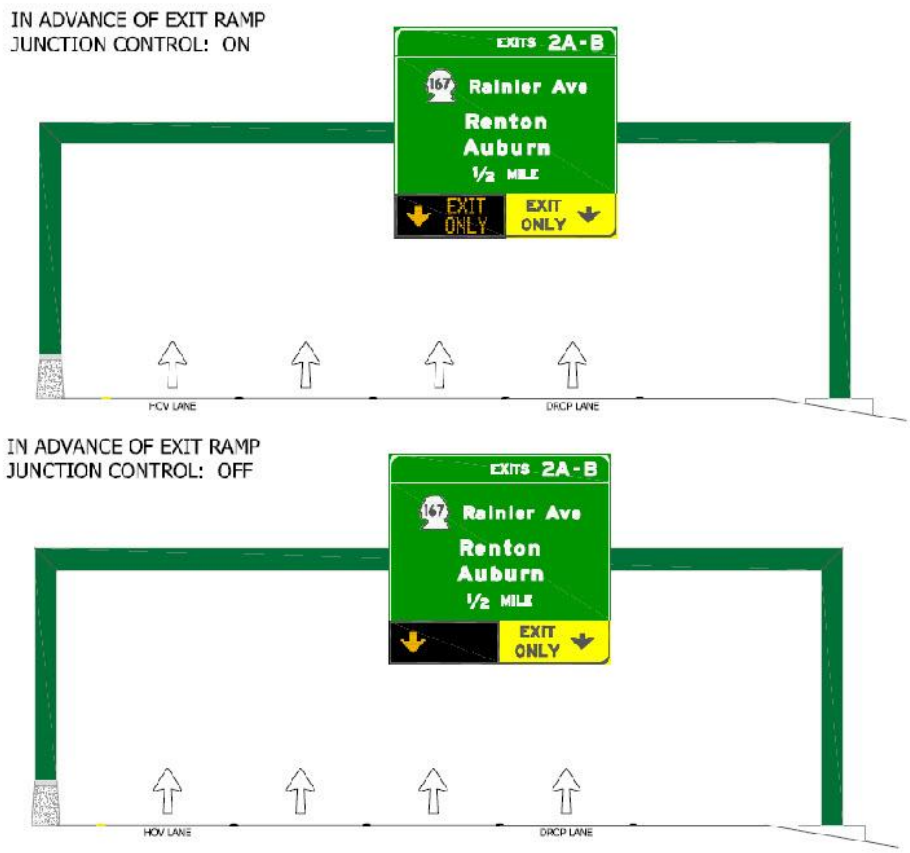

Figure 8. WSDOT Junction Control Conceptual Sign Design at Exit Ramp (*10*).

Table 19. FDOT Applications of Hybrid Static-Dynamic Signs (Adapted from *106*).

Application	Specific Situations
Countdown	Drawbridge opening School zone traffic diversion Traffic diversion to avoid train crossing Arrival time information at bus/train stops Train arrival time information on freeways
Travel Time Information	Travel times on distance signs Comparative travel times for express lane facilities
Speed Control	Automated speed control Advisory progression speed
Other	Parking availability information

One TCD application that has been deployed in Europe and has been experimented with in the U.S. is in-pavement lighting to supplement traditional striping. As part of the UPA project in Minnesota, Mn/DOT installed in-pavement lighting to support the PDSL application. While the lighting installation survived the winter months, it was terminated due to corrosion (*12*).

A concern with all traffic control devices installed within the roadway environment is the ability for drivers to see the signs with enough time to correctly respond to the messages being conveyed. An analysis of the study simulated driver performance for the managed motorway concept in Australia assessed three sign scenarios: all signs mounted on an overhead gantry, all signs mounted on the shoulder, or a mixture of both (*107*). The purpose of the study was to determine if drivers had difficulty seeing the signs within the roadway environment, particularly if heavy trucks obscured their view. No practically significant differences were observed between the three scenarios, though some minor statistical differences were scene at some speeds (*107*). However, sign placement and design for shoulder mounted signs can reduce the likelihood of signs being obscured by heavy trucks when a significant proportion of them are in the traffic stream (*108*), and potential obscuration of shoulder-mounted signs in the simulation did present some concerns to subjects (*109*). However, overall, subjects understood the scenario and the managed motorways layout with all lanes running (ALR), no shoulders, and emergency refuge areas.

CHAPTER 11 – IMPLEMENTATION & DEPLOYMENT

11.1 Overview

Fully dynamic ATM strategies were recently introduced in the U.S., and there is a relatively low-level of comfort in implementing and deploying these strategies. The growing interest in ATM brings to the forefront the need for information and guidance on critical issues related to implementation and deployment of ATM strategies. Similar to many investment projects undertaken by transportation agencies, a successful implementation of ATM strategies requires several elements to be considered including: political support, adequate funding, detailed planning and design of the project under consideration, identification and engagement of stakeholders within and across agencies, outreach and marketing, and appropriate technological expertise (*94*).

ATM implementation starts well before strategies are physically deployed and finishes after the strategies have been successfully tested in the field. Prior to considering any strategy implementation and purchasing relevant equipment, the project team must evaluate the implementation potential by conducting the following activities:

- Review speed, congestion, and collision patterns in each corridor for roadway segments that are most likely to benefit from potential ATM strategies;
- Determine which ATM strategies could feasibly be implemented to maximize efficiency, improve throughput or minimize collisions; and
- Assess the roadway geometry to determine if any physical restrictions would preclude the application of the identified ATM strategy (*53*).

