Next Generation of Traffic Management Systems and Centers: A Primer

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16. Abstract
Traffic management systems (TMSs) and their centers are critical resources that offer agencies the potential to improve the safety and mobility of travel on the surface transportation system. TMSs also assist agencies with fulfilling the ever-increasing transportation needs of travelers (e.g., travel times), service providers (e.g., transit, emergency services), other agencies, and the public (e.g., incidents). TMSs are complex resources that integrate technologies, software, and data to improve the safety and mobility of travel on the surface transportation system.

As agencies explore opportunities to improve the performance of their TMSs, they may encounter challenges expanding the geographical area they serve; adding or enhancing services; and providing the funding and staffing needed to manage, operate, maintain, or improve the system. By continuously looking for opportunities to enhance TMS capabilities, functions, and services, agencies may improve their TMS's performance and help meet their goals. Agencies may consider a range of issues, opportunities, and possible improvements when planning to enhance an existing TMS or preparing for the next generation of their TMS.

The purpose of this primer is to highlight current practices, emerging technologies and methods, and possible approaches to improve the active management and operation of the next generation of agencies' TMSs. The primer examines the basic TMS functions, actions, and services and how they might enhance safety and mobility though a range of operational strategies and capabilities. The motivations for agencies planning and making investments to add or improve TMS capabilities to meet future agency or regional needs are then explored. Through challenges and lessons learned from other agencies, potential benefits, and costs to improve the performance and capabilities of the next generation of an agency's TMSs are then discussed. The information and practices captured in this primer may assist agencies with identifying the issues to consider as they plan, operate, or evaluate possible improvements to their existing or the next generation of their TMSs.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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Traffic management systems (TMS) and their centers are critical resources that offer agencies the potential to improve the safety and mobility of travel on the surface transportation system.(1) TMSs also assist agencies with fulfilling the ever-increasing transportation needs of travelers (e.g., travel times), service providers (e.g., transit, emergency services), other agencies, and the public (e.g., incidents). TMSs are complex resources that integrate technologies, software, and data to improve the safety and mobility of travel on the surface transportation system.

Exploring opportunities to improve the performance of their TMSs, agencies may encounter challenges with expanding the geographical area they serve, adding or enhancing services, or providing the funding and staffing needed to manage, operate, maintain, or improve the system. Agencies can improve their overall TMS performance and help meet their goals by continuously looking for potential opportunities to enhance TMS capabilities, functions, and services. Agencies may consider a range of opportunities and possible improvements when planning to enhance an existing TMS or preparing for the next generation of their TMS.

PRIMER PURPOSE AND OBJECTIVES

The purpose of this primer is to highlight current practices, emerging technologies and methods, and possible approaches to improve the active management and operation of the next generation of agencies' TMSs. The primer examines the basic TMS functions, actions, and services and how they might enhance safety and mobility through a range of operational strategies and capabilities. The motivations for agencies planning and making investments to add or improve TMS capabilities to meet future agency or regional needs are then explored. Through challenges and lessons learned from other agencies, potential benefits and costs to improve the performance and capabilities of the next generation of agencies' TMSs are then discussed. This primer can help agencies identify the possible issues to consider as they plan, operate, or evaluate possible improvements to existing or next-generation TMSs.

Objectives of this primer include the following:

- Identifying current practices, innovative methods, and technologies agencies use to actively manage and operate TMSs.
- Identifying agencies' processes for assessing, evaluating, and reporting on the capabilities and performance of TMSs.
- Identifying agencies' practices with regards to planning, designing, developing, and implementing enhancements to or replacements of their TMSs.

IMPROVING TMS SERVICES TO MEET AGENCY AND REGIONAL NEEDS

Chapter 2 discusses the next generation of an agency's TMSs and opportunities to ensure how improvements to their existing or next generation of their TMSs may support the needs of their agency. The term “NextGen TMS” refers to the needs, capabilities, and potential performance of the next generation of an agency’s TMS and how it may differ from its current or legacy TMS.

The next generation of an agency’s TMS, and its potential improvements to current functions, capabilities, and services, originates from agency and regional needs. Therefore, agency planning processes should incorporate the role and needs of TMSs into other agency planning processes and plans, especially those related to intelligent transportation systems (ITS) and Transportation System Management and Operations (TSMO). The foundation of pursuing a NextGen TMS is first understanding the capabilities and limitations of the current TMS. Enhancement opportunities to improve the functions, capabilities, and services of TMSs may include the following:

- Expanding areas of traffic surveillance.
- Adding predictive capabilities to support operations.
- Managing and operating the TMS actively and remotely.
- Sharing information, actions, and coordinating operations with other systems.
- Coordinating actions and information on traffic incidents with service providers.
- Receiving and using crowdsourced data or other emerging sources (e.g., third-party service providers, probes, connected or automated vehicles).
- Leveraging communications technologies to send enhanced information directly to travelers.
- Automating certain traffic management functions or actions (e.g., lane closures, activation of incident response plans, varying speed limits).

USING TMSS TO ENHANCE SAFETY AND MOBILITY

Chapter 3 introduces the potential safety and mobility benefits of a TMS and the value proposition that transitioning to a NextGen TMS may enhance these benefits. A NextGen TMS will likely consist of continuing many current TMS operational strategies. In addition, a NextGen TMS may include functions, services, and the ability to actively manage and operate more advanced versions of other strategies, such as the following:

- Ramp metering.
- Queue warning.
- Signal priority control.
- Variable speed limits or dynamic speed advisories.
- Traveler information.

These types of operational strategies provide the benefits of TMSs. These strategies are also foundational to agency decisions on whether and how to enhance the capabilities and performance of an existing TMS or to move toward and prepare for the next generation of their TMS.

OPPORTUNITIES TO ENHANCE AGENCY TMS CAPABILITIES

Chapter 4 identifies relevant problems and challenges that can be anticipated when pursuing a NextGen TMS, including real-world examples of how these potential challenges might be overcome. Information to support planning to improve an existing TMS, or to prepare for the next generation of a TMS, is provided. The chapter also discusses how these TMS needs and possible improvements may be integrated with an agency or region's planning, considering the following planning time horizons:

- **Day-to-day operations (Realtime to 1 yr):** Allocating resources within the annual budgeting process that support day-to-day operations and can generally be implemented within current processes, staff efforts, and available funding.
- **Planning and preparing for day-to-day operations (1–3 yrs):** Planning for improvements that may require a ramp-up or start-up time, but for which there is a desire to pursue as soon as possible. These efforts may be possible within existing budgeted funds or may necessitate additional internal or external funding. The efforts include actions such as the implementation of operational strategies and roadway improvement projects.
- **Program planning (3–5 yrs):** Planning for activities that will likely be dependent on other actions or are included within other regional plans and may not be achievable until at least 5 years in the future.
- **System planning (5–10 yrs):** Planning for State or regional technology or initiative-specific system planning activities.
- **State or regional long-range planning (20 yrs):** Building the vision for what a future transportation system could look like and working backward to determine how this can be achieved while considering the many other independent changes that are likely to occur within this time horizon.

