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NEW SHRP 2 REPORT

Institutional Architectures to Improve Transportation Systems Management and Operations

Guidance for State Departments of Transportation

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(Above:) Traffic congestion can be managed by transportation systems management and operations (TSM&O) strategies, including preferential lane use, advanced traveler warnings, and efficient signal timing. (Right:) Bad weather and a truck crash caused delays on I-5 southbound in Eugene, Oregon. Transportation agencies can use TSM&O strategies for incident management to address weather-related emergencies.

As the economy recovers, and congestion, delay, and unreliability increase (1), how are transportation agencies addressing their commitments to improve highway performance and maintain mobility, especially when building a way out of congestion is not an option? Recent research indicates that new strategies and supporting institutional arrangements can provide the means to manage congestion—if not banish it.

Managing Congestion

Congestion will never be eliminated but can be managed to minimize delay, maintain speed and throughput, and improve travel time reliability. Reliability is increasingly important—recurring, daily congestion can be planned for, but the unexpected disruptions of nonrecurring congestion extend travel times beyond what is normally anticipated and introduce uncertainties and costs that frustrate travelers and businesses.

A program that focuses on transportation systems

management and operations (TSM&O) addresses reliability by implementing strategies that prepare for and respond to specific causes of unexpected delay and disruption—crashes, breakdowns, weather, construction, poorly timed signals, and special events. Together, these account for more than half of roadway travel delay and unpredictability.

TSM&O strategies include incident management,



PHOTO: OREGON DOT

advanced treatments for snow and ice, appropriately timed traffic signals, effective management of traffic in work zones, variable speed limits, advanced traveler warnings of traffic problems, metering of expressway ramp traffic, preferential lane use, and others. Two decades of experience have shown that these strategies are cost-effective, minimally disruptive, and quickly implemented.

Implementing TSM&O Strategies

Several state departments of transportation (DOTs) have moved aggressively to capitalize on the potential of these strategies. Nonetheless, the general rate of TSM&O implementation has been modest, and the scope and effectiveness of the strategies vary. In many congested metropolitan areas, the options for adding capacity are limited, yet an aggressive mainstreaming of TSM&O to improve the management of capacity is lacking.

A recent report from the Reliability Focus Area of the Transportation Research Board's (TRB's) Second Strategic Highway Research Program (SHRP 2), *Institutional Architectures to Improve Systems Operations and Management*, has identified the preconditions for implementing TSM&O effectively. The report presents practical guidance for state DOTs and other transportation agencies. The research compared the operations practices and other characteristics of state DOTs and found that the more effective TSM&O programs included features significantly at odds with legacy practices and traditional capacity-oriented programs.

The research suggested that developing the capabilities to support improvements in management and operations requires significant changes in the legacy conventions of the programs, processes, and organization of state DOTs and other transportation agencies. The research specified the capabilities that are needed and identified steps for development.

The report offers guidance to state DOTs in bringing TSM&O into the mainstream as a formal mission and program for managing the highway system (2). The guidance was integrated into a web-based tool and into TSM&O capability improvement workshops sponsored by SHRP 2 and the Federal Highway Administration (FHWA).

Recapturing Capacity and Reliability

Metropolitan highway vehicle travel has increased by 250 percent since 1980—exceeding the design capacity of the highway systems in major metropolitan areas. Congested conditions and low levels of roadway services—even in nonpeak hours—are the result (3–5).



Only about one-half of delays, however, are caused by recurring congestion—that is, by the regular, daily, peak-hour travel delays that characterize shortfalls in capacity. The other half results from nonrecurring congestion, produced by unanticipated events, such as crashes, adverse weather, construction, and the like. Figure 1 (below) shows the relative contribution of these causes of congestion. The causes of recurring and nonrecurring congestion often arise in combinations that can exacerbate their impacts—for example, rush hour conditions can multiply the impacts of a crash or a work zone; crashes in bad weather during rush hour can have effects that are more severe.