After the viability of the project has been determined, project administrators must coordinate with all stakeholders and provide support for implementation. This involves establishing minimum requirements to successfully deploy and operate the ATM strategies, as well as determining resources, hardware/software needs, budgetary limitations, and policy directives. Then practitioners must develop marketing approaches and tools to educate the driving public and inform various agencies about the anticipated benefits of the project. As part of this effort, a series of parties must be targeted including state, regional and local transportation agencies, law enforcement, emergency services, local transit operators, media outlets, and community groups (*75*).

Literature reveals that during the implementation and deployment stages of a project, agencies often encounter several challenges related to practical limitations of strategies, determining speed limits, installing traffic control devices, enforcement strategies, and incident management. The overall success of an ATM strategy, as well as its acceptance and perception by the public, largely rely on how these issues are addressed by the implementing agency. For example, in the case of dynamic shoulder use and dynamic speed limits, enforcement needs to be in place to ensure compliance, which is directly related to the success of these strategies. However, practice has shown that both automated and manual enforcement can pose challenges that agencies need to address prior to implementation (*110*). Another example is Minnesota's speed harmonization strategy that is designed to dynamically set and post advisory speeds on a section along I-35W.

The advisory speeds displayed by the system are often lower compared to the operating speeds that can be accommodated by the corridor. The end result is longer travel times that contradict with the objective of other improvements that aim at reducing travel times in the same corridor (*12*). Consequently, implementing various strategies may complicate the assessment of their impacts and benefits (*21*).

Throughout the lifetime of an ATM strategy, general institutional or other unexpected issues may emerge that require agencies to take appropriate mitigation measures (*21*). Inadequate funding, legislative issues, safety problems, or other inter-agency and intra-agency issues can impede the project implementation and deployment. A major challenge associated with institutional issues is the lack of consistent and systematical approaches to address them. Overcoming such issues involves a series of actions such as early engagement of stakeholders, enhanced coordination, marketing, and collaborative planning and development (*34*). Past experiences and lessons learned from other agencies can be useful not only during the planning and design phases of a project, but also during implementation and deployment as unforeseen situations arise (*21*). Agencies need guidance regarding implementation approaches and tradeoffs along with related policy issues to ensure optimal conditions for potential success.

11.2 Project Implementation

The first step in project implementation is the development of the concept of operations (ConOps). A ConOps is developed prior to a project's design and is what informs that design. The ConOps describes the characteristics of the proposed system and in some cases may involve the system engineering process for developing it (*111*). Based on the requirements defined in the ConOps document and prior to deployment, agencies must define the overall framework for the system. FHWA's *Systems Engineering Guidebook for ITS* can be used as a guide in this process (*111*).

11.2.1 Design Review

According to the guide, there are two levels of design: high-level and detailed design (*111*). The purpose of high-level design or architectural design is to define an overall structure for the project that may consist of several computer systems, a communications network, distributed devices, facilities, and people. Detailed design involves specifying these components in detail and defining how the system requirements will be met. Based on these specifications, the software team develops the software modules and the hardware components are fabricated or purchased (*111*).

There are several system design elements that need to be reviewed not only to ensure that the project requirements are met, but also to avoid potential issues during implementation or deployment. These elements include, but are not limited to, different types of detectors and sensors, cameras, communications, power, operator confirmation and override, and a police notification process. For example, prior to implementing a VSL system, the project team must review whether there is adequate speed and visibility sensor coverage in the vicinity of each VSL sign (*100*). Another important consideration is to ensure that all the actions and changes (e.g., speed display changes) of the system are safely stored in a log and backed-up frequently (*100*).

Although FHWA's guidebook provides useful information on how systems engineering can be applied to implementing Intelligent Transportation Systems (ITS), it does not include specific information and recommendations tailored to each ATM strategy. Literature reveals lack of guidelines with respect to design review of ATM strategies. Furthermore, the majority of the research studies do not describe system design considerations in detail. Even those that have tested various ATM strategies in the U.S. are based on assumptions, design configurations, and concepts used by previous works.

Previous implementation efforts show that system and technology requirements vary, depending on the strategy under consideration, pre-existing technology, and the capabilities of each traffic management center (TMC) (*94*). For example, continuous real-time monitoring of arterial performance requires permanent traffic detectors in the field and capacity communications between the field and the central office. Dynamic signal control requires software at the control center and/or in the field. Dynamic geometric control requires display hardware in the field and software in the field and/or in the control center. Dynamic traveler information may require display hardware in the field with communications between the central office and the field, or it may require cell phone and web-based technologies (*94*).

The FHWA *International Scan Tour Report* (*13*) lists a series of elements required for the following strategies: speed harmonization, temporary shoulder lane use, queue warning, dynamic merge control, truck restrictions, dynamic rerouting and traveler information, and automated enforcement. For example, according to the report, a speed harmonization system should include the following:

- Sufficient sensor deployment for traffic and weather monitoring to support the strategy;
- Adequate installation of sign gantries to ensure that at least one speed limit sign is in sight at all times;
- Placement of speed limit signs over each travel lane;
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical that this expert system be reliable and accurate to gain the trust and acceptance of the public;
- Connection to a traffic management center that serves as the focal point for the system;
- Passage of enabling legislation and related laws to allow for dynamic speed limits;
- Uniform signing related to speed harmonization and its components;
- Modeling tools to assess the impacts of speed harmonization on overall network operations;
- Closed-circuit television cameras to support the monitoring of the system;
- Dynamic message signs to provide traveler information and regulatory signs as appropriate; and automated speed enforcement to deter violations (*13*).