Agencies go through a series of planning processes before a TMS can be developed and implemented. Planning to scope and scale; obtain support and funding; and designing, developing, installing, and operating a TMS are processes that are most effective when driven by objectives and desired outcomes, which can be revealed through these various planning processes. Incorporating TMSs in these processes may enhance the performance of the portions of the surface transportation network managed by TMSs in a manner that is designed to meet agency, regional, and State goals.

WHO SHOULD READ THIS PRIMER?

Readers will be provided with a basis to improve their understanding of TMS capabilities, how these capabilities are being managed and operated, the potential to improve safety and mobility, and opportunities for further enhancements with the next generation of an agency's TMS. The intended audience of this primer includes the following:

- Practitioners responsible for or involved in planning, designing, developing, implementing, evaluating, managing, and operating TMSs.

- Practitioners who may support or make decisions that might influence or may be impacted by TMS' capabilities or how they are managed or operated.

- Stakeholders who have the potential to allocate resources, influence local practices, or contribute to the operational strategies, services, information, and TMSs used to manage and operate traffic on the surface transportation system.

PRIMER ORGANIZATION

This primer contains the following chapters:

- **Chapter 2: Positioning TMS to Meet Future Agency and Regional Needs**—Provides an overview and definitions of key concepts to identify current practices and innovative methods related to existing and NextGen TMSs.

- **Chapter 3: TMS Improving Safety and Mobility**—Discusses potential benefits and costs of NextGen TMSs through example projects and practices.

- **Chapter 4: Opportunities to Improve TMS Performance and Capabilities**—Presents key challenges and opportunities for successful implementation of a NextGen TMS.

- **Chapter 5: Summary of NextGen TMSs and the Safety and Mobility Improvements They Enable**—Concludes the primer by summarizing its findings.

CHAPTER 2. POSITIONING TMS TO MEET FUTURE AGENCY AND REGIONAL NEEDS

This chapter provides an overview of issues, key concepts, technologies, emerging trends, and opportunities to consider when exploring improvements to an existing TMS or planning for a NextGen TMS. The purpose of this chapter is as follows:

- Identify current practices for actively managing and operating TMSs.
- Identify emerging methods and technologies being used to improve the capabilities and performance of TMSs.
- Explore the range of issues, concepts, and opportunities for agencies to consider in the planning or preparation for the next generation of their TMS.

FOUNDATIONAL TMS CONCEPTS

A TMS is a system that comprises a complex, integrated blend of hardware, software, processes, and people performing a range of functions, actions, and services. TMSs are focused on improving the safety, efficiency, and predictability of travel on the surface transportation network. An effective TMS has the agency's resources, culture, and capability to actively manage and operate traffic and coordinate with stakeholders. TMSs are complex systems, combining field equipment, operations personnel, communications, and information technology (IT) to meet their missions.(1)

Operational strategies are a set of functions and combinations of actions that achieve transportation agency objectives, which are often related to safety, mobility, and reliability. TMSs actively manage and use a suite of operational strategies (e.g., ramp metering, lane control) to coordinate efforts and share information with stakeholders to enhance the safety and mobility performance of the roadways being managed. Operational strategies also enhance performance and user experience by managing traffic demand based on the conditions unique to each roadway to improve safety and enhance mobility (e.g., improve travel reliability, reduce delays).

As agencies implement operational strategies, a TMS needs to perform specific functions, actions, and services to support the active management and operation of these strategies. An action is a basic, singular task of a component or a person. A function is a series or combination of actions that support an operational strategy. A service is a set of functions and/or actions that support system operations. An example of a service could pertain to an external system or subsystem, or an internal system (e.g., agency data hub) that would need to connect to the TMS through a mechanism, such as an application programming interface.