The impact of nonrecurring congestion goes beyond delays. The disruption from unpredictable travel times is significant in a just-in-time economy that highly values individual time and places a premium on schedule and delivery predictability.

Traffic congestion in Pittsburgh, Pennsylvania. Midsize cities also feel the effects of increased metropolitan highway travel—up 250 percent since 1980.

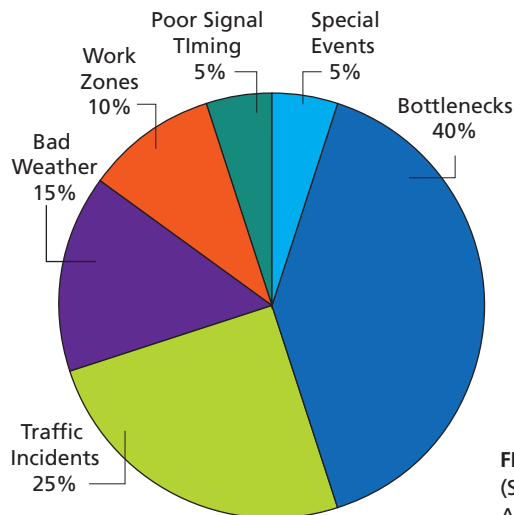


FIGURE 1 Causes of delay. (Source: Federal Highway Administration)



PHOTO: NATIONAL INSTITUTES OF HEALTH

In contrast to expanding roads to deal with increased highway use, TSM&O strategies address potential problems at the source—such as restoring capacity after an incident.

Mobility Strategy

Increasing capacity has only a modest effect on non-recurring congestion. In contrast, TSM&O strategies focus on the specific causes of congestion and delay at the point of the problem—in real time—to reduce the impacts significantly. Some strategies, such as ramp metering, modify roadway operations

as the demand varies; some quickly restore capacity after an event, as in incident management for crashes; some anticipate problems, such as snow and ice control; and others provide travelers with advance information and guidance to improve flow or to support effective route or travel decisions.

Best practice indicates that aggressive TSM&O applications at the network operational level can counter much of the capacity loss caused by congestion and disruptions. The strategies are relatively low in cost compared with adding capacity, can be implemented in two to three years, and offer substantial benefits—for example, a benefit–cost ratio of 10:1 (6). Table 1 provides some examples (below).

Institutional Architecture

The research indicated that TSM&O requires a characteristic set of agency capabilities different from those that support capacity programs. Special demands are placed on leadership, organization, staffing, resources, and relationships, as well as on technical and business processes. Although some

TABLE 1 TSM&O Strategy Effectiveness (2)

Strategy and Payoff	Example Applications	Benefit–Cost Ratio and Other Metrics
Incident and emergency management	Organize the management and clearance of disruptions and responses to emergencies to reduce delay and driver exposure to secondary accidents; improve reliability and responder safety via incident detection, verification, response, clearance, accident investigation, medical response, and traffic control	2:1 to 42:1; incident duration reduced by 30% to 40%
Road weather information systems	Generate advance and current information about disruptive weather conditions to minimize traveler delay and improve efficiency of agency’s weather-related roadway maintenance with a combination of roadway environmental sensing, weather information, treatment and clearance strategies, and weather information dissemination	2:1 to 10:1; up to 50% of travelers in mountainous areas adjust plans
ITS-supported work zone traffic management plans	Provide dynamic, traffic-responsive controls in work zones via lane use and speed control and warnings to improve safety for drivers and construction workers; improve traffic flow for specific projects via detection, surveillance, lane use and speed control, signs, and signals	2:1 to 42:1; 300% reduction in dangerous merges
Traffic-responsive or traffic-adaptive signals	Provide traffic-responsive or -adaptive signal operation at intersections to minimize delay throughout corridors and networks via traffic detection, transit vehicle preemption, and appropriate signal control and network-level regimes	17:1 to 62:1; 2% to 3% reduction in delays
Ramp metering	In accordance with traffic conditions, control the rate and spacing of traffic entering a freeway, to minimize disruptions and safety hazards; improve travel time via freeway volume detection and related traffic-responsive ramp signals	15:1; up to 15% reduction in delay
Freeway operations and active traffic management	Harmonize speeds and balance lane use, including shoulders, to minimize queuing, delay, and secondary crashes via variable speed limits, advisories, and lane use controls, including detection, communications, and dynamic message signs	Up to 25% reduction in crashes and 10% to 20% reduction in delay
Advanced traveler information	Provide current and anticipated travel and weather conditions, route and mode options, and other information to support travelers’ optimal choice of route, timing, and mode via multiple media—web, 511 phone, Twitter, e-mail, and text—and via overhead or roadside changeable messaging and in-vehicle information	3% decrease in crashes