Similar system elements can be found in this report for the remaining ATM strategies (*13*). A similar example is a study undertaken in 2012 by the Virginia Center for Transportation Innovation and Research (VCTIR). The final report includes several criteria and elements needed for three strategies. Those required for hard should running techniques include:

- Deploy with VSLs
- Uniform treatments through entrance and exit ramps
- Adequate installation of sign gantries

- Placement of lane control signals over each lane
- Uniform marking of shoulders
- CCTV cameras
- Provision of pullouts for minor incidents with detection
- Lighting to enhance visibility of shoulder
- Incident management capability and incident detection
- Connection to TOC (*54*).

Similar elements are provided for queue warning systems and dynamic junction control strategies (*54*).

11.2.2 Schedule/Installation

After reviewing and ensuring that all requirements have been met and the required system components (e.g., hardware, software, other equipment) have been included, the project team must develop an implementation schedule and arrange all the details for the installation of the system. This mainly involves installing new software and hardware, integrating existing with new technologies, and installing equipment in the field. These activities require coordination among a series of stakeholders including, but not limited to, the following:

- Personnel responsible for installing the equipment in the field;
- Personnel responsible for modifying, upgrading, and integrating old with new software and hardware;
- System operators;
- Ground personnel such as law enforcement, first responders, and other incident management staff; and
- Personnel responsible for operation and maintenance;

As stated previously, depending on a wide variety of factors such as roadway and design characteristics of the segment examined, existing facilities and equipment, and technical capabilities of the TMC, each ATM strategy requires different system components. As a result, the installation of these components cannot be governed by general rules. Previous implementations show that a successful installation largely relies on enhanced and early coordination among the involved parties as well as on a comprehensive implementation plan that addresses all possible details that may affect this effort.

11.2.3 Testing and System Acceptance

Prior to deployment and after the system has been installed, it must be tested to ensure that all its components function properly and meet their requirements, all stakeholders fully understand their duties and their roles, and the system serves its intent and the goal of the ATM strategy. Providing accurate and reliable information to the system is necessary for the safe and effective implementation of any strategy. This is important to earn drivers' trust and compliance for the system (*53*). Additionally, the algorithms of the system must operate in real-time and minimize human control, except for situations where operators must confirm certain pre-set actions (*34*). Currently, there are no standard testing procedures and protocols that could assist agencies in testing the system. This could be another topic for future consideration.

In order to test technical systems and equipment, several ATM deployments in the U.S. have begun with an initial demonstration or pilot project (*112*). In addition to testing the system, these pilot studies can serve other needs and purposes as well. For example, they can be used as a mechanism to assess the benefits and impacts of the strategies deployed. Another application is to test transit signal priority along with other traffic signal control techniques and thus, alleviate potential concerns related to traffic operations. In general, such pilot projects form the basis to gain system acceptance and build trust that would enable further implementation of a strategy across a larger region (*6*).

11.2.4 System Phasing and Development Considerations

A review of past works in this area unveils that there are no specific guidelines on what the most appropriate deployment phases of an ATM system are. As mentioned earlier, some studies have attempted to list the most important data types, along with essential and preferable elements required for a strategy. Nonetheless, they do not provide information with regard to system phasing during deployment. This is a topic that needs to be examined in the future.

11.2.5 Coordination with Local and Regional Agencies

The majority of mobility issues are concentrated in the cities and urban suburbs, yet transportation departments and FHWA are not responsible for the urban infrastructure. With that said, state agencies need to create partnerships with their cities, metropolitan planning organizations (MPOs), tolling agencies, regional planning authorities, transit agencies, elected community leaders, court personnel, environmental groups, communications industry, high-tech firms; and other similar stakeholder groups. Previous studies have emphasized that poor coordination among stakeholders is an institutional issue that can affect the successful implementation of an ATM project (*53*). Therefore, fostering collaborations at the beginning of the process with these entities and engaging as many potentially affected stakeholders as possible are essential to receive continuous support, avoid potential conflicts, and gain advocates for ATM (*21*, *104*).

Coordination with law enforcement and emergency response is imperative. ATM techniques must be discussed with the state patrol and other key stakeholders, who must also have a good understanding of the purpose and the operation of the ATM strategies. All parties involved must be united when it comes to enforcement. For example, in the case of speed harmonization, enforcement should focus on speed violators. Officers need to know any time of the day what the legal speed limit is and when the last change to the speed display was made. Practitioners must also discuss and identify with enforcement agencies the locations where law enforcement can be safely stationed to view compliance and where vehicles can be safely pulled over without affecting traffic operations (*6*). In the case of hard shoulder running, enforcement must concentrate on traffic safety, whilst emergency responders must understand that their response time will most likely be affected by the shoulder (*9*, *53*). Moreover, enforcement personnel needs to be involved during planning and design activities of an ATM project in order to provide input on how the system can accommodate enforcement and how officials should enforce it (*34*).

As noted in a previous section, the project team must collaborate with legislators, decision-makers and governmental officials, who need to fully understand the ATM concepts (*10*). Early coordination with legislators is necessary to include ATM strategies in proposed budgets or add

them to contracts for construction mitigation. Likewise, decision-makers must engage in the early stages of the process having a supporting role. Local agencies must also participate in discussions with the other stakeholders to identify potential issues that may arise in the future (*53*). Additionally, stakeholders should collaborate with other state agencies that have already deployed similar techniques as they can benefit by sharing their experiences, lessons learned, and strategies developed to address institutional and engineering issues (*34*). Lastly, early coordination should take place internally among executives, maintenance personnel, planning and budgeting staff, policy makers, and operations staff who would be implementing the ATM strategies. All involved parties share the goal of enhancing the network performance and contribute to the development of different system components that nonetheless, need to be harmonized for the successful deployment of a holistic strategy (*34*, *113*).