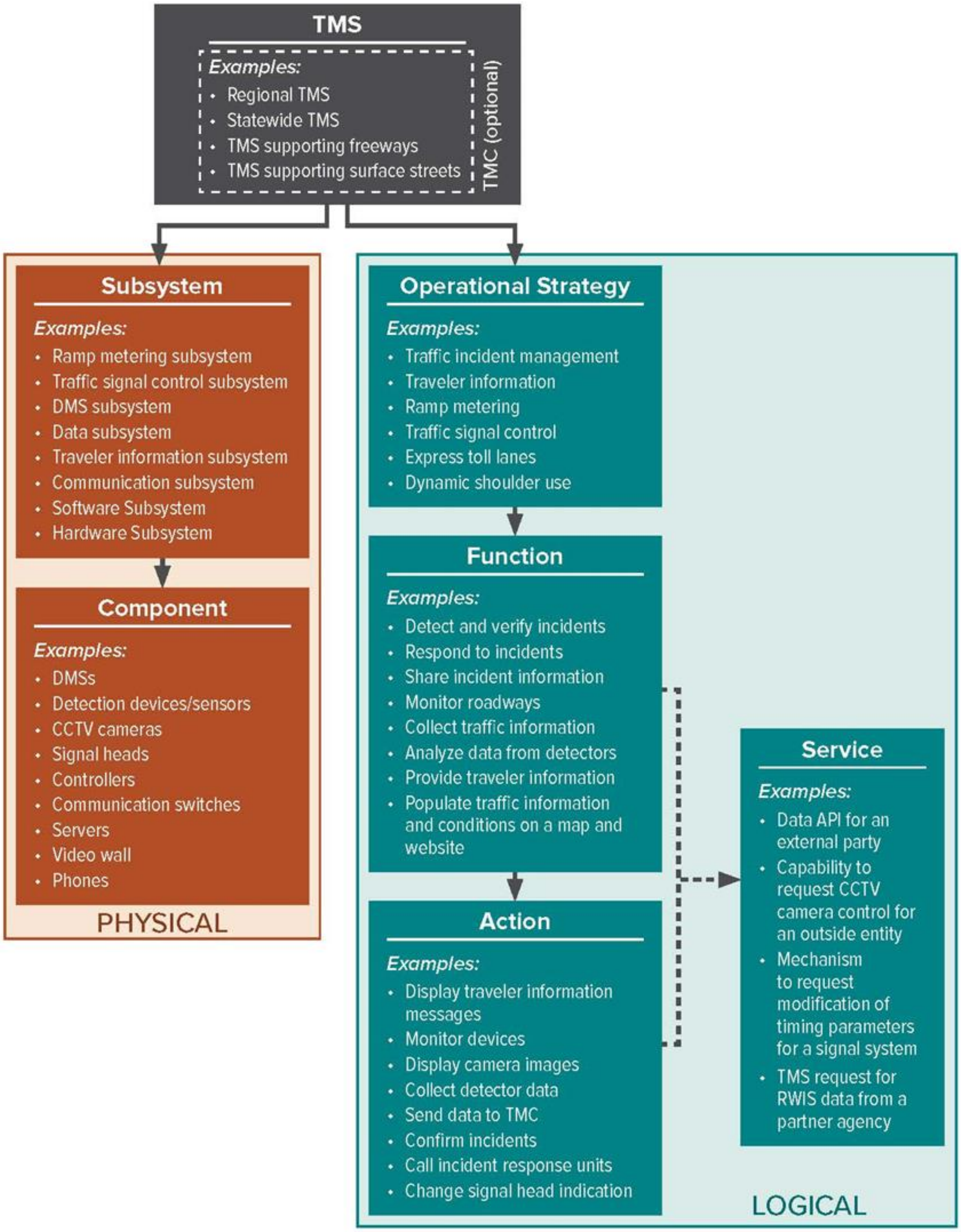
Finally, a traffic management center (TMC) is often an important component of operating a TMS because it is typically located where the physical elements of the TMS connect to each other and to communications and computing power. Therefore, a TMC is often a highlighted element in planning for a TMS. The TMC operation should support the TMS vision, goals, and objectives.

For example, in a TMS that is actively managed, TMC operators are constantly monitoring the transportation infrastructure for incidents or other sources of degradation in operations and traffic flow. TMC operators and managers have firsthand experience with the huge impact that incidents have on the performance of TMSs that individuals outside of the TMC may not consider. In addition, TMC staff can provide input into the operational planning for the TMS.

STRUCTURE AND ELEMENTS OF A TMS

TMSs comprise multiple subsystems, components, and operational strategies. A subsystem is a group of self-contained and interactive components that support one or more operational strategies as a part of a TMS. As technologies, operational strategies, and components have evolved, so too has the operation, management, and maintenance of these systems.

The design or structure of a TMS can be broken down into its physical elements and its logical elements. The physical elements include the subsystem and the components. The logical elements are the operational strategies, functions, actions, and services. Figure 1 provides examples for each of the logical and physical elements of a TMS. The examples shown in this diagram are not meant to be all inclusive of every element that may exist in a TMS, but rather the examples are meant to highlight some common elements that agencies may encounter in their own systems.



Source: Federal Highway Administration (FHWA).
CCTV = closed-circuit television; DMS = dynamic message sign; RWIS = roadway weather information system.

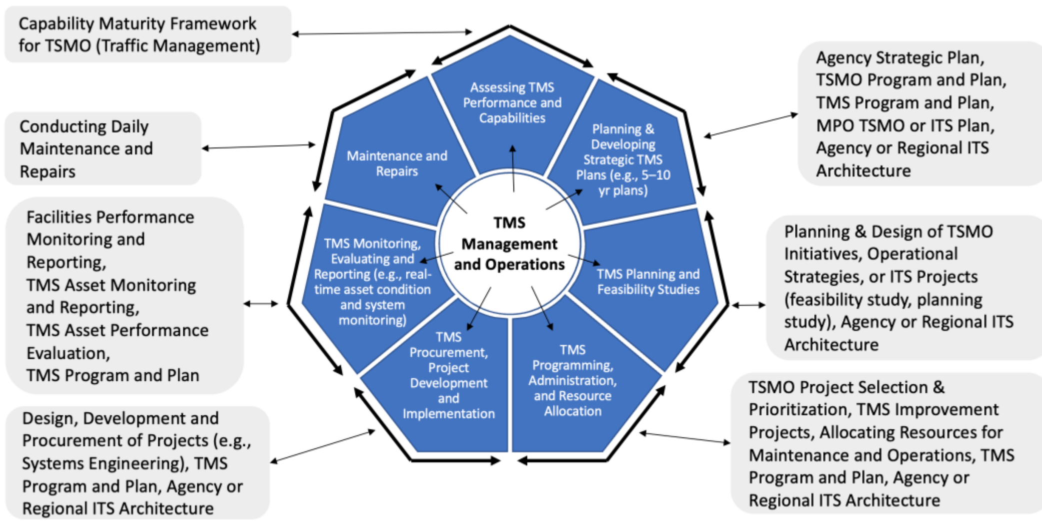
Figure 1. Diagram. Examples of TMS physical and logical elements.[(1)]

VALUE OF PLANNING FOR TMS IMPROVEMENTS

Planning for possible improvements to an existing TMS or for the next generation of an agency's TMS has great value. A new or improved next generation of an agency's TMS provides many opportunities for innovation and introduces many challenges. To address these challenges, agencies interested in pursuing improvements to their existing TMS, or the next generation of their TMS, should begin the planning processes early. Planning will help agencies identify relevant challenges, include the appropriate stakeholders in the process, and obtain the resources needed so issues can be addressed before they become major problems. By considering a range of issues and potential enhancements, agencies have the potential to improve the capabilities and performance of their TMSs, have better sharing of information, enhance their ability to coordinate with other systems and service providers, and utilize limited resources available to enhance TMS capabilities and services.

Agencies are encouraged to go through a planning process to identify, scope, and prioritize the proposed improvements to their existing TMS. The resulting plan from this effort may include the scope, funding, and resources to enhance the capabilities and performance of a TMS or to pursue specific enhancements. The identification of these needs, scope, and funding affords agencies the opportunity to include these needs or projects in their programming processes to allocate the funding needed to advance a project. Once a project has been approved and funding provided, agencies may begin the process to pursue developing the project.