Additional sources:

Investment Opportunities for Managing Transportation Performance Through Technology. Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation, 2009.

Benefits of Using Intelligent Transportation Systems in Work Zones: A Summary Report. FHWA, April 2008.

Conventional Agency Processes Taking Place in Administrative Time				
Scoping and Business Processes	Accommodate program in portfolio	Interagency coordination		
		Plan and program	Systems engineering	
Technology and Systems Deployment			Infrastructure for situational awareness	Infrastructure for control
Maintenance				Asset management
Operations Actions Taking Place in Real Time				
Systems Operations and Performance Monitoring	Real-time mobilization of equipment and personnel	Interagency coordinated execution of event response activities		
	Situation status communications and reporting (internal and external)			
	Performance monitoring			

FIGURE 2 TSM&O activity demands (3).

TSM&O-related activities fit well into the 9-to-5 culture of a project development-oriented civil engineering entity, the applications take place in real time with extensive ongoing collaboration and performance monitoring on a 24-hour, 7-days-a-week basis. Figure 2 (above) illustrates the unique combinations needed.

The research compared the more- versus less-effective TSM&O programs of state DOTs. The findings suggested that neither technical knowledge nor relative funding levels were the key differences. Instead, the more effective programs customized the business and technical processes of planning, programming, systems engineering, asset management, and performance monitoring. Implementing these processes depended on adjustments to the institutional architecture of the agencies, affecting leadership, organizational structure, staff capabilities, program framework, and resources (Figure 3, right).

Capability for TSM&O

The research traced the relationships between program effectiveness and the associated capabilities and aggregated the key processes and institutional characteristics into six major dimensions that appeared most influential. These relationships were used to develop guidance for state DOTs in improving TSM&O.

Key findings for the six dimensions included the following:

◆ **Business processes, including formal scoping planning, programming, and budgeting.**

TSM&O is not typically integrated into the state or regional planning process, which focuses on allocating federal and state funds within the conventional construction and maintenance programs. TSM&O investments tend to be ad hoc, without a clear and sustainable improvement program; in self-evaluations, state DOTs have given themselves low ratings on formalizing TSM&O as a program (7).

Few state DOTs have a clear understanding of what they spend on TSM&O. Of the agencies that track the information, a few spend up to 2 percent of their total budgets on TSM&O despite its potential to address more than half of the causes of delay and most of the causes of unreliability.

FIGURE 3 Dependence of TSM&O program on process and institutional arrangements (9).