Several examples of stakeholder agreements can be found in the literature. For the expansion of I-10 Katy Freeway project, the Texas Department of Transportation (TxDOT), the toll agency (Harris County Toll Road Authority), transit operator (Houston METRO), and the MPO (Houston-Galveston Area Council) came into an agreement about expansion project funding, construction, and operational responsibilities (*114*, *115*). In the case of the I-25 HOT lane in Denver, an intergovernmental agreement between the DOT, transit operator (Regional Transportation District), and enforcement agency (the Colorado State Patrol) specified evaluation and monitoring roles and a communication decision-making process for the facility (*104*). For the Long Island Expressway HOV facility, NYSDOT formed an HOV task force in 1991 that consists of representatives from local government, law enforcement, mass transit agencies, the business community, and environmental groups. The intent of the Task Force is to provide ongoing input on HOV-related issues (*104*, *116*).

11.3 Upgrades and Expansions

The most efficient and expedient way to implement any selected ATM strategy is to consider it during the planning and design stages of a project.

Currently, there are limited guidelines regarding potential upgrades and expansions of existing systems. In 2009, the Center for Transportation Research conducted a study that discusses what is recommended or what has been used in the past for each infrastructure element necessary to deploy speed harmonization and peak period shoulder use. Information is provided to help practitioners compare the existing features of a candidate site to the desired ATM features and also to identify the corresponding capital and operational/maintenance costs necessary for the improvements (*74*). The study concluded that each candidate site exhibits unique characteristics and challenges that are not addressed in the guidance. Human judgment is essential to identify solutions and appropriate mitigation measures (*74*). Future research is needed to address this gap in the literature.

Another area that needs further investigation is how ATM strategies can incorporate connected and autonomous vehicle technology, which has received significant attention over the last few years. Connected vehicle technologies use leading-edge wireless communications, on-board computer processes, advanced vehicle sensors, GPS navigation, and “smart” infrastructure to communicate with the driver, other vehicles, roadway infrastructure, and web-services. For example, they allow the vehicle to identify threats and hazards on the roadway and transfer this

information over wireless networks to give drivers alerts and warnings. At the core of this technology is a networked environment supporting very high speed transactions among vehicles (V2V), and between vehicles and infrastructure components (V2I) or hand-held devices (V2D) to enable numerous safety and mobility applications. The technologies collect information that could lead to improved traffic signal control, ubiquitous traveler information, better transportation planning, and reduced cost for gathering information about the performance of the transportation system. This technology can also be used to improve vehicle safety, vehicle efficiency, and travel times.

Fully automated or autonomous or self-driving vehicles do not require direct driver input to control the steering, acceleration, and braking of a vehicle. They are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode. The National Highway Traffic Safety Administration (NHTSA) has defined five levels of vehicle automation, ranging from Level 0 (no automation) to Level 4 (full self-driving automation). Currently, only Level 0 through Level 2 are available to the public. Several ongoing efforts focus on researching, developing, and testing Level 4 automation technologies in some states that have passed enabling legislation. At the same time, more states are working towards passing relevant legislation.

Although the benefits associated with the use of such technologies are worthwhile, a series of potential challenges and issues pertaining to vehicle connectivity and autonomy must be addressed. These issues pertain to privacy, security, data analytics, and aggregation due to the abundance of data related to this type of vehicles. Future efforts must also concentrate on developing specifications and standards on what type of technologies can be incorporated into different ATM strategies and under what circumstances.

CHAPTER 12 – OPERATIONS & MAINTENANCE

As with most ITS and other advanced technology deployments, operations and maintenance are critical to ensuring the long-term success and benefit of ATM strategies. Operations involves the application and integration of programs, technologies, and business processes that govern the day-to-day use and functioning of the ATM strategies to response to situations and circumstances generated by traffic demands and environmental condition. Maintenance involves those actions, both corrective and preventative, taken by agencies to sustain and continue the useful life those programs, technologies, and business processes.

As ATM deployments are relatively few in the United States, limited guidance exists in the literature related to the operations and maintenance of ATM strategies. Much of the guidance available through the current literatures relates to specific applications of ATM strategies – namely variable speed limits, and hard shoulder running. Interviews with current and developing ATM deployments, such as in Washington, Minnesota, California, and Oregon offer another potential source of obtaining guidance and lessons learned relative to operating and maintaining ATM deployments.

12.1 Operations

The literature was very clear that planning for operations should begin at the early stages of project development. FHWA's *Guidelines for the Use of Variable Speed Limit Systems in Wet Weather* (*34*) provided recommendations on the need and content of an Operations and Maintenance Plan for VSL systems. The report listed important elements related to VSL that should be clearly addressed in an O&M Plan, including the following:

- Identification of the personnel responsible for O&M;
- Identification of human resources and facilities (including tools) needed for O&M;
- Identification of funding sources for on-going O&M;
- Descriptions of O&M activities to be performed;
- Descriptions of the checks to be made and the data to be collected for system health and performance monitoring;
- Necessary training for operators and maintenance personnel on a continuous basis;
- Identification of other documents used in O&M such as relevant policy directives, system configuration documents and O&M manuals;
- Preventative as well as emergency maintenance procedures and activities; and
- Life expectancy of system and end-of-life replacement and upgrade processes.

Agencies need to develop policy decisions on implementation, operation, maintenance, enforcement, to ensure successful deployments of ATM systems. Potential policy decisions need to be made in tandem with the planning and implementation. Some strategies (such as hard shoulder running) may require special procedures that clearly describe how to activate and deactivate the strategies (e.g., opening and closing the shoulder to traffic operation), and assign roles and responsibilities for operators both in the field and in the TMC. Moreover, considerations related to maintenance, compliance, and enforcement, and institutional issues (such as regulatory and legal issues, finance, organization and management issues, and human resources) must be studied carefully (*89*).