Examples of planning activities that can benefit an agency include assessing a TMS, performing studies to assess the feasibility of improvements to a TMS, and framing the strategic direction and future evolution of a TMS (e.g., through a strategic plan or a multiyear plan of improvements or projects). These planning activities can help an agency build the support to address the identified needs, resources, and priorities associated with improving the management and operation of the TMS or pursuing actual improvements to the system. All are part of the lifecycle of a TMS. This lifecycle as it relates to planning activities is shown in figure 2, where the TMS monitoring and evaluation, maintenance and repair, assessing TMSs, planning for specific improvements, and multiyear planning for the NextGen TMS are all coordinated and interrelated in support of the ongoing development of the TMS.



Source: FHWA.

Figure 2. Diagram. Processes and activities supporting TMS management and operations.[(1)]

Many agencies do not conduct feasibility or planning studies when exploring possible TMS improvements. Additionally, many agencies may not have multiyear strategic plans for their TMSs. Such a strategic plan lays the groundwork and provides the direction for future improvements to their existing TMS or prepares for the next generation of their TMS. Developing and integrating plans for TMSs into existing agency planning efforts, especially TSMO plans and ITS strategic plans, can help fill this gap. Leveraging existing planning efforts is crucial when preparing for improvements to TMSs to assess specific enhancements to meet the needs of an agency, region, or any specific geographical area. Stakeholders often start from scratch when they begin exploring options to pursue or plan for improving TMSs because nationally developed resources are still being developed to assist with these studies.

EMERGING TMS TRENDS AND OPPORTUNITIES

The following emerging operational strategies, data sources, and technologies have led to an interest in agencies considering the need to prepare or plan for the next generation of their TMSs:

- **Active transportation and demand management (ATDM):** ATDM strategies can help address safety and congestion by supporting new and emerging implementation approaches. This process relies on agencies, and therefore TMSs, doing more with existing components and technologies.
- **New data sources:** Currently, TMSs tend to utilize traditional infrastructure-based detection technology to operate and optimize performance. Some systems use other sources of data, such as probe vehicle data. Information captured from probe vehicle data and locations is provided by several companies and are widely available to transportation agencies. These types of probe vehicle data are typically used to infer speed and travel time, similar to how connected and automated vehicle (CAV) data are expected to be used in the future.

- **CAVs:** The anticipated entry of CAVs to the transportation network promises to provide new forms of data, and, accordingly, the operation of TMSs is likely to evolve. In addition to data from CAVs, NextGen TMSs also are expected to benefit from the autonomous vehicle functions in the CAV and the ability to communicate from the infrastructure to CAVs. For example, a NextGen TMS could communicate directly to CAVs by sharing electronic messages recommending which lanes and at what speed vehicles should travel. This capability could be considered a very advanced form of ATDM or speed harmonization.

- **Sharing and using third-party and service provider data:** A growing number of agencies are using innovative and emerging technologies to monitor their systems to advance their TMS and operations. Other local agencies, transportation service providers, and public and private third-party entities can be both users and suppliers of information related to a TMS. This information, coupled with organizational and cultural changes, provides an opportunity to improve system monitoring and response. Examples of emerging technologies supporting this trend include decision-support systems, the Internet of Things, cloud computing, big data, machine learning, crowdsourcing, and CAVs. These recent innovations provide a broad range of tools that can help agency TSMO programs reach their potential by improving operational strategies to become more proactive and data driven.

- **Methods and use of technologies to expand surveillance and coverage:** Surveillance technologies can be used to monitor real-time network conditions and collect data on traffic flow and roadway performance. For example, some agencies have been successful with using automated incident detection algorithms, in conjunction with surveillance cameras, to quickly locate incidents. The geographical coverage of travel condition information provided by emerging data sources presented can dramatically increase the availability of information compared to data historically collected via point detection and CCTV surveillance at key locations along the network, enhancing these surveillance capabilities.

NextGen TMSs offer the potential to share information, connect, and coordinate with stakeholders and agencies by leveraging these emerging tools, capabilities, and trends.

NEXTGEN TMS STRUCTURE AND CAPABILITIES

The emerging trends and opportunities presented in the prior section will impact the structure of TMSs in a variety of ways, especially as they are transitioned to the next generation. One example is cloud computing, which provides on-demand availability of computer system resources, especially data storage and computing power, without directly managing physical components or operating systems. Cloud computing allows agencies to reduce physical components and data management requirements within their TMS.

Cloud storage involves storing data in remote servers that are typically maintained by a cloud storage service provider. By using cloud storage and cloud computing as an alternative to local servers and data storage, hardware and software development and acquisition can be reduced, as well as maintenance costs. This functionality has the potential to greatly simplify management of

NextGen TMSs and their data and allow agencies to deploy innovative operational strategies that might otherwise be unfeasible.

On the data side, probe vehicle data is increasingly being provided by third parties to transportation agencies as a data service. Similarly, crowdsourced data can overcome some of the known challenges of real-time system monitoring. Crowdsourcing utilizes technology to collect data from a large quantity of people to address a need or problem. Types of crowdsourced data that could be useful to an agency include travel speeds, travel times, events, travel behavior, and traveler sentiment, often obtained through social media platforms, third-party data providers, or mobile applications developed for transportation needs.

Because crowdsourced data are obtained whenever and wherever people travel, agencies have the potential to capture in near realtime what happens between sensors, in rural regions, along arterials, and beyond jurisdictional boundaries. Complementing existing data sources with crowdsourced data enriches the information available to TMS operators and reduces their reliance on traditional data sources. Crowdsourced data may offer options to obtain information in locations where an agency may not currently collect data or where it may be costly to deploy and maintain the technology to collect the data.

Complementing the emerging data sources are a set of new technologies that are likely to drive innovations in transportation management. Some of these innovations, such as ATDM and TMS data sharing, have already been deployed by some agencies. Other innovations, such as how to leverage decision-support tools, archived data, and computing capabilities, offer the potential to improve the capabilities and performance of TMSs.

Traffic management relies on timely decisionmaking for monitoring traffic conditions, detecting and managing unplanned events, scheduling and managing planned events, improving traffic signal timing, assessing and planning for adverse weather, and managing critical infrastructure. The management and operation of TMSs rely on an agency expert's decisionmaking, which involves unique knowledge, skills, and experience. Improving the timeliness and effectiveness of decisionmaking is a focus for agencies exploring opportunities to improve the capabilities of their TMSs along with how they are managed and operated.