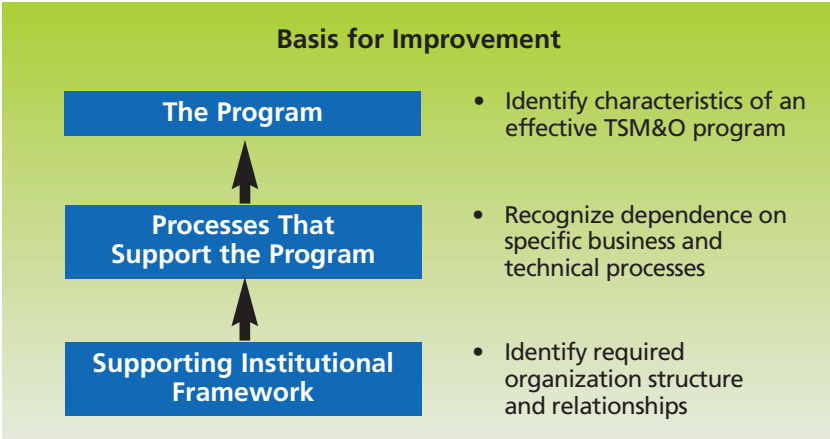




PHOTO: MISSOURI DOT

Missouri DOT applied variable speed limits of between 40 and 60 mph along I-270 in St. Louis.

◆ **Systems and technology, including systems architecture, interoperability, standardization, and documentation.**

State DOT technical staff—especially at the regional or district level—have a well-developed understanding of systems and technology issues, in part because of federal support but also because of professional interest in technology. Most states have developed systems architectures with extensive federal guidance. But states are struggling with standardization, upgrades, and integration, especially with the rapid rate of technology development. In several states, private-sector systems and service providers are playing an increasing role in day-to-day operations and maintenance.

Implementation of preferential lanes and other TSM&O measures often require a receptive DOT culture.

◆ **Performance measurement, including measures definition, data acquisition, analysis, and utilization.**

Improving the effectiveness of any TSM&O strategy depends on performance measurement. Some state DOTs measure their TSM&O by the amount of activities they perform, and they conduct debriefings after major crashes and storms. Nevertheless, state DOTs have limited knowledge of the effects of their routine TSM&O activities in reducing delay, unreliability, and crashes. Even at the national level, information on the benefits of TSM&O activities is fragmentary, which makes improving procedures and protocols difficult and hampers efforts to justify the program.

Changes can be expected, however, with the strong federal emphasis on performance measurement, along with the private sector's growing involvement in supplying such measures as vehicle probe-based traffic information.

◆ **Culture, including technical understanding, leadership, policy commitment, outreach, and program authority.**

In many DOTs, senior executive recognition of the potential of TSM&O is limited, as reflected in formal agency policy and programs. Most DOTs have a legacy culture of public works—the related values, expertise, and practices support a focus on capital improvements. In this context, real-time operational management has not been a focus. Many of the more effective TSM&O programs have been initiated after an external crisis, such as a major crash, a weather-related traffic disaster, or the challenges of accommodating a major event. Many of the more successful programs have depended on middle management champions, who apply extra energy and entrepreneurship to cobble together a coherent program.

◆ **Organization and workforce, including organizational structure, staff capacity development, and retention.**

TSM&O is not yet a top-level unit in state DOT organizational structures. Its key components are often fragmented into intelligent transportation systems, traffic engineering, and traffic operations units—in the third or fourth level of the management hierarchy, reporting to maintenance managers in regional or central offices. As a result, deliberations by senior management about the agency's program, budget, and staffing do not typically include representation from TSM&O, and accountability for operations services is not evident.

TSM&O is often understaffed—not only because of agencywide constraints, but also because of the



PHOTO: OREGON DOT

TABLE 2 Examples of State DOT Innovation (9)

Incentivized partnerships	Florida DOT's Rapid Incident Scene Clearance (RISC) program and Georgia DOT's Towing and Recovery Incentive Program (TRIP) are public-private partnerships that use both incentive payments and disincentive liquidated damages to shorten clearance times for heavy vehicle wrecks. RISC and TRIP have reduced the average clearance times dramatically.
Staff training in program development	The 16-state I-95 Corridor Coalition has supported an Operations Academy, a two-week residential program for state DOT middle and upper managers in TSM&O state of the practice.
Formal program and budget	The Maryland State Highway Administration's Coordinated Highways Action Response Team (CHART) program is a formal, multiyear, budgeted ITS and operations program; an advisory board provides oversight and strategic direction for CHART.
High-level reorganization	Virginia DOT has created a senior management post of Deputy Director for Operations and Maintenance, responsible for all TSM&O activities and maintenance resources.
Measuring performance	Washington State DOT has made a strong, transparent commitment to performance measurement; the quarterly <i>Gray Notebook</i> tracks performance based on five legislative goals, including mobility and congestion, and includes updates on applying operations strategies such as incident management and high-occupancy toll lanes.

difficulty in finding and retaining qualified staff. TSM&O is not yet established as a rewarding career track within DOTs, with job specifications, competitive positions, and clear opportunities for advancement. Moreover, outsourcing key responsibilities to private entities is a growing trend.