12.1.1 Standard Operating Procedures

Standard operating procedures are the rules and procedures that define and govern the day-to-day use of the system in response to different operating and environmental conditions. These include but are not limited to: personnel and organizational structure, hours of operation, staffing requirements, operations concept, policies and procedures, control plans, remote operation, security procedures, startup and shut down procedures, failure recovery, command structure, emergency contact numbers, notification procedures, operational logs, maintenance policies, procedures, and plans, data archiving and warehousing, emergency procedures, and interagency coordination (*117*).

Reference (*16*) contains operating principals associated with lane use management, variable speed limits and traveler information displays for Victoria, Australia. These operating principles include the following:

- Fundamental rules preventing conflicting symbols and policy rules for managing traffic with lane use management systems;
- An overview of how the ATM system will operate during incident conditions, with sign failure, during congestion, and under free-flow condition; and
- General operating principles for traveler information systems.

Reference (*74*) provides the specific recommendations on the following for the use of speed harmonization and peak period shoulder running strategies:

- Use and need for traffic surveillance equipment;
- The types and placement of ITS technologies needed to execute a response; and
- Use and need for outreach and public education before commencing operations.

The *Ramp Management and Control Handbook* (*64*) presents guidelines on the types of operational policies and procedures that need to be in play before beginning ramp management procedures (including ramp metering). These include hours of operations; monitoring needs; staffing and other support tools and procedures [including operations checklists, after hours on-call roster, operator logs; agency and jurisdictional contacts; and media procedures (i.e., media communications policy].

Concepts of operations can be very important in development standard operating procedures. As part of the initial system engineering for the Seattle ATM signage deployment, WSDOT, in describing their Operational Scenarios, provided their initial vision on how the VSL/queue warning; hard-shoulder running, and junction control and travel time signs would operate during different scenarios -- both as part of a basic freeway section and as part of a HOT/HOV operation. The operational scenarios also described staffing and maintenance needs to achieve a desired level of operation (*10*).

The *Handbook for Developing a TMC Operations Manual* (*117*) provides recommendation and guidance on the elements that need to be addresses as part of a standard operating procedure for traffic management procedures. The elements include the following:

- Daily Operations – This sections includes rules and procedures relate personnel and organizational structure, hours of operation, staffing requirements, operations concept, policies and procedures, control plans, remote operation, security procedures, startup and

shut down procedures, failure recovery, command structure, emergency contact numbers, notification procedures, operational logs, maintenance policies, procedures, and plans, data archiving and warehousing, emergency procedures, and interagency coordination.

- Operational Concepts – This section provides information related to traffic control concept strategies, traffic monitoring procedures, data analysis and warehousing, interagency coordination, interjurisdictional coordination, and emergency procedures.
- Control System Operations Procedures – This section includes information related to the locations of devices, access security, system layout, first suppression, power sources and locations, etc.
- Maintenance Procedures – This section includes information on startup/shutdown and failure recovery procedures; routine, preventative, and emergency maintenance needs, system operational logs and reports; and risk management procedures.

12.1.2 Performance Management and Budgeting

FHWA (*118*) defines performance management as a "strategic approach that uses information to make investment and policy decisions to achieve [specific] performance goals." Performance management includes the following:

- A regular, ongoing process that is systematically applied;
- Provides key information to help decision makers to understand the consequences of investment decisions;
- Improvement communications between decision makers, stakeholders, and the public; and
- Ensures targets and measures are developed in cooperative partnerships based on data and objective information.

Only a few reports provided very specific recommendation related to the processes, procedures, and technologies need to perform performance monitoring and linking performance management objectives to budgeting. FWHA's *ATM Screening Guidance* (*6*) indicates the need for and importance of developing operating, monitoring, and maintenance procedures for all ATM strategies.

Reference (*13*) contains functional requirements and "advice" for building and deploying VSL across multiple countries in Europe. The report recommends that VSL system should have a log that stores data about posted speed limits, error messages, etc. System log reports are critical for maintenance and legal purposes. The report also stresses the importance of verifying that VSL system operator correctly and show relevant speeds according to the conditions. This means that much effort should be put into quality control and maintenance.

12.1.3 Staffing and Knowledge, Skills, and Abilities (KSAs)

Depending on the type and size of the ATM strategies to be deployed, agencies may find it necessary to increase the workload of the existing TMC operators, and/or acquire additional staff. Even with systems that are highly automated, operators may be responsible for monitoring and possible manual override certain ATM strategies. Procedures are needed to provide staff with the information needed to do their job – which includes both technical and human resources or personnel procedures.

A few reports were identified that discussed staffing and training needs related to ATM deployments. Concerns were expressed about potential operator workload issues, particularly with the need to operate system 24 hours a day, 7 days a week (*53*).

Regarding both operations and maintenance, additional staffing requirements will likely be necessary for ATM deployments. Although their systems have a high level of automation, both the Minnesota Department of Transportation (Mn/DOT) and Washington State Department of Transportation (WSDOT) identified the need for additional operators in their TMCs to monitor and manage the ATM lane control signage. Ultimately, deploying hundreds of additional dynamic ATM signs to a corridor increases responsibility and expectations that the agency will deploy accurate, reliable information in a timely manner. The need for staff may be less for junction control or arterial applications, which may be more automated and require less frequent manual checks (*53*).