Improving the responsiveness, timeliness, and effectiveness of real-time decisionmaking is a central focus for agencies that manage and operate TMSs. Decisionmaking relies on having a strong knowledge of the surface transportation system, understanding agency policies and operational procedures, and processing and assimilating a wide range of data and information.

Computer—and noncomputer—based decision-support tools (DSTs) support a range of traffic management activities. Noncomputer-based DSTs are paper-based (e.g., incident response plans and decision trees) and can be printed and collated into references or tools. Computer-based DSTs are based online and provide real-time information (e.g., traffic analyses and lookup tables). Computer-based DSTs can potentially play a key role in improving the real-time decisionmaking of traffic operations personnel by complementing and enhancing the operational capabilities of TMSs.

DSTs can aid operations personnel in monitoring and assessing conditions (e.g., environmental factors, transportation facilities, or transportation networks), detecting and verifying adverse conditions, and identifying and evaluating appropriate response strategies to planned and unplanned events. DSTs can also help agencies achieve more consistent and understandable decisionmaking across their transportation management staff. Within a TMS, DSTs are computer-based instruments that can process vast amounts of data, capture the operational processes of an agency, and potentially mimic the real-time decisionmaking of TMS operators.

One of the objectives of integrating a DST into a TMS is to automate or support the decisionmaking required by operators or a TMS. A DST integrated into a TMS requires an interface, procedures, and/or resources to assist an operator or analyst using the tool. The DST and its software may need to be integrated with the software subsystem and software programs, data subsystem, and computing hardware. This integration allows DSTs to use data (e.g., translated into appropriate formats), make the necessary decisions, and include these decisions in the interface used by operators to manage and operate a TMS.

Examples of possible DSTs agencies may consider for the management and operation of their TMSs may include artificial intelligence (AI) and machine learning. AI enables a computer system to mimic human cognitive functions such as learning and problem solving. Machine learning, an application of AI, is the process of using mathematical models of data to help a computer learn without direct instruction. This enables a computer system to continue learning and improving on its own, based on experience.

CHAPTER 3. IMPROVING TMS CAPABILITIES AND PERFORMANCE

This chapter provides a discussion of potential benefits and costs of the next generation of an agency's TMS. This chapter covers the range of improvement opportunities that may occur throughout the lifecycle of a TMS. These processes may include an assessment of the capabilities of existing TMSs and how these issues may be considered and incorporated in the planning, design, procurement, implementation, and transition to improved TMSs or the agency's NextGen TMS.

CAPABILITIES OF EXISTING TMSS

Agencies considering improvements to a TMS, or a transition to a new or NextGen TMS, may start by assessing the capabilities and performance of their existing TMS. Planning for improvements, including for programs to support TMSs even if improvements are not planned for the immediate future, can help agencies identify opportunities to improve their capabilities and performance. This information may also facilitate agencies building support for initiating a process and obtaining the resources needed to begin preparing and planning for the NextGen of their TMSs. The planning processes include all the activities shown in the lifecycle diagram in figure 2. Specifically related to the TMS self-assessment component of that lifecycle, an existing TMS may have the following defining characteristics to consider in an assessment:

- Active management.
- Operational goals, performance measures, and reporting.
- Operating environment describing the type of facility where the TMS is implemented. This includes freeways, surface streets, and integrated corridors.
- Operational strategies that the system implements, including the functions, actions, and services that support these strategies. The operational strategies can be static, reactive, responsive, and proactive.
- Operation deployment model (or operational implementation model) for a TMS, such as centralized, distributed, virtual, hybrid, and temporary TMS.
- Geographic extent that the TMS covers, describing the area a TMS serves. The geographic extent could include multi-State, State, regional, multiagency corridor, city/county, partial agency coverage, or individual locations.
- Number of agencies involved in the operation of the TMS.

Agencies may choose to integrate legacy and existing capabilities into planning for improvements or to consider pursuing and transitioning to the next generation of their TMS. Integration of siloed functions together typically results in improved efficiency and effectiveness. Replacement of aging (and unsupported or deprecated) services also is a common transition activity. Generally, a transition becomes more challenging as any of the characteristics presented in the previous bulleted list increase in complexity.

TRANSITIONING TO A NEXTGEN TMS

As technology evolves, TMSs may need to be transitioned to new capabilities and functions and be modernized based on deprecation of support for certain underlying processes and components. The following may drive change in transitioning to the next generation of TMSs:

- Providing new capabilities not possible in existing or legacy systems due to the availability of new technologies.
- Replacing existing or legacy capabilities to meet performance objectives (do more, cost less, be more efficient, be more effective).
- Providing the potential for new capabilities through more extensible or flexible platforms.
- Replacing legacy systems at end of life.

If the next generation of an agency's TMS has data subsystems, software subsystems, and computing subsystems that are independent and use agency-owned, agency-owned-and-transferred, or open-source software, then agencies may be able to make incremental enhancements to subsystems in the future rather than having to do an entire NextGen overhaul. In this case, incremental enhancements can help to avoid significant and systemwide replacements at infrequent intervals, which require more substantial resources.

However, when a more substantial transition seems necessary, the following issues can complicate the motivation to transition to the NextGen of a TMS:

- Types of TMSs.
- Agency staffing and capacity for operating and maintaining TMSs.
- TMS capabilities and functions.
- Operations and services enabled by TMSs.
- Information sharing and data exchange.

To help overcome these and other potential issues, a TMS feasibility assessment can be a helpful exercise. The desire to make a transition provides the basis for the TMS feasibility assessment. Generally, the feasibility assessment includes the following:

- The specific issues with the existing TMS and TMS subsystems.
- The rationale that transitioning to a new version or replacement system will resolve specific issue(s).
- Existence of a transition solution, solutions in the marketplace, or the availability of capable suppliers (or in-house resources) to perform bespoke development.
- Articulation of any barriers and challenges to the success of the transition.
- Articulation of available methods to address the challenges during the transition process.
- Assessment of probable cost and availability of funds.
- Assessment of schedule, including consideration for deadlines imposed by other agency projects (e.g., new toll road, new stadium) or industry considerations (e.g., sunset of support for an operating system or software platform).