◆ **Collaboration, including relationships with public safety agencies, local governments, metropolitan planning organizations (MPOs), and the private sector.**

Many of the important TSM&O strategies are beyond the scope of transportation agencies alone. The divided jurisdictions and responsibilities for critical actions regarding incident and traffic management prevent state DOTs from capitalizing on the potential of TSM&O on their own. Several of the most important TSM&O strategies require collaboration with law enforcement, emergency services, and private providers of services—such as towing and recovery—or of information, such as vehicle probe-based traffic data. At the regional level, collaboration is often informal and can be disrupted by staff turnover.

Many states are working to transcend interagency differences in missions, resources, and tactical approaches through formal agreements. Some DOTs are using innovative approaches for public-public and public-private collaboration, including coalitions, cross subsidies, cotraining, and incentive and disincentive contracting.

Table 2 (above) provides examples that suggest definitions of best practices in processes and in institutional arrangements. The SHRP 2 project aimed to

capitalize on the complete range of experience in developing guidance to improve TSM&O effectiveness.

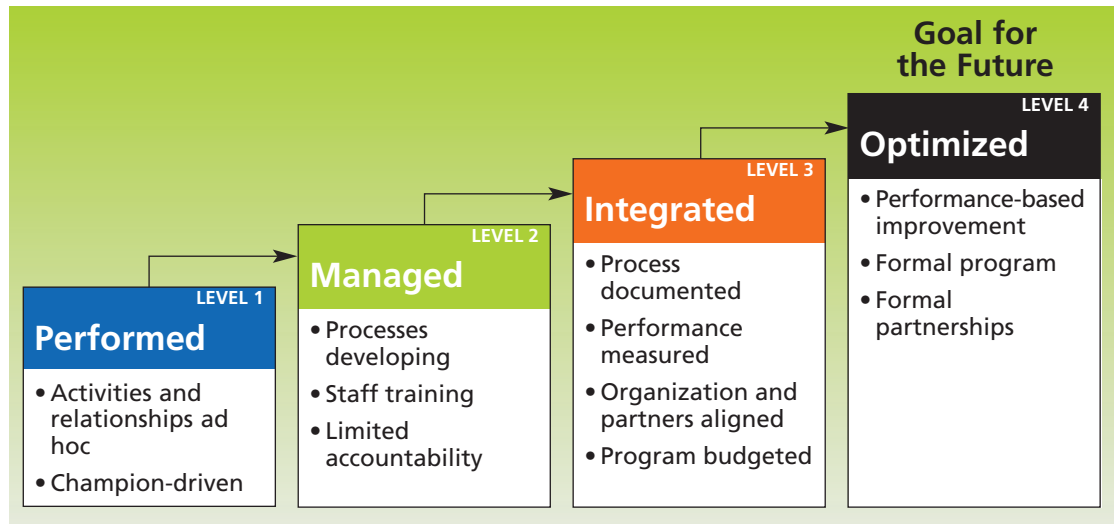
Capability Maturity

Changes in perceptions, practices, and configurations at state DOTs appear to be essential for more effective TSM&O. Guiding the changes presents several challenges, such as reengineering key processes and adjusting the institutional architecture to support them. These adjustments also involve clarifying vague intuitions about culture and organization.

The changes would have to be relevant to agencies at widely varying states of play in each of the key dimensions of capability and provide benchmarks for manageable increments toward improved practice—as evidenced by current best practices. Furthermore, the changes to develop the needed capabilities would have to identify specific actions and levels of improvement. A practical framework was needed.