Reference (*21*) provides the following specific lessons learned related to operations and maintenance staffing needs for ATM:

- Deployments must be accompanied by increase in FTE to operate and maintain.
- The capability of staff must be consistent with the level of deployment of the technology.
- The staff need to have skill and expertise to operate system as intended

12.2 Maintenance

System maintenance refers to “a series of methodical, ongoing activities designed to minimize the occurrence of systemic failures and to mitigate their impacts when failures do occur. Examples of system maintenance activities include replacing worn components, installing updated hardware and software, tuning the systems, and anticipating and correcting potential problems and deficiencies. It also includes an infrastructure and procedures for measuring and monitoring maintenance activities.

As part of the TMC pooled fund study, researchers produced *Guidelines for Transportation Management Systems Maintenance Concept and Plans* (*119*). This document provides technical guidance to practitioners on 1) defining a system’s maintenance concept, 2) determining the elements to include in the concept, 3) integrating the maintenance concept into all phases of system life-cycle. A "maintenance concept" articulates the essential reliability and performance measures necessary to meet stated operational concepts defined for a traffic management system or strategy. Just as the concept of operations drives the system functional requirements, the maintenance concept drives the maintenance requirements. These maintenance requirements then become enabling requirements for input into the system design phase and other implementation and operation phases in the TMS life cycle. This document provides this guidance and identifies:

- How to identify, justify, and document the potential components of a maintenance program. Such a program can provide the necessary resources, environment, policies, procedures, and support services needed to maintain a TMS.
- The need for a multi-year maintenance program plan, including the a) potential components, b) processes, c) stakeholders to be involved, and d) resources required to support the program.

- The idea of a "maintenance concept," the appropriate elements comprising a maintenance concept, how the maintenance concept can be used to develop system and functional requirements, and how the maintenance concept can be used to develop an operations concept for TMS.
- Policies, procedures, system and functional requirements, equipment, resources, and services, and other potential activities needed to maintain and support the TMS.

12.2.1 Infrastructure Maintenance

ITE has developed a handbook related to the maintenance of traffic signal systems (*120*). This provides specific recommendations related to establishment of a maintenance program for traffic signals. This manual includes information on the following related to traffic signal systems:

- Risk management
- Core documentations and processes
- Outsourcing maintenance
- Construction and inspection checklists and approvals
- Preventative maintenance activities
- Reactive (or response) maintenance activities
- Design modifications to support maintenance
- Asset management

Several studies mentioned the need for considering maintenance as part of the initial design of the ATM deployment (*49*, *121*, *32*). Reference (*49*) identified two ways in which maintenance could be addressed at the design phase. First, maintenance personnel should be involved at the design process to assess the "maintainability" of features, such as noise walls, median barrier and ITS device locations. Second, design manuals should include processes and checklists to aid designers in obtaining sign-off on plans by maintenance personnel. The report also provided specific examples of how maintenance need could be addressed at the design level.

12.2.2 Maintenance of Strategies

In addition to maintaining the physical infrastructure, a need also exists to maintain the strategies themselves to keep them operating at maximum efficiency. Traffic volumes and patterns change over time, and to keep system operating at their maximum efficiency, agencies need to have processes and procedures in place to keep strategies “fine-tuned” to changing traffic conditions. Examples of strategy maintenance activities might include the following:

- Recalibration of algorithm thresholds.
- Re-optimization of traffic signal or ramp signal timing plan parameters.
- Development of special response plans to be activated during emergency or special events.

One important element related to the maintenance of ATM strategies is configuration management. Configuration management (CM) is a systems engineering process for establishing and maintaining consisting of a product’s performance, functional and physical attributes with it requirements, and design and operational information throughout the life of the system. Configuration management establishes and protects the integrity of a product or product component throughout its lifespan, from determination of the intended users’ needs and

definition of product requirements through the processes of development, testing, and delivery of the product, as well as during its installation, operation, maintenance, and eventual retirement (*122*).

A Configuration Management plan is the defining guidebook for a CM program. It defines all of the procedures, organizational responsibilities, and tools to be used within the CM process. The plan is the backbone of a CM program, and as such, must either include well-developed, detailed procedures or refer to their locations in other documents. A typical CMP contains includes the following: (*123*)

- General {system} definition and scope.
- Core CM process procedures.
    - Configuration identification.
    - Change control.
    - Configuration status accounting.
    - Configuration audits.
- CM management.
- Organization, roles, and responsibilities.
- Programmatic and organizational interfaces.
- Definitions of terms.

12.2.3 Staffing Maintenance & Training

Ensuring successful operation of ATM strategies and systems requires qualified and well-trained professionals. Successful implementations of ATM strategies rely on expertise and support at all levels, from maintenance and engineering technicians to traffic operations engineers. Regardless of the number of staff or the job classification, certain core functions must be performed to develop and sustain good operations. These functions require specific knowledge, skills, and ability. The depth of knowledge needed varies by staff position and subject matter (*98*).

Reference (*58*) provides user perceptions on the training, operations, and maintenance requirements of adaptive traffic control systems (ATCS). The report found that training is critical to keeping the system operational. The report also stated that it might take a long time for staff to be proficient with understanding how ATCS actually works; and that ATCS components are more demanding than conventional traffic control systems. These concepts definitely apply to ATM strategies and systems as well.

CHAPTER 13 – MONITORING & EVALUATION

Active traffic management (ATM) strategies are relatively new to the United States, and thus have limited examples of monitoring and evaluation. As such, more in-depth analysis of any ATM deployment may be warranted to examine and refine design and operations. Two ATM deployments of particular interest in the United States are those in Minnesota and Washington that include dynamic lane control and dynamic speeds, as well as a dynamic shoulder lane segment. The United Kingdom program called Managed Motorways offers a European example of a major ATM deployment with extensive evaluation. Individual elements of ATM, such as adaptive traffic signal control and adaptive ramp metering, have also been deployed.