CAPABILITIES TMS MAY SUPPORT IN THE FUTURE

For agencies looking more broadly than one specific major TMS improvement, continuously planning for the NextGen TMS can enable these improvements to be integrated into a TMS over time. Potential challenges include programming and budgeting considerations, staffing impacts, and other high-level issues, as well as regularly assessing how improved capabilities may improve TMS performance and travel conditions if multiple changes are being assessed at any time. Performance monitoring of TMS functions for a transition may include a wide variety of metrics depending on the function, application, and business process. Identifying baselines is necessary before improvements can be identified through NextGen software, hardware, and business process changes.

A NextGen TMS can enable an agency to carry out the same overall mission as its current TMS but with many more capabilities. For the purposes of this document, capabilities are similar to requirements but focus on higher-level TMS functions and services. Capabilities are not meant to be a comprehensive set of technical requirements but state what is needed to meet an agency's TMS vision and reflect the TMS concept of operations. These new capabilities can enable new operational strategies by leveraging an increased focus on active management and operation of the TMS.

One common motivation for moving toward a NextGen TMS may include increased expectations regarding performance capabilities of TMSs. Such goals may be improvements to traditional traffic performance measures, such as reductions in crashes or congestion, but also measures internal to the TMS agency, such as improvements to field device uptime, reduced time for TMS users to complete tasks, improved situational awareness, and expanded geographic coverage of applications or functions. A new system may also lead to lower future costs to maintain, manage specific assets, or make future improvements.

CHAPTER 4. OPPORTUNITIES TO PLAN FOR OR PURSUE TMS IMPROVEMENTS

This chapter discusses key challenges and opportunities for successful planning, design, development, implementation, management, and operation of NextGen TMSs. Each section includes an example illustrating the potential value of considering and pursuing improvements.

ASSESSING AND IDENTIFYING OPPORTUNITIES FOR TMS IMPROVEMENTS

By continuously looking for potential opportunities to enhance TMS capabilities, functions, and services, transportation agencies can improve their overall TMS performance and help meet their goals. Agencies should consider and manage the evolution of their system so they can meet their short- and long-range objectives. Agencies should also continually look for ways to improve system capabilities and performance, regardless of the current lifecycle stage of their TMS.

Assessment of current capabilities and of how to meet the future needs envisioned in an agency's relevant plans is key to allowing a TMS to evolve through staged implementation of enhanced capabilities and new operational strategies, functions, and services. The TMS planning lifecycle diagram, figure 2, shows many of the steps and processes that an agency might go through as it works toward a NextGen TMS.

For agencies thinking of taking the first step, determining whether a plan already exists for future improvements and whether the strategic direction exists to move toward the next generation of the agency's TMS is important. If a plan and strategic direction have not yet been established, assessing a TMSs current capabilities and performance, may be an appropriate place to start. This assessment can provide the basis for planning to explore specific enhancements or the next generation of the agency's TMS.

The key to planning for a NextGen TMS is to plan for the system in the short term while also considering opportunities for future expansion. Consideration is also needed for geographic region expansion, and for any systems, external agencies, or applications that may be needed in the future. One way to do this is to include the NextGen TMS in a regional ITS Strategic Plan or similar planning activity so that multiple agencies are aware of and can show they are committed to deployment in the region, the needed resources are identified, and the performance and capabilities of the system are incorporated into these other plans.

EXAMPLE PRACTICE: CONSIDERING POLICY IMPLICATIONS BEFORE TRANSITIONING

Existing agency policies have implications for transitions to specific new TMS services. For example, agency policies regarding allowed and disallowed traffic control strategies can impact which applications are possible to pursue. For example, the California Department of Transportation (Caltrans) does not allow traffic signal splits to be reduced below the pedestrian clearance time. While lower splits may provide better traffic efficiency, the agency considers pedestrian safety to be paramount. Similarly, Caltrans also does not allow for protected-permitted left turn signals on State arterial routes. This practice reduces traffic efficiency but also reduces crashes caused by drivers that misjudge their ability to cross in a gap of oncoming traffic or drivers that misinterpret the circular green signal indication as protected versus only permitted.

Such policies have implications for transitions to new TMS services, such as adaptive traffic signal control and signal timing plans for priority control. Therefore, those leading TMS transitions must be aware of agency policies prior to starting the process of planning for TMS improvements. These policies are examples of the issues agencies need to consider prior to identifying possible improvements.

PLANNING FOR TMS TRANSITIONS

Distinct challenges are inherent in making any changes to an existing system. Activities like preparing a TMS feasibility assessment and a transition plan prior to taking any opportunities to improve TMS capabilities can help address these challenges by framing the range of issues agencies may consider. These issues could include, but are not limited to, the funding, resources, and schedule required for planning, designing, developing, testing, and accepting, and implementing enhancements to, or replacements of, a TMS. Making sure all project phases are included in the budget from the outset can enhance the feasibility of a project and help prevent future cost overruns. Even later stages of the project, such as system verification and acceptance testing, can be included in the initial budgeting process.

A TMS feasibility study is often completed as part of, or in parallel with, the TMS planning process, before agencies move forward with the consideration of and decision to program and fund a project. Once funding is received, the development of the specific TMS enhancements or improvements may proceed. A TMS feasibility study may be the first step in the planning process. Alternatively, feasibility studies may be conducted after TMS plan development or come after agency approval and allocation of funding for the project. TMS feasibility studies are similar to various deliverables that form the planning and design of TSMO initiatives, operational strategies, and ITS projects.

A TMS feasibility study consists of outlining the risks associated with considering possible enhancements or improvements, meeting with various stakeholders to fully understand needs, and sketching out a rough system design to identify challenges and proposed benefits. Considering the rapid pace of technology advancements and the associated impacts on TMSs, it is imperative to understand what factors drive the risk and feasibility of possible TMS improvements and future changes. The TMS feasibility study is a stand-alone document presenting a business case for the potential TMS resource needs, improvements, and its technical, economic, and political feasibility. Major elements may include the scope, funding, sequence, or schedule of possible future improvements.

A TMS feasibility study may result in a recommendation to pilot individual functions without full integration and/or consider NextGen functions through modeling and simulation. These are relatively low-cost ways to identify potential benefits of new functionalities. Updating specific aspects of a TMS could include software platforms, computing platforms, data management subsystems, user interfaces, and field components. Expanding areas of service, enhancing the operational strategies, and expanding services or functions of the system are also possibilities.