Information technology managers have used the capability maturity model (CMM) to identify key dimensions of capability and levels of improvement, determined through self-evaluation. The framework focuses on continuous improvement and combines the key features of quality management, organizational development, and business process reengineering long used as strategic management tools in transportation agencies (8). The guide adjusts the CMM concept for state DOTs by focusing on the key dimensions of institutional architecture, as well as the specific business and technical processes relevant to TSM&O.

FIGURE 4 Levels of agency capability maturity (9, p. 4).



Levels of Capability

The guide defines four discrete levels of agency capability for each dimension, to assess an agency’s status and its targets for improvement. The first three levels were observed in actual agency practice; the fourth level represents a theoretical ideal extrapolated from best practice.

The guidance is structured in terms of criteria that define progressively higher levels of effectiveness through successive stages of capability maturity. The steps lead away from informal and ad hoc, champion-based activities to custom-tailored processes that make TSM&O routine, standardized, documented, and performance-driven, supported by appropriate capabilities and organization. Figure 4 (above) illustrates the criteria for each level and the relationships among the levels.

CMM and Guidance Templates

With the concept of dimensions and levels of capability as a framework, criteria were identified to determine the process and institutional capabilities

for each level. Logical increments in capability were defined in consistent management steps. Specific actions were identified for moving from one level to another in each of the six dimensions.

Table 3 (page 21) illustrates the capability levels for each of the dimensions, as defined by the criteria for each level. Three rules governed the development of the guidance:

1. The six dimensions are interlinked. The dimension at the lowest level of capability usually is the principal constraint to improvement in program effectiveness and therefore the highest priority.
2. Each incremental level of maturity within a dimension establishes the basis for the agency’s ability to progress to the next level of effectiveness.
3. Each of the dimensions is essential—all are interrelated, and all must be addressed. Omitting improvement in any one dimension inhibits continuous improvement.

To identify practical management actions, the six key dimensions were disaggregated into more concrete elements of capability. Each dimension was subdivided into three to four elements (Table 4, page 22), each with its own capability improvement strategy. A high-level version provides agencies with a framework for strategy development driven by self-evaluations.

Validation of the Guidance

The scope of services for the SHRP 2 project included validation of the criteria for the dimensions and the levels of capability. Fifteen state and regional workshops have been conducted for the key participants in TSM&O activities, including staff from state DOTs, MPOs, regional and other local agencies, law



Private tow operators and police help to clear an accident scene in Ohio. A second Strategic Highway Research Program (SHRP 2) project conducted 15 workshops in TSM&O strategies.

enforcement, and the private sector (9).

Workshop participants applied the criteria to evaluate the strengths and weaknesses of their agencies' capabilities in each of the six dimensions. The consensus view of the level of capabilities became the point of departure for identifying strategies to move up to the next level.

The workshops produced action plans that participants are using to improve their agencies' TSM&O activities. The CMM workshop has become a core activity in the SHRP 2 Reliability Implementation Program to be conducted by SHRP 2, FHWA, and the American Association of State Highway and Transportation Officials (AASHTO).

TABLE 3 General Strategies to Advance to the Next Level of Capability (9)