Although there is no specific guidance for monitoring and evaluating ATM deployments, reports from Minnesota (*12*, *37*, *124*), Washington (*41*), and the United Kingdom (*18, 19*) offer examples of the planning, data collection, and analysis efforts necessary for producing comprehensive evaluation reports, as well as the challenges associated with those efforts.

The ITS Evaluation Resource Guide from the Research and Innovative Technology Administration (*125*) offers guidance that can be readily adapted for monitoring and evaluating ATM deployments. Additionally, the FHWA Work Zone ITS Implementation Guide (*126*) is a useful reference for monitoring and evaluation that can be extended to an ATM deployment, as it encompasses ATM strategies as they apply to work zones such as queue warning, dynamic merge, and dynamic speeds.

13.1 Monitoring and Evaluation Planning

Monitoring and evaluation for an ATM project can vary significantly, depending on the nature of the deployment. For example, the Urban Partnership Agreement (UPA) National Evaluation Plan for Minnesota (*37*) and Washington (*41*), as well as the associated series of test plans for each site document the extensive data collection and analysis effort involving traffic and safety data, as well as a number of surveys and interviews for these sites (*33*, *39*). However, Mn/DOT and WSDOT also conducted numerous smaller scale public surveys and internal quantitative evaluations of their ATM system to monitor and evaluate performance (*33*).

The ITS JPO at USDOT has developed the ITS Evaluation Resource Guide, which is a six-step process for evaluating ITS projects and is shown graphically in Figure 9 (*125*).

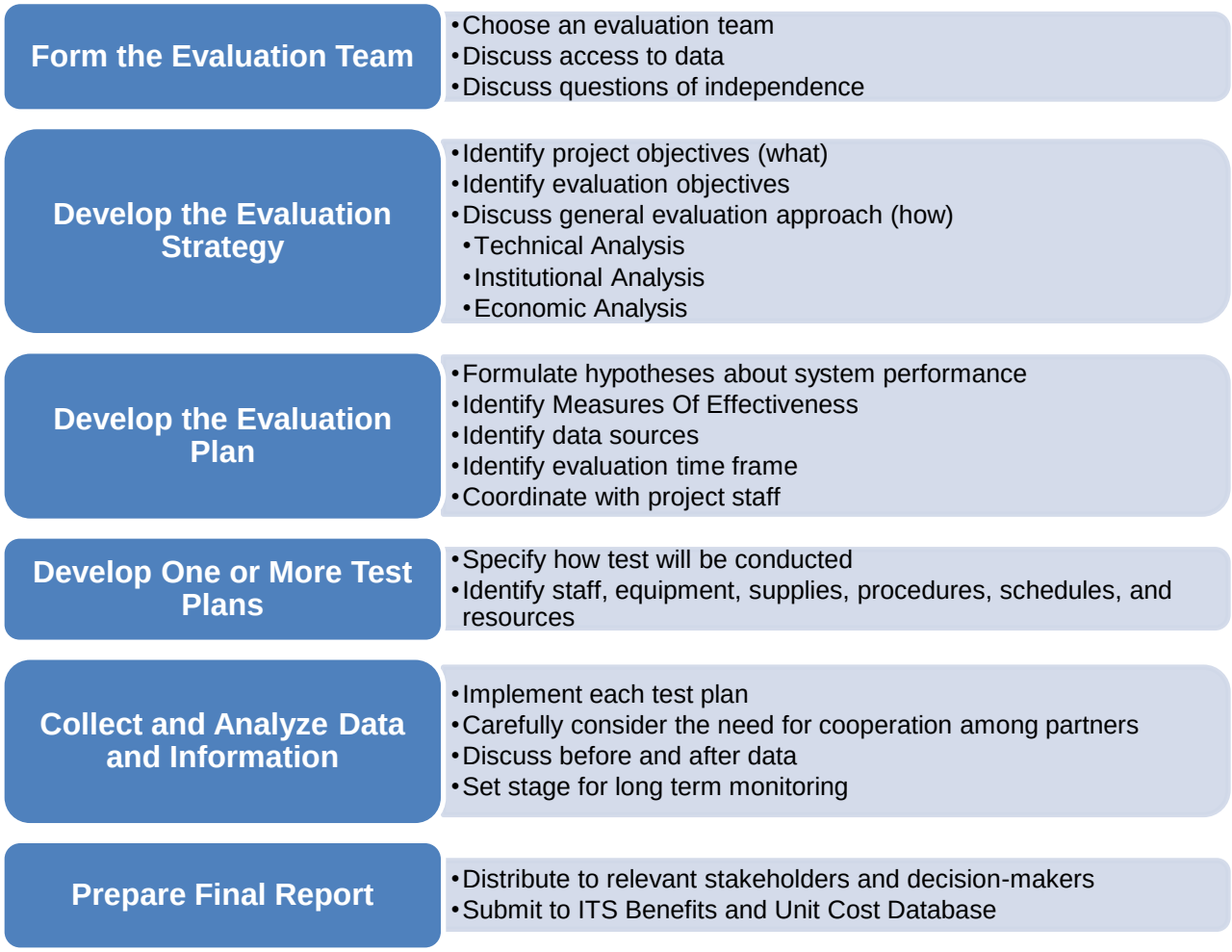

Figure 9. Evaluation Process for ITS Applications (*125*).