EXAMPLE PRACTICE: FEASIBILITY ASSESSMENT

In 2011, a feasibility and cost assessment was performed for a metropolitan planning area joint traffic management center (JTMC) in Albuquerque, NM.(2) The primary purposes of the assessment were to determine the feasibility of implementing a joint TMC, or JTMC, and the costs associated with that implementation. The requirements for the JTMC were developed from the participating agency's input for both the near-term implementation period and 10 yr and beyond. An examination of the existing site and building conditions was conducted to determine any challenges to developing a JTMC and where opportunities for enhancements could be made.

The feasibility study provided the participating agencies with assurance that the JTMC implementation was possible and reasonable. This feasibility study allowed the agencies to proceed with a detailed needs assessment, schematic design efforts, and the development of more detailed budget allocations and phasing plans. This first step was useful in that it enabled regional coordination and stakeholder engagement to guide the earliest phase of the project.

GUIDING THE EVOLUTION OF A TMS

Planning for a NextGen TMS is an inherently iterative process. For example, while a TMS Self-Assessment is presented as the first step in the TMS planning process and is a good first step for agencies just starting out with a TMS, it is a task that is often repeated at various times. As shown in figure 2, where once the seventh and final step in the process (maintenance and repairs) is completed, the cycle begins again. For example, the information collected through the monitoring, evaluation, and reporting process can be folded directly into an updated TMS Self-Assessment. Keeping this diagram in mind throughout a TMS's lifecycle can lead to an understanding of the consistency of the planning process and how it can guide the continual evolution of a TMS.

EXAMPLE PRACTICE: INTEGRATING IN TMS SUBSYSTEMS

The Utah Department of Transportation (UDOT) manages a TMS that is focused on a road weather management operational strategy.(3) UDOT initially deployed the pilot Adverse Visibility Information System (ADVISE) on a fog-prone area along I–215 during the 1995–2000 winter seasons to notify motorists of safe travel speeds. The ADVISE system evolved into the current road weather subsystem that includes meteorologists housed in the TMC to support road weather forecasts as well as a citizen reporting service. The citizen reporting service supplements UDOT's data subsystem by filling in gaps in the existing road condition reports and supporting more timely and accurate forecasts. Bringing in this information required training and support for citizens as well as integration with data from the other TMS component sources. Integrating these subsystems greatly enhanced road weather management, especially in rural areas with lower coverage by other information sources. This constant evolution of the system, with additional capabilities being brought in over time, enabled UDOT to enhance the benefits of its system without a specific system overhaul and instead through a more continuous evolution.

AGENCYWIDE PLANNING PROCESSES AND PLANS

The opportunities agencies may consider when incorporating TMSs into the planning processes are vast and depend on the planning horizon for which the activity is taking place. At a baseline level, opportunities include actions such as developing a TMS self-assessment, TMS feasibility study, or TMS strategic plan. More broadly, TMSs can be included as a core consideration in any TSMO or ITS plans, especially as these plans look into the longer term. Bringing TMS into TSMO and ITS planning can facilitate TMS procurement, project development, and implementation.

None of these actions and plans are developed independently but rather as part of a larger vision to incorporate TMSs into the overarching agency planning processes. As a preliminary list, maintenance of assets, project prioritization, systems engineering, and enhanced traffic management are all core components of other functions at an agency that can be considered in the TMS planning process. These components ensure the TMS can be mainstreamed in agency planning and to ensure the TMS can be successfully implemented.

Many issues need to be considered when planning or preparing for the next generation of an agency's TMS. A couple of high-level issues to consider when planning for the next steps for a TMS are institutional policies and regulations and feasibility of increasing operations personnel. In addition, legal issues, such as restrictions on variable speed limits or other potential strategies, may pose potential challenges to planning TMSs or operational strategies. The complex nature of actively operating TMSs may pose as an additional challenge to implementing TMSs or subsystems. Agencies may need additional staffing to ensure successful implementation of a TMS or an operational strategy.

EXAMPLE PRACTICE: INTEGRATION INTO TRADITIONAL PLANNING PROCESSES AND PLANS

Developing robust practices to include operational strategies in planning and programming processes can ensure a successful rollout of a TMS. The Washington State Department of Transportation (WSDOT) implemented and expanded its TMS on I–5, State Route 520, and I–90 in the past few decades, deploying a variety of operational strategies.[7] WSDOT successfully implemented this substantial set of operational strategies by making active management a priority in its business processes, such as planning and budgeting. Including the enhancements to its TMS into the traditional planning process, within the context of regional goals, helped WSDOT secure funding and support for its project.

INTEGRATING TMS INTO OTHER AGENCY PROCESSES AND PLANS

When an agency wants to enhance or expand its current TMS operational strategies or functions, and especially when an agency wants to implement a new TMS, it is important that the TMS project is included in the agency's overall planning process. Planning helps agencies identify how the TMS will operate and aids in identifying how the TMS will be structured, including any services that could be provided to external entities. Agencies may then integrate the requirements and needed projects to improve or transition to a new TMS into an agency's capital program, TSMO program, or other transportation planning processes at the level of detail applicable to that plan or program. Documenting the TMS requirements and proposed improvements in a plan formalizes the planning process and can help guide future system enhancements, develop and maintain support for the improvements, and obtain support for the needed funding.

An example of a topic area where planning for a NextGen TMS can be integrated into other agency initiatives is data storage and management. Many agencies today are planning to, or are actively pursuing, upgrading their TMS and communication subsystems to prepare for the influx of high-density connected vehicle data that are anticipated to become available in the near future. Planning for the system in the short term is important and so is planning for future expansion by considering landscape changes such as the influx of connected vehicle data. Consideration is also needed for geographic region expansion, changes in the systems or agencies involved, and anticipation of applications that may be needed in the future. One way to cover these needs is to include the integrated management, operation, and coordination among stakeholders within a corridor in the regional ITS strategic plan or TSMO program plan so that agencies are committed to TMS deployment in the region and aware of the investments that will be necessary.

EXAMPLE PRACTICE: PRIORITIZING OPERATIONS AT THE PROGRAMMATIC LEVEL

Many of the challenges with implementing TMSs and improving operational strategies can be addressed at the programmatic level. For example, Caltrans is working to improve its operational strategies by advancing its TSMO program. In 2013, Caltrans utilized an FHWA Regional Operations Forum and capability maturity model assessment to identify organizational gaps and build a tailored approach for statewide implementation.(8) Additionally, TSMO was integrated into the 2015–2020 Caltrans Strategic Management Plan as a major component and was tied to the State's goals.(9)

SYSTEM MONITORING AND PERFORMANCE MEASUREMENT

Data collection and management can be challenges for any TMS but are worth addressing given how valuable effective performance measurement can be. Performance monitoring activities are important to the successful implementation and use of TMS operational strategies to achieve agency goals and objectives. Performance measures can be used to support future planning efforts. The process of monitoring and reporting on TMS performance allows agencies to collect, evaluate, report, and use data about their systems with the purpose of measuring progress toward specific goals. These goals typically relate to improving safety, increasing efficiency, and meeting customer expectations.