Capability Dimension	Level 1	Level 2	Level 3	Level 4
Business processes (planning, programming, implementation)	Processes related to TSM&O activities, ad hoc and unintegrated	Multiyear statewide TSM&O plan and program in place, with deficiencies, evaluation, and strategies	Programming, budgeting, and project development processes for TSM&O standardized and documented	Processes streamlined and subject to continuous improvement
Systems and technology (systems engineering and technology interoperability)	Ad hoc approaches outside systems engineering	Systems engineering employed and consistently used for concept of operations, architecture, and systems development	Systems and technology standardized, documented, and trained statewide, and new technology incorporated	Systems and technology routinely upgraded and utilized to improve efficiency and performance
Performance measurement (measures, data and analytics, and utilization)	No regular performance measurement related to TSM&O	TSM&O strategies measurement largely via outputs, with limited after-action analyses	Outcome measures identified and consistently used for TSM&O strategies improvement	Mission-related outputs and outcomes data routinely utilized for management, reported internally and externally, and archived
Culture (technical understanding, leadership, outreach, and program authority)	Value of TSM&O not widely understood beyond champions	Agencywide appreciation of the value and role of TSM&O	TSM&O accepted as a formal core program	Explicit agency commitment to TSM&O as key strategy to achieve full range of mobility, safety, livability, and sustainability objectives
Organization and workforce (organizational structure and workforce capability development)	Fragmented roles based on legacy organization and available skills	Relationship among roles and units rationalized and core staff capacities identified	Top-level management position and core staff for TSM&O established in central office and districts	Professionalization and certification of operations core capacity positions including performance incentive
Collaboration (partnerships among levels of government and with public safety agencies and private sector)	Relationships on informal, infrequent, and personal basis	Regular collaboration at regional level	Collaborative interagency adjustment of roles and responsibilities by formal interagency agreements	High level of operations coordination institutionalized among key players, public and private

TABLE 4 Guidance Topics

Business Processes	Systems and Technology	Performance Measurement
<ul style="list-style-type: none"> • Planning • Scoping • Programming and budgeting • Project development and procurement 	<ul style="list-style-type: none"> • Regional architectures • Project systems engineering; testing and validation • Standards and interoperability 	<ul style="list-style-type: none"> • Definition of measures • Data acquisition • Utilization of measures
Culture	Organization and Workforce	Collaboration
<ul style="list-style-type: none"> • Technical understanding • Leadership and championship • Outreach • Program status and authorities 	<ul style="list-style-type: none"> • Program status • Organizational structure • Recruitment and retention • Staff development 	<ul style="list-style-type: none"> • Public safety agency collaboration • Local government, MPO, and regional transportation planning agency cooperation • Outsourcing and public-private partnerships

Source: AASHTO Guide to Systems Operations and Management Improvement, www.aashtosomguidance.org.

Web-Based Guidance

Through a partnership with AASHTO's Subcommittee on Systems Operations and Management and the National Cooperative Highway Research Program, a detailed version of the SHRP 2 TSM&O guidance is available online as the AASHTO Systems Operations and Management Guidance (www.aashtosomguidance.org).

The web-based resource, including online self-evaluations, allows users to tailor the guidance to their agency and context. The user's responses to a set of nested questions in three areas generate an evaluation of agency-level maturity for each of the six major dimensions of the CMM. The guidance then provides a set of action plan steps for each dimension, to enable the agency to move up to the next levels of capability.

Practical Approach

Improved TSM&O is essential for reducing delay and unreliability and for improving throughput and safety. The SHRP 2 guidance presents a comprehensive approach to help state DOTs and their partners succeed in improving levels of service. Many of the improvements do not require additional capital or staff but necessitate a clear understanding of the TSM&O strategy, features, and applications—and of the capabilities that are preconditions to success. These capabilities can be managed; the SHRP 2 guidance presents a research-based, practical approach.

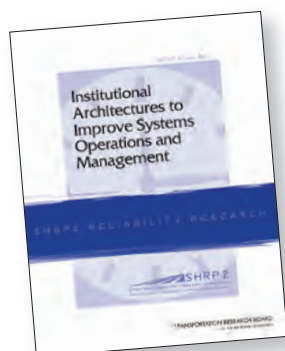
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The findings have been implemented in the web-based AASHTO Systems Operations and Management Guidance and incorporated into the FHWA primer, *Creating an Effective Program to Advance Transportation System Management and Operations* (9). Some of the information in this article is drawn from these products, which were prepared by the research team.

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More information about SHRP 2 Report S2-L06-RR-1, *Institutional Architectures to Improve Systems Operations and Management*, is available at www.trb.org/Main/Blurbs/165285.aspx.