The ITS Evaluation Resource Guide contains a more detailed explanation of this six-step process, as well as a discussion of evaluation measures that correspond to overall ITS goal areas – safety, mobility, efficiency, productivity, environmental impacts, and customer satisfaction (4). Sample evaluation strategies, evaluation plans, test plans, and final reports are also available for downloading from the website (*125*).

The Urban Partnership Agreement National Evaluation Plans for Minnesota (*37*) and Washington (*41*) were developed prior to the deployment of the ATM strategies in those locations. These plans describe the analysis approach, while a series of test plans developed for each site describe the specific data collection and analysis plan.
Table 20 presents some example criteria that were used in the Minnesota ATM evaluation (*37*).

Table 20. Example Evaluation Criteria Used to Evaluate the Minnesota ATM Deployment (*33*).

Evaluation Objective	Hypothesis	Measures of Effectiveness	Required Data
Mobility – Reduce delay and optimize travel times in the corridor.	ATM strategies, including speed harmonization and DMS with transit and highway travel times, will promote better utilization and distribution of traffic to available capacity in the corridor.	Percent change and change in variance in: • Route/corridor travel time by time-of-day • Planning Index and/or Travel Time Index • Vehicle throughput (vehicle volumes) • Number of hours per day and duration of "congested" flow	• Travel times • Time-of-day volume counts • Travel speeds (both pre- and post-deployment)
Safety – Improve traveler safety in the corridor.	ATM strategies will reduce the number and duration of incidents that result in congestion in the corridor.	Percent change and change in variance in: • Incident duration • Incident frequency • Time to normal flow	• Incident duration • Incident response times • Incident frequencies (both pre- and post-deployment)
Customer Satisfaction – Improve travel satisfaction for corridor users	ATM will result in improved satisfaction among corridor users.	Corridor traveler perceptions on the: • Impact of ATM in reducing congestion • Impact of ATM in improving safety • Ease of understanding ATM messages • Quality of ATM messages and information	• Opinions of corridor travelers serving on a panel survey • Wide distribution of customer satisfaction surveys (post-deployment)
Institutional – Improve coordination among implementing agencies.	Institutional factors will impact the success of the ATM deployment: 1. People (e.g., sponsors, champions) 2. Process (e.g., stakeholder outreach) 3. Structures (e.g., networks, partnerships, communications strategies, supportive procedures) 4. Media (e.g., media coverage, public education) 5. Competencies (e.g., conducting research, technical/technological competencies)	• Stakeholder observations • Outreach materials • Media coverage	• Surveys or interviews that document institutional issues • Outreach materials • Media coverage (pre- and post-deployment)

Because the 2009 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) contains limited material specific to ATM signage, more in-depth evaluation may be required. The Minnesota DOT (Mn/DOT) and Washington State DOT (WSDOT) each had to use engineering judgment to apply the principles and existing language of the MUTCD on lane control signals and dynamic message signs in an experimental manner (*33*). As a result, these agencies were required to submit a formal request to experiment to the Federal Highway Administration (FHWA), which included an evaluation plan and process for submitting findings (*33*).

13.2 Data Needs and Collection Approaches

Data needs will vary according to the evaluation plan, but should be collected throughout the course of the ATM deployment. Some ATM strategies may focus on safety impacts, which are not easily assessed until several years of data have been collected for analysis.

Data alone will not be able to address all aspects of the ATM deployment that need to be monitored, and not all ATM benefits can be readily quantified (*33*). For instance, Mn/DOT and WSDOT realized that some of the benefits of ATM signage, such as smoother-flowing traffic and improved motorist understanding of the situation, could not easily be quantified even though drivers and operators observe improved conditions on the corridors with ATM signage (*33*). To document these perceived changes, surveys or interviews can be conducted with the public and operators, as well as law enforcement or transit drivers, for a qualitative assessment to supplement quantitative data (*37*, *41*).

Agency staff make valuable observations in the field. By monitoring cameras during incidents, operators could see how drivers respond to the signage and find ways to improve responses for a better, more desirable response to a given scenario (*33*). For example, it was apparent in Minnesota that some symbols used on the ATM signage were not clear to drivers and modifications were made (*33*). In other instances, traffic calming upstream of an incident might be more effective if conducted over the course of one mile instead of two miles, requiring a change to the configuration of messages (*33*).

13.3 Dashboards and Reporting Requirements

System monitoring and reporting will vary based on the expectations of all groups that require feedback regarding the ATM deployment. Both Mn/DOT and WSDOT conducted ongoing monitoring and internal reporting after the deployment of ATM signage in order to update and improve the algorithms and configuration of messages being displayed (*33*). Shouldn't we recommend at least the consideration of a significant public reporting effort? With the novel nature of these projects, haven't agencies found it really useful to aggressively report what's going on? And to be quick about changing operations if that's needed too? Both of these sites were also required to submit periodic reports to FHWA in compliance with the MUTCD requests to experiment with the signage displays (*33*).

After 1 to 3 years of system deployment, a larger evaluation may be conducted that includes a larger set of mobility and safety data to identify significant trends. In particular, multiple years of crash data are necessary to effectively analyze safety impacts (*12*). The Urban Partnership Agreement National Evaluation (which includes Minnesota and Washington) (*12*) and the

Managed Motorways evaluation reports (*18*, *19*) are examples of large-scale evaluations conducted to comprehensively analyze and document impacts of the deployed systems.

Evaluation reports can be entered in the ITS Benefits and Unit Cost Database,[1] so that the evaluation results can be shared with other interested transportation professionals.

[1] The database is available online at: http://www.benefitcost.its.dot.gov; the website has instructions on how to contribute.

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