However, common challenges include a lack of comprehensive real-time system data that span the entire roadway network and the need to collect and manage data in a way that allows this data to be easily accessed for performance measurement activities.

EXAMPLE PRACTICE: INCORPORATING NEW DATA SOURCES

An example of an agency incorporating the use of new data sources into management and operation is the Kentucky Transportation Cabinet (KYTC).(1) The KYTC has incorporated data from multiple sources, including third-party data providers, a mobile application, social media, and crowdsourced weather data to improve the management and operation of its TMS. KYTC's system processes this information and sends alerts to inform TMC operators of incidents and events. This system is based on open-source, distributed computing software. KYTC was an early adopter of the data lake concept, in which aggregate, raw data are stored in their native form. The data lake allows KYTC to pull data for new use cases as they arise. The data lake also provides resilience for when a mistake is made with production data.

CHAPTER 5. SUMMARY OF NEXTGEN TMS AND THE SAFETY AND MOBILITY IMPROVEMENTS THEY ENABLE

This chapter summarizes the findings of this primer, reflecting on the content presented in the previous chapters to highlight the value of preparing for NextGen TMSs and the safety and mobility benefits they enable.

TMS IMPROVEMENTS TO MEET AGENCY AND REGIONAL NEEDS

The possible functions of TMSs continue to evolve as technologies such as vehicle connectivity, crowdsourced traffic data, AI, data processing capabilities, and video analytics are introduced and adopted. Because modern TMSs are only becoming more complex systems, field equipment, operations personnel, advanced communications, and IT need to be continuously updated to adapt to what becomes possible and would be in the best interests of an agency.

As an agency is considering transitioning to a NextGen TMS, they need to understand what is within the constraints of their existing system and environment and what could be possible if they leveraged new tools as they become available. As part of the continuous process of planning for the next generation of a TMS, agencies should continuously look for and pursue opportunities to improve TMS capabilities, management, and operation to lower operating costs, lower repair costs, and work toward supporting a more effective and efficient transportation system.

As improvements to a TMS are implemented, early and continuous attention to coordination, scheduling, and risk management during the implementation phase is essential to meeting the needs of stakeholders and minimizing schedule and budget overruns. Engaging a broad cross-section of stakeholders has great value, and their input is essential for a successful TMS outcome. As new functions go live, effective performance management via continuous collection and analysis of data becomes essential. These data can also enable more sophisticated algorithms, such as the ability to leverage cloud computing for faster processing or AI and machine learning for continuous performance improvement.

CONTINUALLY IMPROVING THE ACTIVE MANAGEMENT, OPERATION, AND CAPABILITIES OF TMSS

Constantly improving the operations and capabilities of a TMS is known as “active management.” Active management can be applied in a real-time operational environment or over a longer term timeframe where the TMS capabilities are continuously being assessed and improved. Active management is the idea that an agency can improve system performance by operating and managing the transportation system in a way that is dynamic and adaptive to current and future conditions, rather than with a fixed strategy. Agencies that adopt and implement these more proactive measures of assessing TMS performance are better positioned to achieve agency performance objectives, allowing agencies to prioritize their resources based on actual system performance metrics. Active management is also applicable to assessing and continually considering possible improvements to a TMS’s capabilities, while planning and preparing for the NextGen of the TMS. Active management principles can help agencies envision a framework for continuously improving the management, operation, and performance of their TMS, expanding the TMS's service area, sharing information and coordinating with other service providers and stakeholders, and examining how this information supports other processes to assess and consider future improvements to their TMS.

PUTTING PRINCIPLES INTO ACTION TO SUPPORT TMS CAPABILITIES

Not all of the planning activities or opportunities suggested in this primer will be appropriate for every agency, at least not immediately. Agencies can consider where their TMS is today and where it is headed, as well as where the agency is with TSMO planning, support, and resources available. However, starting this planning processes as soon as possible can open an agency up for a plethora of opportunities that they can begin to build support, which can help them obtain the needed resources to begin preparing for and implementing a NextGen TMS.

Agencies have many options for moving the planning process forward. These options range from inclusion in high-level agency documents, particularly those on the strategic planning level, to allocating resources within day-to-day operations. A continuous process of planning for a NextGen TMS in real-time, while considering needs that may be met even decades into the future, can help ensure that an agency's TMS continues to meet the next generations of what is possible and what can provide the highest benefit to the agency and the traveling public.

Because technology is constantly changing, existing system capabilities can be regularly assessed by evaluating the capacity of the current systems to support adaptation and integration with evolving technologies. Once this evaluation is complete, an agency can develop requirements for the new system, determine whether and how any components can be maintained, and identify data archiving capabilities and needs. Focusing on the evolution of capabilities for specific subsystems is important to allow for incremental changes and updates.

Establishing ongoing maintenance and support for the existing system while transitioning to a new system is a critical step, as is coordinating with both internal agency departments and external agencies to determine overlaps in data and technologies that can be streamlined and shared. Finally, assessing personnel roles to determine skill sets and identifying any adjustments that need to be made to match the vision of the new system and its operations is helpful. To avoid integration issues with new and existing systems, engage system integrators and system providers early in the planning process to discuss interoperability and to figure out options for issues that may be unique to each system.

When utilizing the information provided in this primer, agencies need to keep in mind that their local and regional plans and planning processes are unique. This primer is not intended to provide a single approach but rather to present multiple options for agencies to pursue if they want to upgrade their existing TMS or create a new TMS that meets NextGen TMS principles and capabilities. Agency staff and stakeholders know their agency and local conditions best and, therefore, know the capabilities and constraints their NextGen TMS will need to meet to be effective. Some agencies may have a historic series of strong ITS or TSMO Strategic Plans that guide their technology investments, others may be undergoing a technology-focused planning process for the first time, but all agencies can benefit from pursuing the planning process when considering their NextGen TMS.

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